Biochar in combination with compost reduced Pb uptake and enhanced the growth of maize in lead (Pb)-contaminated soil exposed to drought stress

Sifau Adenike Adejumo, Dorcas Omotayo Arowo, Mary Bosede Ogundiran & Prashant Srivastava

Journal of Crop Science and Biotechnology

ISSN 1975-9479
Volume 23
Number 3

J. Crop Sci. Biotechnol. (2020)
23:273-288
DOI 10.1007/s12892-020-00035-8

Springer

Journal of Crop Science and Biotechnology (2020) 23:273–288
https://doi.org/10.1007/s12892-020-00035-8

ORIGINAL RESEARCH

Biochar in combination with compost reduced Pb uptake and enhanced the growth of maize in lead (Pb)-contaminated soil exposed to drought stress

Sifau Adenike Adejumo[1] · Dorcas Omotayo Arowo[1] · Mary Bosede Ogundiran[2] · Prashant Srivastava[3]

Accepted: 1 April 2020 / Published online: 20 April 2020

Abstract
Crops are constantly faced with the challenges of different abiotic stresses on the field. Development of sustainable approach for stress amelioration on crop is pertinent. This study investigated the ameliorative roles of biochar and compost on maize crop simultaneously subjected to drought and heavy metal (Pb) stresses. Metal stress was imposed by growing maize on Pb-contaminated soil while drought stress was imposed by reducing the soil field capacity to 25 and 50%. Four levels (0, 5, 10 and 15 t/ha) of biochar and compost replicated three times as well as their combinations were used. Pb uptake, translocation factors, photosynthetic pigments, osmolytes (proline and cysteine), biomass accumulation in stressed maize crop, and post-cropping soil Pb concentration were determined. Combination of stresses reduced biomass accumulation in maize. Biochar in combination with compost, however, enhanced biomass production in stressed maize crop by 50–75% compared to unamended soil (control). Proline accumulation was more under the single stress of heavy metal (100% FC) compared to combined stresses. Unlike proline, combined stresses of Pb and 50% FC enhanced chlorophyll and cysteine accumulation more than single stress. Their concentrations were further increased with amendments compared to control. Pb accumulation in maize crop was more under combined stresses than single stress (100% FC). Compared to other soil amendments, application of biochar alone at 10 t/ha, generally reduced Pb uptake by maize and post-cropping soil Pb concentration. Biochar and compost reduced Pb uptake, and enhanced biomass and osmolyte production in stressed maize crop.

Keywords Heavy metals · Oxidative stress · Osmolytes · Contamination · Organic amendments · Abiotic factors

Introduction

Maize is one of the most important staple food crops in Africa and ranks third after rice and wheat (Raji 2003). It serves as raw material for industries (Ayoola and Makinde 2007) and source of income to the farmers. Maize yield is, however, affected by a range of biotic and abiotic stress factors. Abiotic stress factors, such as high salinity, low soil fertility, soil contamination with heavy metals and drought pose serious threats to crop production and food security. Among these, drought and soil contamination are the major abiotic factors that affect agricultural productivity (Jaleel et al. 2009). International Maize and Wheat Improvement Centre (CIMMYT) also attributed the poor yield of maize in the field to poor soil fertility and drought (Edmeades and Deutsch 1994).

Though agricultural crops are generally faced with different environmental challenges during their lifecycle land contamination with heavy metals and drought has more deleterious effects on the crop growth and development (Aslam et al. 2006; Jaleel et al. 2009). Apart from reduction in crop yield which is common to both, heavy metals also have direct effects on consumer health through food chain as a result of accumulation in the food crop (Boussen et al. 2013). Lead (Pb) is most importantly considered as one of the most toxic elements to plants and animals (Ginneken et al. 2007; Padmavathiamma and Li 2010; Huang et al. 2012) due to

✉ Sifau Adenike Adejumo
nikade_05@yahoo.com

[1] Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria

[2] Department of Chemistry, University of Ibadan, Ibadan, Nigeria

[3] Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE), University of Newcastle, ATC Building, Callaghan, NSW 2308, Australia

its persistence and phytotoxicity effects. They cause excessive accumulation of reactive oxygen species (ROS) such as hydroxyl radicals, hydroperoxyl radicals, ozone, singlet oxygen, hydrogen peroxide (H_2O_2), and superoxide (O^{2-}) due to disruption in cellular metabolism (Miller et al. 2010; Hossain et al. 2012). The production of excessive ROS from molecular oxygen has been identified with different biotic and abiotic stresses. This leads to the degradation of cell macromolecules which is referred to as oxidative stress and eventual plant death (Steffens et al. 2013).

To achieve optimal yield in the face of emerging environmental challenges and feed the ever-increasing population, especially in the developing countries, sustainable measures must be developed to increase crop tolerance to toxic metals and avoid drought stress. Most of the strategies being proposed for the remediation of contaminated sites and improving crop tolerance to abiotic stresses are, however, expensive, labor intensive and require special skills. These include chemical and physical methods of soil remediation such as adsorption and desorption (Srivastava et al. 2005, 2007; Rashti et al. 2014) as well as plant breeding, bioengineering, and irrigation system against drought stress. Meanwhile, in the developing countries majority of the farmers are peasants and resource poor.

Plants naturally have in-built mechanisms which allow them to tolerate environmental stresses (Bah et al. 2011) and scavenge the reactive oxygen species. These include production of different osmolytes such as proline, glycine betaine, glutathione, carotenoids, and cysteine. These serve as antioxidants for stabilizing macromolecules (Ashraf and Foolad, 2007; Islam et al. 2009). Production of elevated levels of proline by higher plants as a non-enzymatic response to different biotic and abiotic stress factors and as a result of impaired protein synthesis or accelerated protein degradation has been widely reported (Tripathi and Gaur 2004; Szabados and Savouré 2010; Mourato et al. 2012). The ability of plant to accumulate high proline is positively correlated to abiotic stress resistance (Mishra and Dubey 2006; Fidalgo et al. 2013). Similarly, an increase in free cysteine levels in response to various abiotic stress factors has been reported (Harms et al. 2000; Ruiz et al. 2002). Cysteine is the final product of the process by which sulphur is taken up by plants. It is a central metabolite that serves as a sulphur donor for the synthesis of methionine, glutathione (GSH), and thiol-containing proteins (Hell and Wirtz 2011). In most studies, the increase in cysteine was reported together with increase in GSH concentrations. This is because cysteine is needed for the biosynthesis of sulphur-rich compounds such as GSH and stress-related proteins (Bashir et al. 2012; Pravina et al. 2013). In the face of severe stress, however, strategies must be developed for the enhancement of osmolyte production in stressed crop and improved tolerance to stress.

The use of organic amendments is being suggested as an adaptive, affordable, and sustainable approach to increase agricultural production and ensure food security. It is an environmentally friendly and cost-effective approach for adapting crop to various climatic conditions and improving their tolerance. For instance, addition of organic amendments, such as compost is a common practice for immobilisation of heavy metals in contaminated soils (Kham et al. 2000; Clemente et al. 2005; Adejumo et al. 2010; Rennevan et al. 2010; Saifullah et al. 2010; Joshi et al. 2011). Similarly, organic amendments have been used to enhance crop growth under drought stress. Recently, the use of biochar is also gaining attention as a sustainable approach for improving soil fertility and ameliorating stress. Biochar is a carbonaceous product obtained through the thermal decomposition of biomass in the absence of oxygen or little oxygen and at high temperature. It has good physical properties like high porosity and large surface area (Van Zwieten et al. 2010), which enhance nutrient and water uptake by plant (Glaser et al. 2002; Lehmann and Rondon 2006; Warnock et al. 2007). Aged biochar has also been found to increase nitrogen retention and reduce ammonia volatilization (Esfandbod et al. 2017). Increasing crop yield with biochar application has been reported by several authors (Lehmann and Rondon 2006; Warnock et al. 2007; Islami et al. 2011; Adejumo et al. 2016).

Furthermore, majority of the research only focus on a single stress factor, whereas crops are faced with different stresses simultaneously on the field. There is need, therefore, for a research focusing on multiple stress factors. Multiple stresses have been reported to provoke complex biochemical pathways resulting in positive or negative impact of one stress over the other and consequently, the plant involved (Farooq et al. 2009). This research work was, therefore, carried out to investigate the response of maize crop to combined stresses of drought and Pb contamination and determine the ameliorative roles of biochar and compost in stressed maize crop in terms of yield, photosynthetic pigments, and osmolyte production.

Materials and methods

Soil sampling and pre-planting operations

The contaminated soil used for the experiment was collected from the dumpsite of a defunct lead-acid battery manufacturing company in Nigeria. The site has been reported to contain high concentration of Pb (Ogundiran and Osibanjo 2009; Ogundiran et al. 2012). It is located in Lalupon, Lagelu Local Government Area, Ibadan Metropolis, Oyo State in Southwestern, Nigeria. Soil sampling was carried out by collecting the top soil (0–15 cm depth) at five equidistant points mapped out on the field. Enough soil for the pot experiment was collected and taken to the University of Ibadan where the study was conducted. The soil was mixed thoroughly for homogeneity, air-dried, crushed, and passed through the 2-mm sieve. Before distributing the soil into different pots, composite sample was taken for pre-cropping soil physico-chemical analysis using standard methods (IITA 1979). Soil pH was measured using a pH meter-Electrometric Method in 1:1 w/v of soil to water. Soil organic carbon was determined by Walkey–Black method, phosphorus (mg/kg) by vanado-molybdate yellow method while total nitrogen was determined using Kjeldahl method (Brehmmer 1965). Heavy metal determination was carried out following the procedure described by Ogundiran and Osibanjo (2009) by digesting 1 g of soil sample with 10 ml of 2 M nitric acid in a water bath (90–100 °C) for 2 h, cooled and later filtered into 100 ml standard flask and made up to the mark with distilled water. Total concentrations (mg kg^{-1}) of extractable micronutrients/heavy metals were then estimated from the digest using atomic absorption spectrophotometer (Buck Scientific Model, 210 VGP, Chicago, Illinois, USA). From the analysis, the soil used for the experiment was slightly acidic (pH 6.3), low in organic matter (0.88%), total nitrogen (0.09%), and available phosphorus (7.56 mg/kg) but contained high concentrations of Pb (53,750 mg/kg), cadmium (60 mg/kg), and chromium (30 mg/kg).

Sources and types of organic amendments

Compost was prepared from Mexican sunflower and poultry manure in ratio 3:1 of plant and animal materials on dry weight basis (Adejumo et al. 2011) while biochar was produced using rice husk as feedstock. The rice husk was pyrolysed at 400 °C using the fabricated pyrolyser at the Department of Mechanical Engineering, University of Ibadan, Ibadan, Nigeria, following the procedure described by Adejumo et al. (2016) under slow pyrolysis. The chemical properties of the biochar were carbon 36%, nitrogen 1.32%, Fe 366.5 mg/kg, Zn 5.2.mg/kg, Cu 1.85 mg/kg, Mn 175.5 mg/kg, P 0.80 cmol/kg, Mg 0.02 cmol/kg, and Ca 0.09 cmol/kg (Adejumo et al. 2016).

Plant materials and planting procedure

Maize variety (DTMA W) that was used for the study was collected from International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The seeds were first cleansed with 0.1% NaoCl solution before planting. Each experimental pot of 5 kg capacity, diameter of 20 cm and depth 22 cm was filled with 2 kg of contaminated soil. Before planting, the soil was first mixed with different amendments (Mexican sunflower compost and rice husk biochar) at different rates depending on the treatment allocations and equilibrated for 10 days for proper mineralisation. The treatments consisted of five application rates (0 t/ha (Control), 5 t/ha, 10 t/ha and 15 t/ha). These were denoted as 0 t/ha: B0 and C0, 5 t/ha: B1 and C1, 10 t/ha: B2 and C2 and 15 t/ha: B3 and C3 for biochar and compost, respectively, to give ten treatments together with the combination of biochar applied at 10 t/ha (B2) with different compost rates (B2C1, B2C2, B2C3 and B0C0: Control). B0 C0 = No biochar, no compost, that is, control. B1 = Biochar at 5 t/ha, B2 = Biochar at 10 t/ha, B3 = Biochar at 15 t/ha, C1 = Compost at 5 t/ha, C2 = Compost at 10 t/ha, and C3 = Compost at 15 t/ha. The 5 t/ha was equivalent to 5 g of compost/2 kg of soil, 10 t/ha was 10 g/2 kg of soil while 15 t/ha was 15 g/2 kg soil. The same thing goes for biochar.

Each treatment was replicated three times. Three to four maize seeds were then planted in each pot and emerging seedlings were later thinned down to two per pot. The drought stress commenced at two weeks after planting to cover the vegetative stage and the treatments were imposed by varying the watering regimes to give 25, 50, and 100% (Control) field capacity of the experimental soil. To achieve this, the field capacity of the soil was first determined and then tensiometer was used to measure the soil moisture content and maintain it at 25% and 50% field capacities by allowing the water level to go down to predetermined levels while 100% FC was receiving water continuously. Water was also been added to bring the water level to either 25 or 50% FC by following the tensiometer readings. The pots were arranged in completely randomized design (CRD). The experiment was terminated at eight weeks after planting. Data were collected on plant biomass, Pb accumulation in plant parts (shoot and root), translocation factors, photosynthetic pigments (chlorophyll, carotenoid and porphyrin), proline, and cysteine production as well as post-cropping soil Pb concentration.

Chlorophyll, carotenoid and porphyrin estimations

Photosynthetic pigments were determined following the method described by Sarropoulou et al. (2012) using UV–Vis spectrophotometer (Spectrum Lab 7525, Ningbo, China). The absorbance was measured at 665 and 649 nm for chlorophylls a and b, respectively, while total chlorophyll was determined according to Wintermans and Mots' (1965) equation: (Chl $(a+b) = (6.10 \times A_{665} + 20.04 \times A_{649}) \times 15/1000/\mathrm{FW}$ (mg/g FW). The absorption peak of carotenoids was measured at 440 nm. Carotenoids were estimated from the equation: Carotenoid $= (4.69 \times A_{440} - 1.96 \times A_{665} - 4.74 \times A_{649}) \times$ volume of supernatant (15 ml) × dilution factor/sample weight (0.1 g). Total porphyrins were determined by summing up the values of protoporphyrin, Mg–protoporphyrin and protochlorophyllide which are measured at absorbances, 575, 590, and 628 nm, respectively, using the equation given by Sarropoulou et al. (2012).

Estimation of proline and cysteine content

Free proline content was determined according to the procedure of Bates et al. (1973) and 5 g of sample materials was homogenised in 5 ml of 3% aqueous sulfosalicylic acid. The homogenate was filtered through Whatman No. 1 filter paper and then 2 ml of the filtrate was mixed with 2 ml of glacial acetic acid and 2 ml of freshly prepared acid ninhydrin (1.25 g ninhydrin warmed/dissolved in 30 ml glacial acetic acid and 20 ml 6 M phosphoric acid). The samples were then heated in boiling water bath for 1 h and the reactions were terminated by placing the tubes in ice bath. Four (4) ml of toluene was added to the reaction mixture and stirred well for 30 s. The toluene layer was separated and warmed to room temperature. Absorbance of chromophore was read at 520 nm against toluene as blank in an Elico SL-159 spectrophotometer. The amount of proline in the samples was calculated in µg proline g^{-1} fresh weight. The cysteine content was determined according to Gaitonde (1967) method. 5 g of sample materials was homogenised in 10 ml of 5% PCA (perchloric acid), and centrifuged at 2800 rpm for 1 h at 5 °C. 2 ml of supernatant was mixed with 2 ml of ninhydrin and kept at room temperature. Absorbance of chromophore was read at 580 nm against blank of PCA.

Biomass determination and heavy metal analysis in plant and post-cropping soil

At harvesting, the plants were cut from the soil surface while the roots were carefully uprooted and rinsed severally with tap water to remove attached soil. The plants were partitioned into shoot and root before oven-drying at 80 °C to a constant weight. They were later weighed for the dry matter yield. Plant samples were taken from each treatment and analysed for heavy metal (Pb). This was done using spectrophotometric method after dry ashing. One gram (1 g) of plant sample was ashed in the furnace at 500 °C for 12 h and the ash re-dissolved in 10 ml of 2 M nitric acid (HNO3), filtered into the 50-ml standard flask and made up to the mark (Ogundiran 2007). The filtrate was now analysed for metal using atomic absorption spectrophotometer. After uprooting the maize plants, soil samples were also taken from below the root zone of each treatment and analyzed for post-cropping soil Pb concentrations using Ogundiran and Osibanjo (2009) method as described above.

The translocation factor (TF) for metals within a plant was determined to evaluate the extent of metal translocation from roots to shoots. It was calculated as the ratio of metal in the shoot/metal in the root.

Data analysis

Data were analyzed using ANOVA of the IBM Procedure of SPSS package (2014). Means were separated using Duncan multiple range test (DMRT) at $P < 0.05$.

Results

Biomass accumulation and partitioning in maize crop under heavy metal and drought stresses

Combination of drought and heavy metal stresses generally reduced maize growth and biomass accumulation compared to heavy metal stress alone (100% FC). Water stress at 25 and 50% FC on Pb-contaminated soil irrespective of the treatments reduced biomass accumulation in maize more than 100% FC. Drought stress at 25% FC and heavy metal contamination significantly reduced maize growth and resulted in the death of some maize plants (Fig. 14). Biomass accumulation in the shoot, however, responded positively to biochar and compost amendment to Pb-contaminated soil compared to unamended soil except in C1 and C2. Under 25% field capacity, 15 t/ha of compost (C3) enhanced dry matter accumulation of maize compared to other treatments. At 50% FC, soil amended with compost and biochar enhanced dry matter in stressed maize more than unamended control with other treatments combination of biochar (10 t/ha) and compost (10 t/ha) (B2C2) being superior ($P < 0.05$) while maize plant grown on lead-contaminated soil without amendment recorded the lowest (Fig. 15). The trend was the same under single stress of heavy metal (100% FC) with the highest biomass accumulation obtained in the shoot and root of maize crop grown on soil amended with 10 t/ha of biochar in combination with 10 t/ha of compost (B2C2) (Fig. 16). In all, the dry matter partitioning was in favour of shoot than root (Fig. 1).

Proline and cysteine production in maize crop under heavy metal and drought stresses

Proline production in response to stress and organic amendments varied considerably. Single stress with heavy metal (100% FC) and without amendments (BOCO) was found to enhance proline production more than combined stresses under 25% and 50% field capacity and amended soils (Fig. 2). The effect of biochar and compost on proline production also varied depending on the treatment rates and combinations. Compared to other amended soils, application of 10 t/ha of biochar in combination with 5 t/ha of compost (B2C1) enhanced proline synthesis in maize under combined stresses (25 and 50% FC) compared to single stress (100% FC) and this was more than what

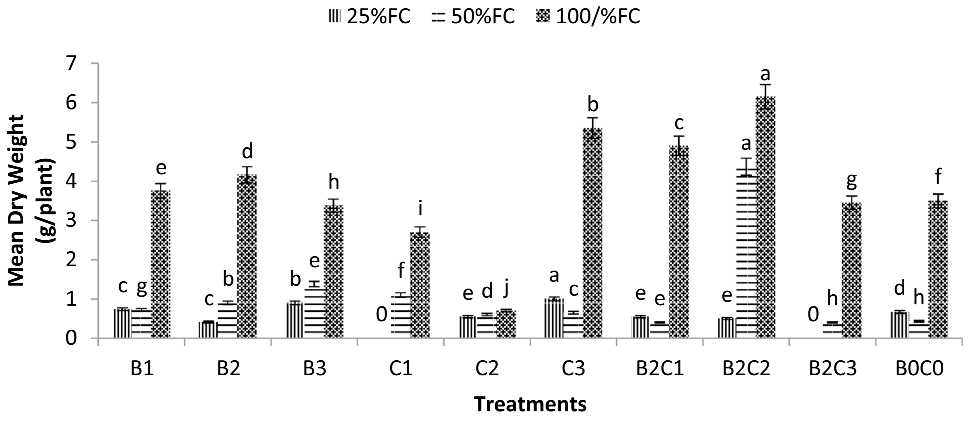

Fig. 1 Maize dry matter yield under heavy metal and drought stresses as influenced by different organic amendments. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P < 0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. *B0 C0* no biochar, no compost, that is, control, *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

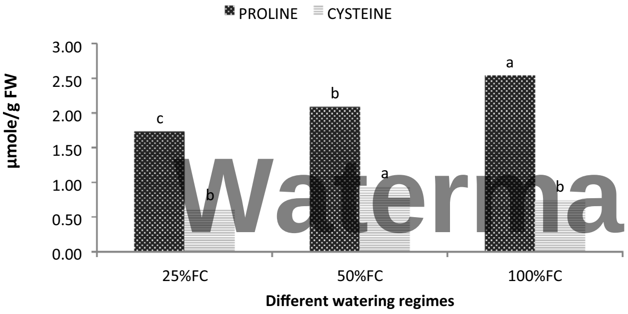

Fig. 2 Effect of different water regimes on osmolyte production in maize crop grown on Pb-contaminated soil

was recorded under 25% and 50% field capacity without amendment. Compost applied alone performed better than biochar in terms of proline accumulation in maize crop under 50 and 100% FC. The concentration increased under 100% FC as compost rate increased while it decreased under 50 and 25% FC. It was, however, observed that combination of biochar and compost (B2C2 and B2C3) reduced proline concentration under 25 and 50% FC compared with other amendments and control (Fig. 3). Unlike what was observed for proline, the cysteine production in the amended soil varied based on the type of organic treatment and rate of application. Under 100% FC,

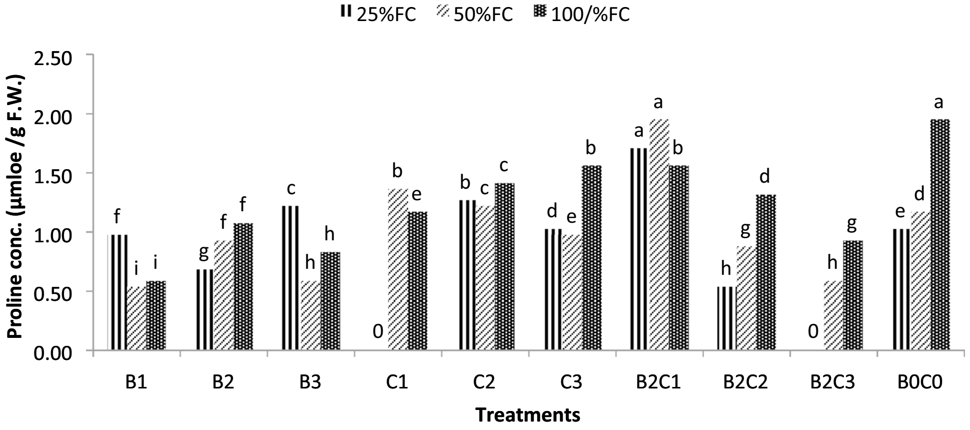

Fig. 3 Effect of biochar and compost on proline production in maize exposed to heavy metal and drought stresses. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P < 0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. *B0 C0* no biochar, no compost, that is, control, *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

application of compost alone and combination of compost with biochar at different rates increased cysteine accumulation more than biochar alone. The proline concentration was increasing as the compost rate was increasing while it was decreasing as the biochar rate was decreasing with the lowest amount recorded in B1. Generally, with the combination of compost and biochar, the proline concentration under different watering regimes was decreasing as the compost rate was increasing. However, unlike proline, combined stresses of heavy metal contamination and 50% FC gave the highest cysteine accumulation in maize in unamended soil (Fig. 3). This was followed by that of the maize treated with C1 under 50% FC and as biochar application increased, cysteine concentration was also increasing consistently unlike compost though with higher amounts of cysteine in C1 and C3 compared to biochar treatments. Under this stress combination, B2C3 gave the lowest amount of cysteine followed by C2. Combined stresses of heavy metal and 25% FC in soil treated with 10 t/ha of compost significantly influenced production of cysteine more than other treatments and control. This was followed by cysteine concentration in the leaf of maize grown on soil amended with B2C1 and C1. Under this stress combination, B2C2 gave the lowest amount of cysteine followed by B3. The cysteine concentration in maize leaf grown on soil amended with B2C2 recorded the lowest concentration of cysteine compared to other treatments. However, the trend of cysteine production under 50% FC showed that control had the highest cysteine concentration of 0.14 µmole/g FW. followed by those of 10 t/ha and 15 t/ha compost treatments while 10 t/ha of biochar in combination with 15 t/ha of compost (B2C3) recorded the lowest concentration. The higher the rate of compost combined with biochar, the lower the concentration of cysteine (Fig. 4).

Photosynthetic pigment production in maize crop under heavy metal and drought stresses

Different watering regimes and stress had different effects on photosynthetic pigment formation. Porphyrin was more than carotenoid and the highest was recorded in the contaminated soil exposed to 50% FC. Carotenoid production was also enhanced in combined stresses than single stress of heavy metal contamination alone and 100% FC. It was also more in drought stress of 50% FC compared to 100 and 25% FC (Fig. 5). In the case of chlorophyll content, it was discovered that combined stresses of heavy metal and drought (50% FC) increased the production of chlorophyll in all the treatments including control compared to 25 and 100% FC in all the treatments except in B2C1 where it was more under 25% FC. Compared to control, the chlorophyll production was enhanced with the application of B2C3 and B3 under 100% FC, B2C2 and C2 under 50% FC, and B2C1 and B2C2 under 25% FC. Chlorophyll production in maize was also enhanced under 25% FC in sole application of 5 t/ha of biochar (B1) and 15 t/ha of compost (C3) compared to control (no amendment). Sole application of biochar and compost at the rate of 10 t/ha was, however, found to reduce chlorophyll content in maize leaf. Soil amendment with 10 t/ha of biochar in combination with 10 t/ha of compost (B2C2) under 50% FC gave the highest chlorophyll concentration followed by higher compost application rate (C3). The concentration of chlorophyll under 25% FC also responded positively to soil amendments with 10 t/ha biochar in combination with 5 t/ha and 10 t/ha of compost. Under 100% FC sole application of 15 t/ha of biochar influenced higher production of

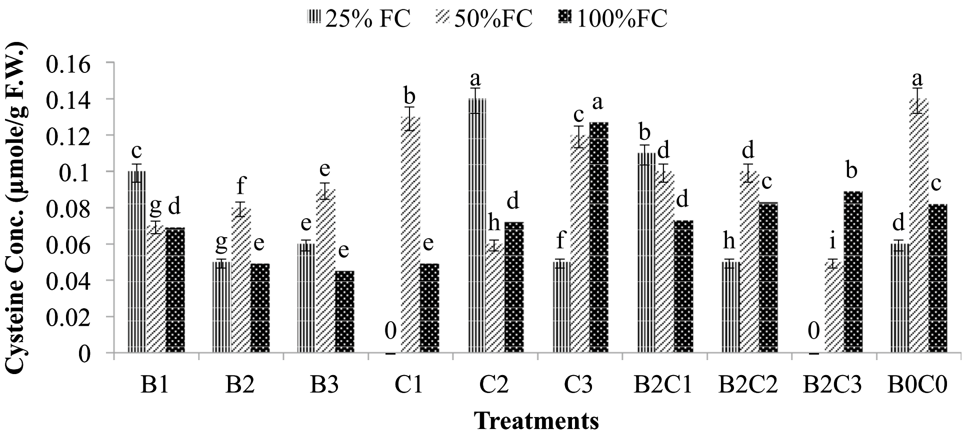

Fig. 4 Effect of compost and biochar on cysteine production in maize crop exposed to heavy metal and drought stresses. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P < 0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. *B0 C0* no biochar, no compost, that is, control, *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

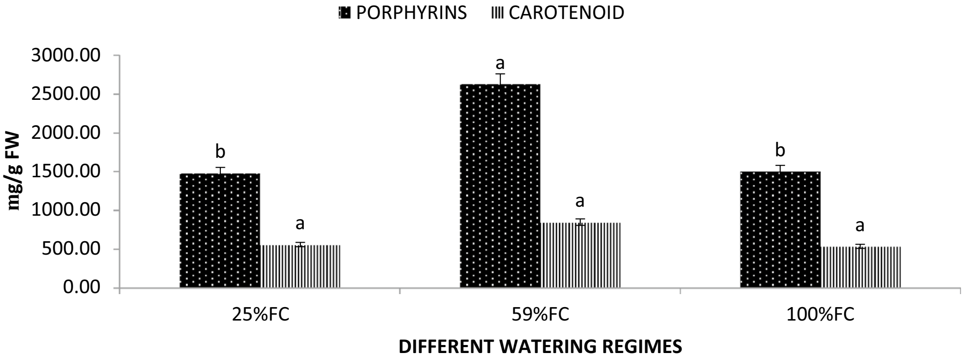

Fig. 5 Effect of different water regimes on photosynthetic pigment production in maize crop grown on Pb-contaminated soil

chlorophyll than other treatments while maize grown on soil amended with 10 t/ha of compost recorded the lowest chlorophyll content in their leaves. It was observed that the higher the rate of compost combined with biochar, the higher the amount of chlorophyll produced in maize leaf under 100% FC (Fig. 6). The carotenoid production under 25% FC was positively influenced by the application of B2C2, C3, and B3. Higher rates of compost and biochar performed better than lower rates with compost being superior to biochar when applied singly using 10 and 15 t/ha of compost and biochar. Combination of biochar with compost (B2C2) was, however, found to enhance better production of carotenoid in maize under 25 and 50% FC compared to their sole applications. Conversely, sole application of 10 t/ha of biochar and compost reduced carotenoid contents compared to control (Fig. 7). Porphyrin production in maize plant grown on lead-contaminated soil without amendment (Control) was increased with the drought stress of 50% FC as observed for carotenoid. Similarly, in almost all the treatments, combined stresses (Heavy metal and drought) enhanced porphyrin production more than single stress of soil contamination alone. Amendment with biochar and compost, however, enhanced porphyrin production in all the amended soils compared to control most especially with the combination of compost and biochar. With 25% irrigation level and soil amendment with 10 t/ha of biochar in combination with 10 t/ha of compost (B2C2) and 15 t/ha of compost alone increased porphyrin concentration in maize leaf. Compost applied singly at 10 t/ha and 15 t/ha was also better in porphyrin production than biochar applied at the same rate (Fig. 8).

Lead accumulation in maize plant parts and post-cropping soil

Across the water regimes, 50% FC increased Pb accumulation in the shoot and root compared to 25 and 100% FC. The lowest was recorded under 100% FC. In the soil, 50% FC also had the highest mean concentration followed by 100% FC while 25% FC had the lowest (Fig. 9). Without amendment (B0C0), Pb accumulation in the shoot of maize was more under combined stresses than single stress. On the effect of biochar and compost amendments, Pb concentration in the shoot was significantly reduced by some amendments and increased in others. Under 25% FC, sole

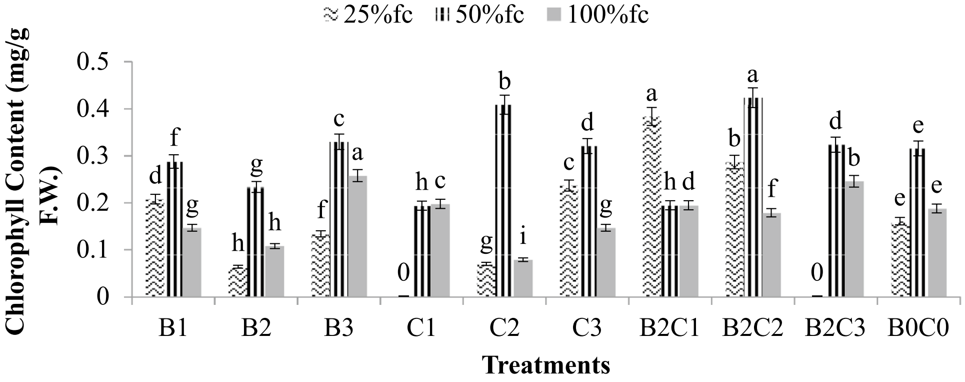

Fig. 6 Effect of biochar and compost on chlorophyll content in maize crop exposed to heavy metal and drought stresses. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P < 0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. *B0 C0* no biochar, no compost, that is, control, *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

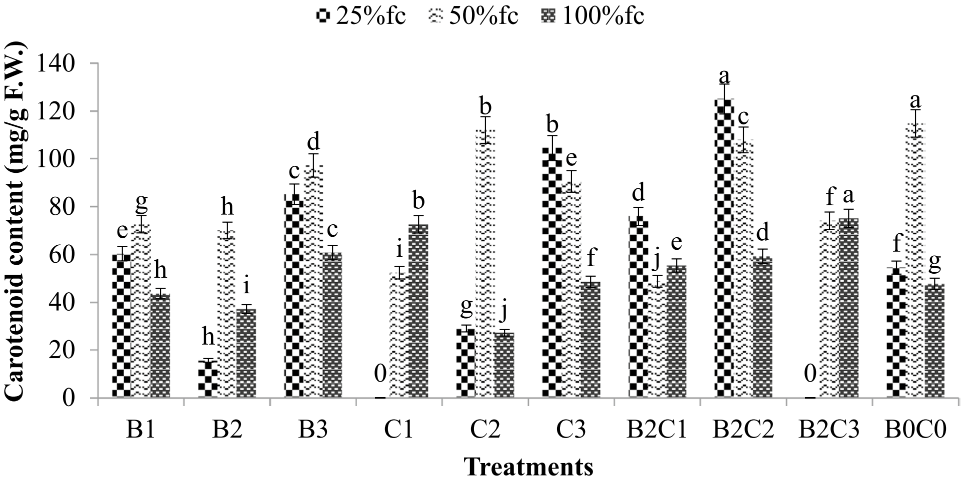

Fig. 7 Effect of biochar and compost on carotenoids in maize grown under lead contamination and drought stress. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P < 0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. *B0 C0* no biochar, no compost, that is, control, *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

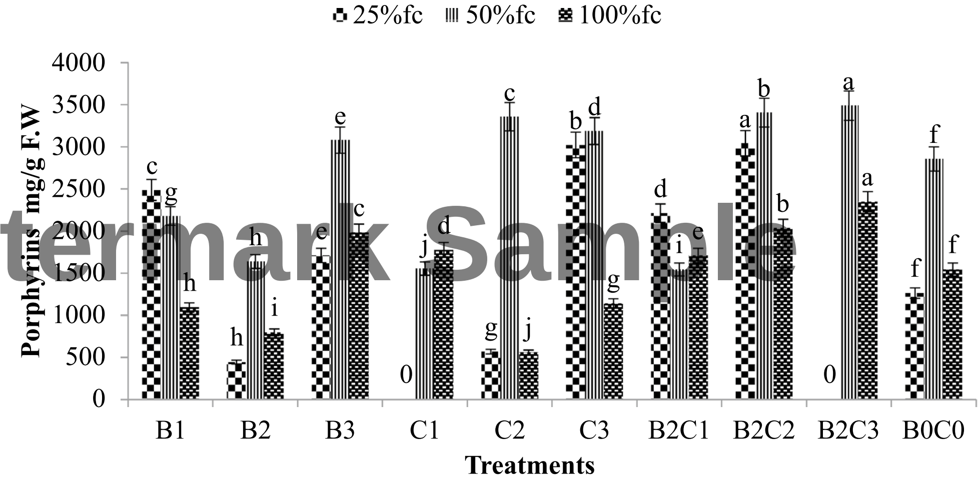

Fig. 8 Effect of biochar and compost on total porphyrins in maize crop exposed to heavy metal and drought stresses. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P < 0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. *B0 C0* no biochar, no compost, that is, control, *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

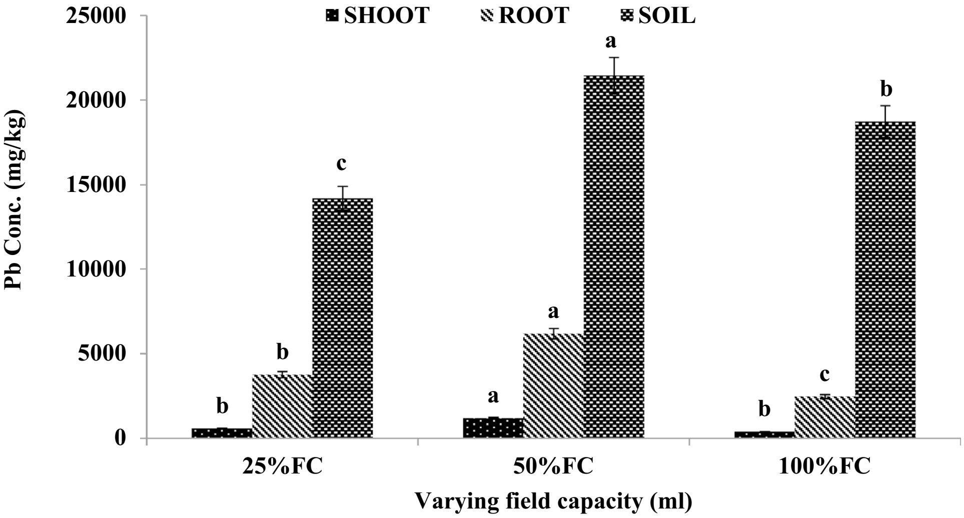

Fig. 9 Effects of different water regimes on Pb concentration in maize plant tissues and post-cropping soil

application of 10 t/ha of biochar gave the lowest Pb concentration of 60 mg/kg in the maize shoot compared to control (770 mg/kg). Combination of 10 t/ha of biochar with 10 t/ha of compost and 15 t/ha of compost alone reduced Pb uptake in maize shoot having 177 mg/kg and 228 mg/kg, respectively, compared to control. With 50% FC, sole amendment with biochar at different rates and 5 t/ha of compost reduced lead uptake in maize shoot. Combination of biochar at the rate of 10 t/ha with 5 t/ha (648 mg/kg) and 10 t/ha (584 mg/kg) of compost also reduced Pb uptake in maize shoot compared to control (807 mg/kg). Meanwhile, combination of 10 t/ha of biochar with 15 t/ha of compost (B2C3) abnormally increased Pb accumulation in maize shoot (5460 mg/kg) compared to other treatments (Fig. 10). The Pb concentration in the root also varied based on the amendments and stress levels. Without organic amendment, combined stresses reduced the concentration of Pb in the root compared to single stress. With organic amendment and 25% FC, there was increase in the root Pb more than control (without amendment) with 957 mg/kg Pb while the highest concentration (11,475 mg/kg) was found in the root of maize grown on soil amended with 5 t/ha of biochar. As was observed under 25% FC, the least was found in the control root under 50% FC having 1493.6 mg/kg Pb while the highest concentration (11,170 mg/kg Pb) was found in the root of maize grown on soil amended with 10 t/ha of biochar in combination with 5 t/ha of compost (B2C1). Unlike 25% and 50% FC, 100% irrigation reduced concentration of Pb in maize root on soil amended with 10 t/ha of biochar in combination with 15 t/ha of compost (635 mg/kg Pb) (Fig. 11). The effect of amendments on post-cropping soil Pb concentration showed that, under 25% irrigation level, Pb was reduced in the soil amended with 10 t/ha of biochar in combination with 15 t/ha of compost giving a mean value of 5278 mg/kg. Other amendments that reduced lead concentration in the soil include 10 t/ha of biochar alone, 10 t/ha of biochar in combination with 5 t/ha and 10 t/ha of compost with 9173 mg/kg, 9474.5 mg/kg and 11,375.5 mg/kg Pb, respectively, compared to control (17,576 mg/kg Pb). On the other hand, reduction in the post-cropping soil Pb under 50% FC was observed in soil amended with 10 t/ha of biochar in combination with 5 t/ha having 9907 mg/kg. Reduction was also observed in soil amended with biochar at the rate of 15 t/ha and 10 t/ha. Decrease in lead concentration under 100% FC was influenced by the sole application of compost at the rate of 5 t/ha and 10t/ha which had 8026 mg/kg and 8104 mg/kg, respectively, and were not significantly different from each other (Fig. 12).

Translocation factors of Pb in maize crop

Variations were observed with regard to the type of organic amendment and different watering regimes. Without amendment, the Pb translocation factor (TF) was the highest in maize crop grown on Pb-contaminated soil and under 25% FC followed by that of 50% FC while the lowest value was recorded for 100% FC. Generally, the TF was high in the control plant (treatment without organic amendment) under 25% FC compared to those grown on organic amended soils and under 50 and 100% FC. Under the severe water stress (25% FC), addition of organic amendments reduced the TF in the

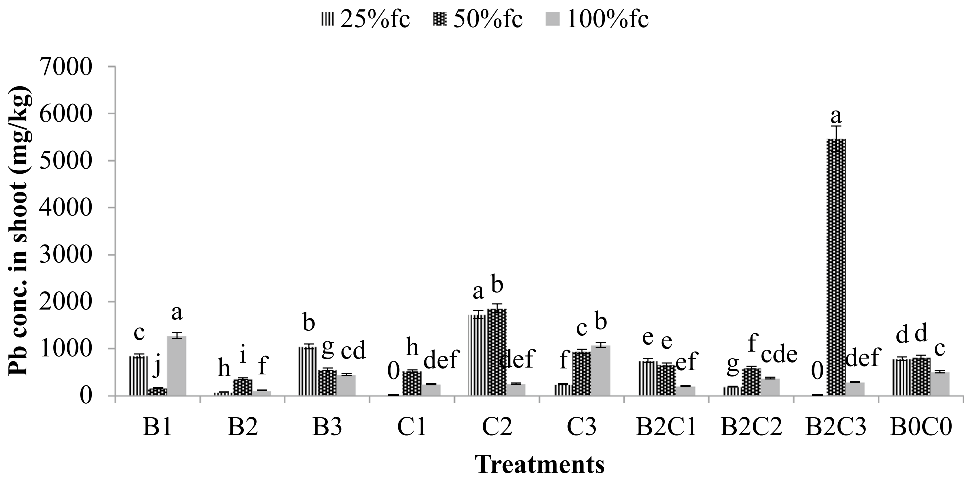

Fig. 10 Effect of biochar and compost on lead concentration in maize shoot grown under lead contamination and drought stress. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P < 0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. NB: *B* biochar, *C* compost, 1 = 5 t/ha, 2 = 10 t/ha, 3 = 15 t/ha. *B0 C0* no biochar, no compost, that is, control, *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

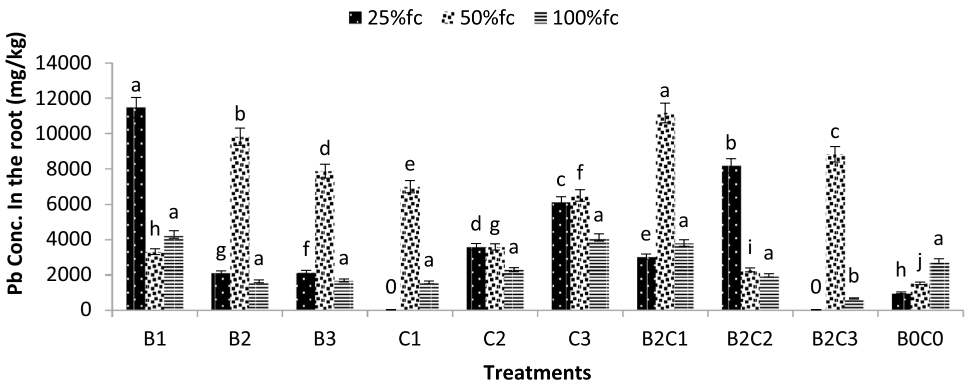

Fig. 11 Effect of biochar and compost on lead concentration in maize root grown under lead contamination and drought stress. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P < 0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. *B0 C0* no biochar, no compost, that is, control. *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

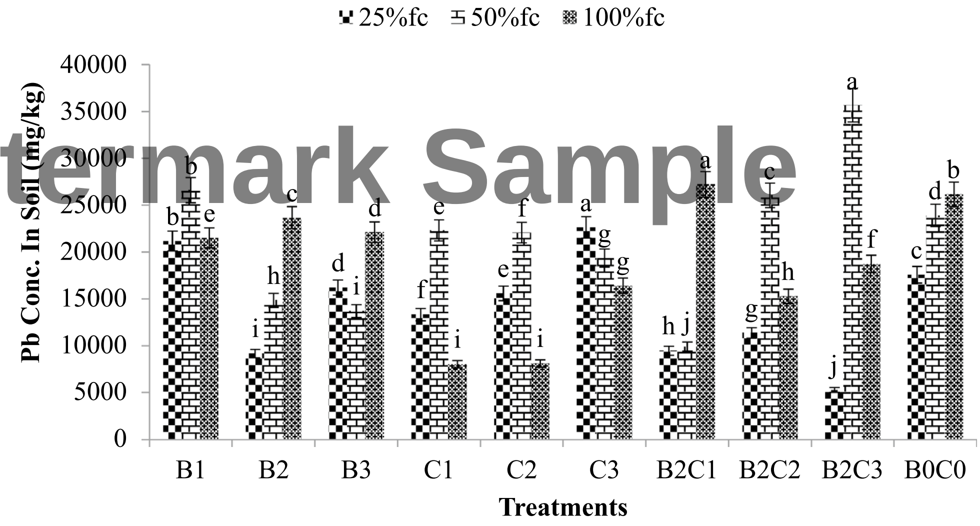

Fig. 12 Effect of biochar and compost on lead concentration in post-cropping soil under lead contamination and drought stress. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P < 0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. *B0 C0* no biochar, no compost, that is, control, *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

maize crop grown on soil amended with B2C2, C3, and B3 treatments. With 50% FC, TF was the highest in the maize grown on soil amended with B2C3 followed by that of C2 while biochar treatments at different rates and in combination with the lowest rate of compost performed better than other treatments in reducing the Pb translocation factors. Addition of organic amendments (most especially B2C3) to Pb-contaminated soil increased the Pb TF in maize plant under Pb stress alone (100% FC) more than the control (without amendment) except in B2C1 and B2 treatments with B2 having the lowest TF value under 100% FC (Fig. 13).

Discussion

Lead contamination of agricultural soils and drought have been known to have detrimental effects on crop yield and biomass characteristics due to changes in metabolism and physiology of plants (Azad et al. 2011). The effect of single stress is, however, less than that of multiple stresses as was also observed in this study. It was observed in this study that there was an increase in the growth of maize crop in response to different organic amendments. Biochar

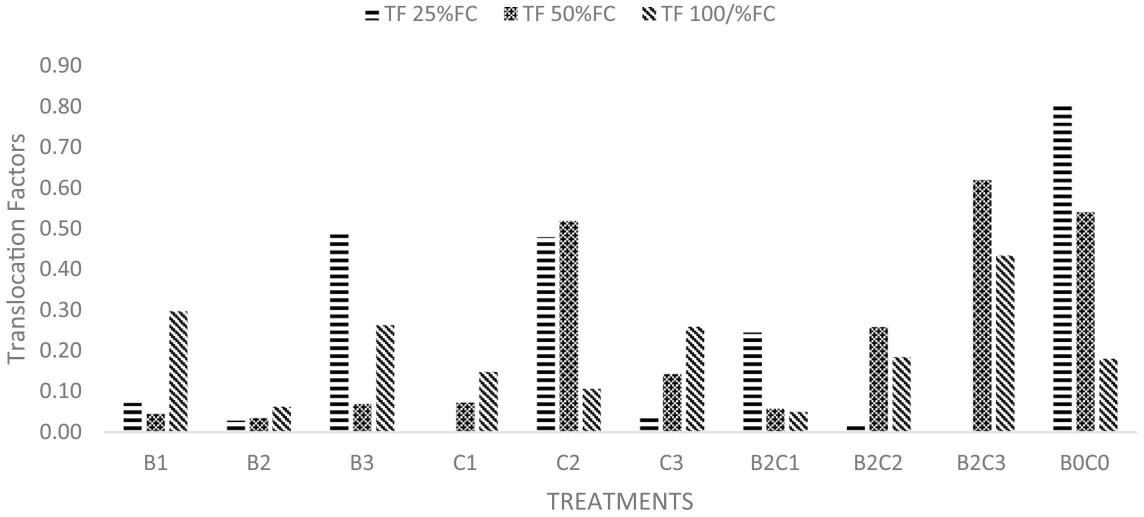

Fig. 13 Effect of biochar and compost on translocation factors of Pb in maize crop under lead contamination and drought stress. Data were analyzed using ANOVA and means separated using Duncan multiple range test (DMRT) at $P<0.05$. Treatments denoted by the same letter on same chart are not significantly different according to DMRT at $P \leq 0.05$. *B0 C0* no biochar, no compost, that is, control, *B1* biochar at 5 t/ha, *B2* biochar at 10 t/ha, *B3* biochar at 15 t/ha, *C1* compost at 5 t/ha, *C2* compost at 10 t/ha, *C3* compost at 15 t/ha

applied in combination with compost performed better than sole application. This confirmed the previous reports that combination of biochar and compost enhanced crop growth better than when applied singly (Glaser et al. 2007; Glaser and Birk 2012). It has also been reported that addition of organic amendments, such as compost, biochar, fertilizers, and wastes, helps in soil improvement which in turn might have had a positive effect on the plant growth and development (Krogstad, 1983; Elliott et al. 1996; Amlinger et al. 2007; Adejumo et al. 2010; Rennevan et al. 2010). Drought, whether mild or severe, has been reported to decrease crop growth and development (Sadras and Milroy 1996; Shaw 1988; Aslam et al. 2006) but application of organic amendment was found to increase biomass production under low water regime compared to control without amendments (Figs. 14, 15, 16).

Among various compatible solutes, proline is known to have various functions under stress conditions in plants (Ashraf and Foolad 2007). Proline is regarded as a non-enzymatic antioxidant that crop uses to mitigate the adverse effects of reactive oxygen species (ROS) (Islam et al. 2009). It is well documented that there was a dramatic accumulation of Proline following salt, drought, and metal stresses due to increase in its synthesis or decrease in its degradation (Shah and Dubey 1998). The decrease in proline accumulation across the organic treatments and at varying water regimes showed the effect of organic amendment in enhancing stress tolerance by reducing the availability of heavy metals and increasing the water retention capacity of the soil (Uchimiya et al. 2010; Herth et al. 2013). Increase in accumulation of proline in the control treatment at 100% FC showed that stress caused by heavy metal alone enhanced proline production more than combined stress. The accumulation could also be attributed to availability of water for protein degradation. An increase in free cysteine levels has also been reported in response to various abiotic stress factors. This increase was reported together with increase in glutathione (GSH) concentrations, leading to the conclusion that cysteine is mainly needed for the biosynthesis of sulphur-rich compounds such as GSH and stress-related proteins with anti-stress activity (Harms et al. 2000; Ruiz et al. 2002). In this study, with 50% field capacity, increase in cysteine accumulation was observed in maize grown on lead-contaminated soil with no amendment than those treated with biochar and compost which confirms the ameliorative roles of organic amendments.

Chlorophyll is an extremely important biomolecule critical in photosynthesis. One of the biochemical indicators of environmental stress is the degradation of chlorophyll (Arnao and Hernandez-Ruiz 2009). Chloroplast degeneration occurs through the progressive loss of proteins, such as Rubisco and chlorophyll-binding proteins (Arnao and Hernandez-Ruiz 2009). Although photosynthesis has long been known to be partially or completely suppressed by severe water stress due to chlorophyll degradation (Boyer 1976), in this study, compost and biochar enhanced chlorophyll formation across the water probably due to the availability of nutrients such as Mg which is needed for chlorophyll formation. A possible reason for the decrease in plant chlorophyll in the other treatments and control could be attributed to the ability of heavy metal most especially Pb in replacing the central Mg ion or inhibiting chlorophyll

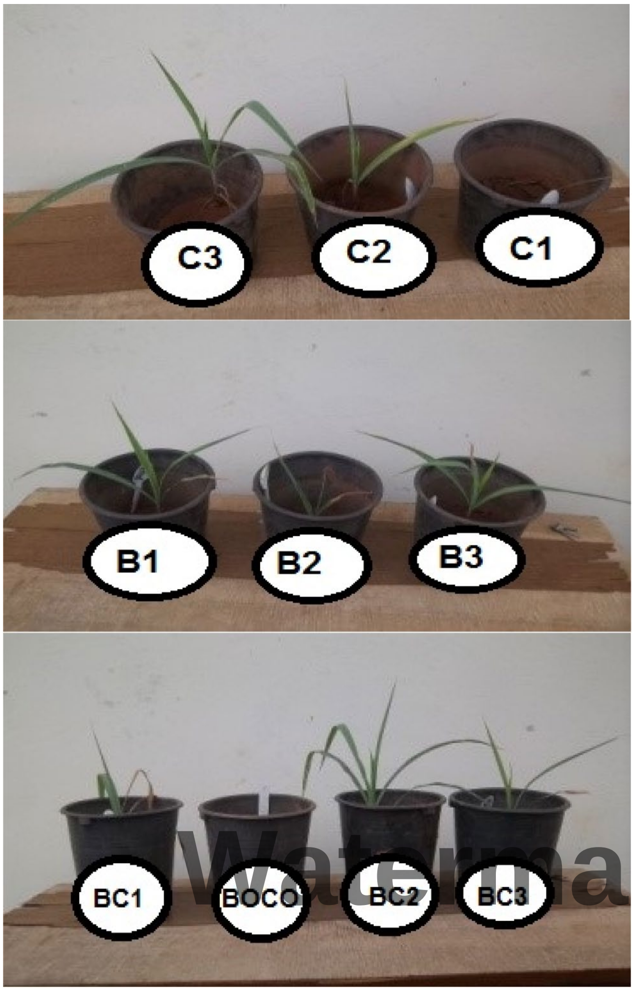

Fig. 14 Maize plants under 25% FC in response to different amendments at harvesting

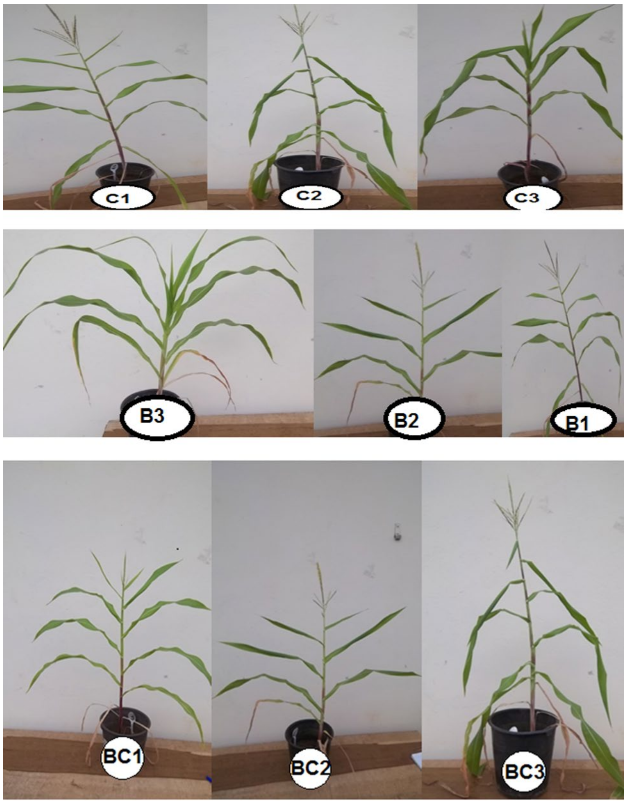

Fig. 15 Maize plants under 50% FC in response to different amendments at harvesting

synthesis by disrupting the activity of chlorophyll-synthesizing enzyme (Pflugmacher et al. 1999; Manios et al. 2003). Carotenoid is also a non-enzymatic antioxidant pigment that protects chlorophyll, membrane and cell genetic composition against ROS under drought and heavy metals stress (Nemeskeri 2006). In the previous reports, it is suggested that decrease in carotenoid content is a common response to metal toxicity (Rout et al. 2001) while the increase might be due to the important role of this pigment in detoxifying ROS (Tewari et al. 2002; Chandra et al. 2009). For example, Nemeskéri (2006) reported that drought stress significantly reduced the seed total carotenoid contents in a study with different pea cultivars under drought condition, but this decrease in carotenoid contents was not uniform in the pea cultivars. In this present study, increase in carotenoid content was significantly enhanced in maize leaves by the application of B1, B3, C1, C3, B2C1, B2C2, and B2C3 under 25% and 100% field capacity. With 50% field capacity, maize grown on soil with no amendment also recorded the highest carotenoid content. The porphyrins are enormous group of organic compounds in plants which are also regulated to overcome drought-induced stress conditions (Phung et al. 2011). The level of porphyrins was significantly higher with the application of B2C2 and B2C3 across the varying water regimes.

The changes in soil chemistry due to soil amendment could have also influenced the transformation, mobility, and bioavailability of Pb; hence, the variations observed in Pb uptake by maize crop in response to different organic amendments (Salati et al. 2010; Fleming et al. 2013). Pb concentration in maize shoot was lower than that of the root while the concentration in the root was lower than the one remaining in the soil. Higher Pb concentration in the root confirmed the previous report that 90% of the total Pb is accumulated in the root partly because of Pb poor mobility or mass flow mechanism (Kumar et al. 2012). Meanwhile, this has also been described as a tolerance mechanism to avoid the upward movement of Pb to the shoot where important metabolic activities are taking place (Fahr et al. 2013). Pb concentration in the shoot and root across the varying water regimes was reduced with 25% and 100% field capacity compared to 50% while across the treatments, lower rates of compost and biochar (B2 and C1) as well as their combination (B2C1)

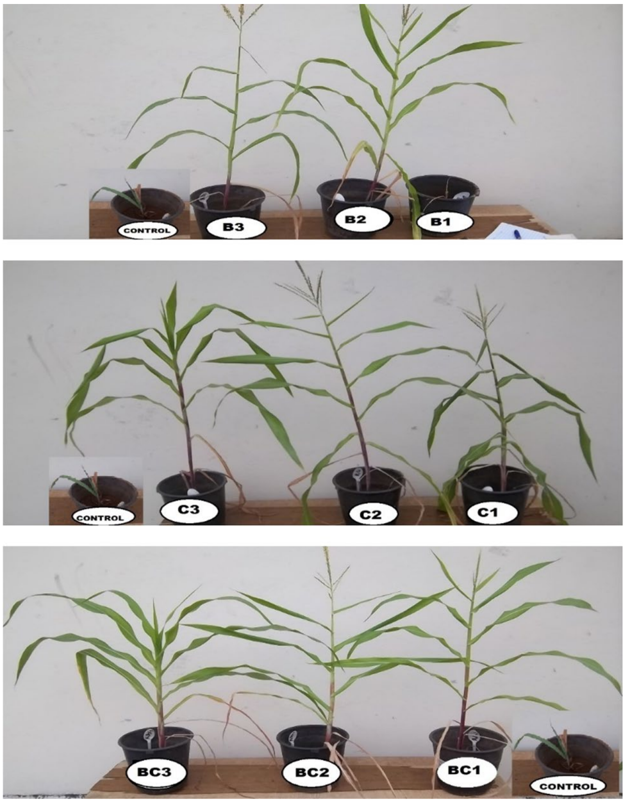

Fig. 16 Maize plants under 100% FC in response to different amendments at harvesting

reduced Pb concentration in maize plant parts compared to the higher rates.

It has been reported that the efficiency of compost is based on its application rate and the materials used for composting. However, in some situations, these are not directly correlated. This is why, it is important to determine the optimum application rate that gives the best result when using organic amendment to achieve different objectives. Similarly, from this study, it was clear that the behavior of different organic amendments was not concentration dependent and varied greatly depending on the type of materials, rate of application, and the stress treatments. The variation observed in the behavior of organic amendment in this study which was not consistent with the application rates might be due to the fact that many factors and various experimental conditions could have influenced the behavior of organic amendment in the soil matrix regardless of the amount. For instance, there have been conflicting reports on the role of organic amendment in the immobilization or solubilization of heavy metals in contaminated matrices depending on the form and rate of application (Bolan et al. 2003; David et al. 2004; Salati et al. 2010). Higher application rate in some cases has been found to immobilize heavy metal (Adejumo et al. 2010) whereas in another situation higher application rate has been reported to increase the mobility of metal in the soil (Fleming et al. 2013) due to increase in the concentration of DOM which in turn increases the metal extractability from the soil through plant uptake (Antoniadis and Alloway 2002; Ashworth and Alloway 2008; Salati et al. 2010; Fleming et al. 2013). This might be responsible for the higher Pb concentration in the shoot of maize plant treated with 10 t/ha compost (C2) under different watering regimes which was more than that of control and other organic treatments. The higher amount of Pb in the shoot could have also been responsible for the lower biomass recorded in that treatment as reflected in the other growth parameters taken (data not shown) probably due to phytotoxicity effect.

According to Fleming et al. (2013), heavy metal uptake is also influenced by soil nutrient status. This could possibly explain the higher Pb concentration found in maize grown on some amended soil compared to soil with no amendment. Soil pH is also an indicator for soil acidity or soil alkalinity and it is important for crop cultivation (Kögel-Knabner et al. 1996; Diez and Krauss 1997). In this study, the soil pH was increased across the water regimes and organic amendments (data not shown). It has been reported in previous research that regular application of organic amendments enhances soil pH (Ouedraogo et al. 2001) and organic matter (Amlinger et al. 2007; Adejumo et al. 2010). In this study, B2C3 increased the soil organic matter at 50%, while B2, B3, and B2C3 had high organic matter at 100% FC. All these were responsible for the maize growth under stress (Termorshuizen et al. 2005).

Conclusion

Combination of drought and heavy metal stresses reduced maize growth and biomass accumulation. Application of biochar in combination with compost, however, enhanced biomass production in stressed maize crop. Heavy metal stress alone increased the accumulation of proline better than combined stresses unlike cysteine and photosynthetic pigments. Combined stresses most especially at 50% FC increased photosynthetic pigment formation, and cysteine and Pb accumulation in maize crop compared to single stress of heavy metal alone. Osmolytes and photosynthetic production were also enhanced with biochar and compost amendments under stress compared to control whereas proline accumulation was reduced with amendments except in B2C1 treatment compared to control. Sole application of biochar at 10 t/ha reduced Pb uptake by maize and post-cropping soil Pb concentration. Different watering regimes also had varying effects on Pb uptake and translocation in the maize crop. The concentration in the shoot and root across the varying water regimes was reduced under 25 and 100% field capacity compared to 50% while organic treatments were found to reduce Pb concentration in plant parts. Compost applied singly performed better than biochar alone in term of biomass and osmolytes accumulation. Though no metal speciation or DOM quantification was considered in this study, the result obtained showed that thorough understanding of the DOM contents and functional groups of different organic amendments and their combination with respect to their different rates of application under different environmental conditions is needed.

References

Adejumo SA, Togun AO, Adediran JA, Ogundiran MB (2010) Effects of compost application on remediation and the growth of maize planted on lead contaminated soil. J Agric Sci Technol A 3:216–225

Adejumo SA, Togun AO, Adediran JA, Ogundiran MB (2011) Field assessment of progressive remediation of soil contaminated with lead-acid battery waste in response to compost application. Pedologist (Special Issue) 54(3):182–193

Adejumo SA, Owolabi MO, Odesola IF (2016) Agro-physiologic effects of compost and biochar produced at different temperatures on growth, photosynthetic pigment and micronutrients uptake of maize crop. Afr J Agric Res 11:661–667

Amlinger F, Peyr S, Geszti J, Dreher P, Karlheinz W, Nortcliff S (2007) Beneficial effects of compost application on fertility and productivity of soils. Literature study, Federal Ministry for Agriculture and Forestry, Environment and Water Management, Austria. https://www.umweltnet.at/filemanager/download/20558/

Arnao MB, Hernandez-Ruiz MB (2009) Protective effect of Melathionin against chlorophyll degradation during the senescence of barley leaves. J Pineal Res 46:58–63

Antoniadis V, Alloway BJ (2002) The role of dissolved organic carbon in the mobility of Cd, Ni and Zn in sewage sludge-amended soils. Environ Pollut 117:515–521

Ashraf M, Foolad MR (2007) Roles of glycine betaine and proline in improving plant abiotic stress resistance. Environ Exp Bot 59:206–216

Ashworth DJ, Alloway BJ (2008) Influence of dissolved organic matter on the solubility of heavy metals in sewage-sludge-amended soils. Commun Soil Sci Plant Anal 39:538–550

Aslam M, Khan IA, Saleem M, Ali Z (2006) Assessment of water stress tolerance in different maize accessions at germination and early growth stage. Pak J Bot 38:1571–1579

Ayoola OT, Makinde EA (2007) Fertilizer treatment effects on performance of cassava under two planting patterns in a cassava-based cropping system in South West Nigeria. Res J Agric Biol Sci 3:13–20

Azad HN, Shiva HA, Malekpour R (2011) Toxic effects of lead on growth and some biochemical and ionic parameters of sunflower (*Helianthus annuus* L.) seedlings. J Biol Sci 3:398–403

Bah AM, Dai H, Zhao J, Sun H, Cao F, Zhang G, Wu F (2011) Effects of cadmium, chromium and lead on growth, metal uptake and antioxidative capacity in *Typha angustifolia*. Biol Trace Elem Res 142:77–92

Bashir H, Ahmad J, Bagheri R, Nauman M, Qureshi MI (2012) Limited sulfur resource forces *Arabidopsis thaliana* to shift towards non-sulfur tolerance under cadmium stress. Environ Exp Bot. https//doi.org/10.1016/j.envexpbot.2012.05.004

Bates LS, Waldren RP, Teare ID (1973) Rapid determination of free proline for water stress studies. Plant Soil 39:205–207

Bolan N, Naidu R, Choppala G, Park J, Mora ML, Budianta D, Panneerselvam P (2010) Solute interactions in soils in relation to the bioavailability and environmental remediation of heavy metals and metalloids. Pedologist 53:1–18

Bolan NS, Adriano DC, Naidu R (2003) Role of phosphorus in (im) mobilization and bioavailability of heavy metals in the soil–plant system. Rev Environ Contam Toxicol 177:1–44

Boussen S, Soubrand M, Bril H, Ouerfelli K, Abdeljaouad S (2013) Transfer of lead, zinc and cadmium from mine tailings to wheat (*Triticum aestivum*) in carbonated Mediterranean (Northern Tunisia) soils. Geoderma 192:227–236

Boyer JS (1976) Water deficits and plant growth. In: Kozlowski TT (eds) Academic Press, London, pp 153–190

Brehmmer JM (1965) Total nitrogen. In: Block (ed) Methods of analysis. American Society of Agronomy, Madison, WI, pp 1149–1176

Chandra R, Bharagava RN, Yadav S, Mohan D (2009) Accumulation and distribution of toxic metals in wheat (*Triticum aestivum* L.) and Indian mustard (*Brassica campestris* L.) irrigated with distillery and tannery effluents. J Hazard Mater 162:1514–1521

Clemente R, Fuente CD, Moral R, Bernal MP (2007) Changes in microbial biomass parameters of a heavy metal-contaminated calcareous soil during a field remediation experiment. J Environ Qual 36:1137–1144

David JW, Rafael C, Bernal MP (2004) Contrasting effects of manure and compost on soil pH, heavy metal availability and growth of *Chenopodium album* L. in a soil contaminated by pyritic mine waste. Chemosphere 57:215–224

Diez T, Kraus M (1997) Wirkung langjähriger Kompostdüngung auf Pflanzenertrag und Bodenfruchtbarkeit. Agribiol Res 50:78–84

Edmeades GE, Deutsch JA (1994) Stress tolerance breeding: Maize that resists insects, drought, low nitrogen, and acid soils. CIMMYT, Mexico

Elliot HA, Liberati MR, Huang CP (1986) Competitive adsorption of heavy metals by soils. J Environ Qual 15:214–219

Esfandbod M, Phillips IR, Miller B, Rashti MR, Lan ZM, Srivastava P, Singh B, Chen CR (2017) Aged acidic biochar increases nitrogen retention and decreases ammonia volatilization in alkaline bauxite residue sand. Ecol Eng 98:157–165

Fahr M, Laurent L, Najib B, Valerie H, Mohamed E, Didier B, Abdelaziz S (2013) Effect of lead on root growth. Front Plant Sci 4:175

Farooq M, Wahid A, Kobayashi N et al (2009) Plant drought stress: effects, mechanisms and management. Agron Sustain Dev 29:185–212

Fidalgo F, Azenha M, Silva AF et al (2013) Copper-induced stress in Solanumnigrum L. and antioxidant defense system response. Food Energy Secur 2(1):70–80

Fleming M, Tai Y, Zhuang P, McBride MB (2013) Extractability and bioavailability of Pb and As in historically contaminated orchard soil: effects of compost amendments. Environ Pollut 177:90–97

Giatonde MK (1967) A spectrophotometric method for direct determination of cysteine in the presence of other naturally occurring amino acids. Biochem J 104:627–633

Ginneken LV, Meers E, Guisson R, Ruttens A, Elst K, Tack FMG, Vangrons-veld J, Diels L, Dejonghe W (2007) Phytoremediation for heavy metal-contaminated soils combined with bio energy production. J Environ Eng Landsc Manag 15:227–236

Glaser B (2007) Pre historically modified soils of central Amazonia: a model for sustainable agriculture in the twenty-first century. Philos Trans R Soc Biol Sci 362:187–196

Glaser B, Birk JJ (2012) State of the scientific knowledge on properties and genesis of Anthropogenic Dark Earths in Central Amazonia (terra preta de Índio). Geochim Cosmochim Acta 82:39–51

Glaser B, Lehmann J, Zech W (2002) Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal—a review. Biol Fertil Soils 35:219–230

Harms K, von Ballmoos P, Brunold C, Höfgen R, Hesse H (2000) Expression of a bacterial serine acetyl-transferase in transgenic potato plants leads to increased levels of cysteine and glutathione. Plant J 22:335–343

Hell R, Wirtz M (2011) Molecular biology, biochemistry and cellular physiology of cysteine metabolism in *Arabidopsis thaliana*. Arabidopsis Book 9:0154

Herath HMSK, Arbestain MC, Hedley M (2013) Effect of biochar on soil physical properties in two contrasting soils: an Alfisol and an Andisol. J Geoderma 209–210:188–197

Hossain MA, Pukclai P, Jaime A, Teixeirada S, Masayuki F (2012) Molecular mechanism of heavy metal toxicity and tolerance in plants: central role of glutathione in detoxification of reactive oxygen species and methylglyoxal and in heavy metal chelation. J Bot 2012:1–37

Hou W, Chen X, Song G, Wang Q, Chang CC (2007) Effects of copper and cadmium on heavy metal polluted waterbody restoration by duckweed (*Lemna minor*). Plant Physiol Biochem 45:62

Huang H, Li T, Gupta DK, He Z, Yang X, Ni B, Li M (2012) Heavy metal phytoextraction by *Sedum alfredii* is affected by continual clipping and phosphorus fertilization amendment. J Environ Sci 24(3):376–386

Islam MM, Hoque MA, Okuma E, Banu MN, Shimoishi Y, Nakamura Y et al (2009) Exogenous proline and glycine betaine increase antioxidant enzyme activities and confer tolerance to cadmium stress in cultured tobacco cells. J Plant Physiol 166:1587–1597

Islami T, Guritno B, Nurbasuki SA (2011) Maize yield and associated soil quality changes in cassava and maize intercropping system after 3 years of biochar application. J Agric Food Technol 1:112–115

Jaleel CA, Manivannan P, Wahid A, Farooq M, Somasundaram R, Paneerselvam R (2009) Drought stress in plants: a review on morphological characteristics and pigments composition. Int J Agric Biol 11:100–105

Joshi D, Srivastava PC, Srivastava P (2011) Toxicity threshold limits of cadmium for leafy vegetables raised on mollisol amended with varying levels of farmyard manure. Pedologist 54:249–256

Kahle P, Belau L (1998) Modellversuche zur Prüfung der Verwertungsmöglichkeiten von Bioabfallkompost in der Landwirtschaft. Agribiol Res 51:193–200

Kham AG, Kuek C, Chandhry TM, Khoo CS, Hayes WJ (2000) Role of plants, mycorrhizae and phytochelators in heavy metal contaminated land remediation. Chemosphere 41:197–207

Kögel-Knabner I, Leifeld J, Siebert S (1996) Humifizierungsprozesse von Kompost nach Ausbringung auf den Boden. In: Neue Techniken der Kompostierung. Kompostanwendung, Hygiene, Schadstoffabbau, Vermarktung, Abluftbehandlung—Dokumentation. In: Stegmann R (ed) Hamburger Berichte Economica Verlag, Bonn, vol 11, pp 73–87 (ISBN 3-87081-196-X)

Krogstad T (1983) Effect of liming and decomposition on chemical composition, ion exchange and heavy metal ion selectivity in sphagnum peat. In: Scientific reports of the Agricultural University of Norway AAS, p 79

Kumar V, Mahajan M, Yadav S (2012) Toxic metals accumulation, tolerance and homeostasis in brassica oilseed species: overview of physiological, biochemical and molecular mechanisms. In: Anjum NA, Ahmad I, Pereira ME, Duarte AC, Umar S, Khan NA (eds) The plant family Brassicaceae. Springer Netherlands, Dordrecht, vol 21, pp 171–211

Lehmann J, Gaunt J, Rondon M (2006) 'Bio-char sequestration in terrestrial ecosystems. A review. Mitig Adapt Strat Glob Change 11:403–427

Manios T, Stentifor EI, Millner PA (2003) The effect of heavy metals accumulation on the chlorophyll concentration of *Typha latifolia* plants, growing in a substrate containing sewage sludge compost and watered with metaliferus water. Ecol Eng 20:65–74

Miller G, Suzuki N, Ciftci-Yilmaz S, Mtttler R (2010) Reactive oxygen species homeostasis and signalling during drought and salinity stresses. Plant Cell Environ 33:453–467

Mishra S, Dubey RS (2006) Heavy metal uptake and detoxification mechanisms in plants. Int J Agric Res 1(2):122–141

Mourato M, Reis R, Martins L (2012) Characterization of plant antioxidative system in response to abiotic stresses: a focus on heavy metal toxicity. In: Montanaro G, Dichio B (eds) Advances in selected plant physiology aspects. Intech, Rijeka, vol 93, pp 23–44

Nemeskéri E (2006) Breeding strategy for improvement of colour quality and carotenoid levels in dry pea seeds. Commun Biometry Crop Sci 1:49–55

Ogundiran MB, Osibanjo O (2009) Mobility and speciation of heavy metals in soils impacted by hazardous waste. Chem Spec Bioavail 21:59–69

Ogundiran MB, Nugterena HW, Witkamp GJ (2012) Immobilisation of lead smelting slag within spent aluminate—fly ash based geopolymers. J Hazard Mater 249:29–36

Ogunsumi LO, Ewuola SO, Daramola AG (2005) Socio-economic impact assessment of maize production; technology on farmers' welfare in South West, Nigeria. J Central Eur Agric 6:15–26

Ouedraogo E, Mando A, Zombre NP (2001) Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. Agric Ecosyst Environ 84:259–266

Padmavathiamma PK, Li LY (2010) Phytoavailability and fractionation of lead and manganese in a contaminated soil after application of three amendments. Bioresour Technol 101:5667–5676

Parvaiz A, Satyawati S (2008) Salt stress and phyto-biochemical responses of plants—a review. Plant Soil Environ 54:89–99

Pflugmacher S, Geissier K, Steinberg C (1999) Activity of phase I phase II detoxification enzymes in different cormus parts of *Phragmites australis*. Ecotoxicol Environ Saf 42:62–66

Phung TH, Jung HI, Park JH, Kim JG, Back K, Jung S (2011) Porphyrin biosynthesis control under water stress: sustained porphyrin status correlates with drought tolerance in transgenic rice. Plant Physiol 157(4):1746–64

Pravina P (2013) Cysteine—master antioxidant. IJPCBS 3(1):143–149

Raji JA (2003) Inter. cropping soybean and maize in a derived Savanna ecology. Afr J Biotechnol 6:1885–1887

Rashti MR, Esfandbod M, Adhami E, Srivastava P (2014) Cadmium desorption behaviour in selected sub-tropical soils: effects of soil properties. J Geochem Explor 144:230–236

Rennevan H, Tony RH, Abir A, Andy JM, Mike LJ, Sabeha KO (2007) Remediation of metal contaminated soil with mineral amended composts. Environ Pollut 150:347–354

Rout G, Samantaray S, Das P (2001) "Aluminum toxicity in plants: a review". Agron EDP Sci 21:3–21

Ruiz J, Blumwald E (2002) Salinity-induced glutathione synthesis in *Brassica napus*. Planta 214:965–969

Sadras VO, Milroy SP (1996) Soilwater thresholds for the responses of leaf expansion and gas exchange: a review. Field Crops Res 47:253–266

Saifullah GA, Zia MH, Murtaza G, Waraich EA, Ok YS, Srivastava P (2010) Comparison of organic and inorganic amendments for enhancing soil lead phytoextraction by wheat (*Triticum aestivum* L.). Int J Phytorem 12:633–649

Salati S, Quadri G, Tambone F, Adani F (2010) Fresh organic matter of municipal solid waste enhances phytoextraction of heavy metals from contaminated soil. Environ Pollut 158:1899–1906

Sarropoulou V, Kortessa D, Ioannis T, Magdalene K (2012) Melatonin enhances root regeneration, photosynthetic pigments, biomass, total carbohydrates and proline content in the cherry root stock PHL-C (*Prunus avium* x *Prunus cerasus*). Plant Physiol Biochem 61:162–168

Shah K, Dubey RS (1998) Effect of cadmium on proline accumulation and ribonuclease activity in rice seedlings: role of proline as a possible enzyme protectant. Biol Plant 40:121–130

Shaw RH (1988) Climate requirement. In: Sprague GF, Dudley JW (eds) Corn and corn improvement, 3rd edn. Agronomy series, vol 18, pp 609–633

Smejikalova M, Milkanova O, Boruvka L (2003) Effects of heavy metal concentrations on biological activity of soil micro-organisms. Plant Environ 7:321–326

Srivastava P, Singh B, Angove M (2005) Competitive adsorption behaviour of heavy metals on kaolinite. J Colloid Interface Sci 290:28–38

Srivastava P, Gräfe M, Singh B, Balasubramanian M (2007) Mechanisms of Cd and Pb desorption kinetics from kaolinite. In: Barnett M, Kent G (eds) Adsorption of metals by geomedia, vol II. Developments in Earth and environmental sciences. Elsevier, New York, pp 209–238

Stamatiadis S, Werner M, Buchanan M (1999) Field assessment of soil quality as affected by compost and fertilizer application in a broccoli field. Appl Soil Ecol 12:217–225

Steffens B, Steffen-Heins A, Sauter M (2013) Reactive oxygen species mediate growth and death in submerged plants. Front Plant Sci 4:179

Szabados L, Savouré A (2010) Proline: a multifunctional amino acid. Trends Plant Sci 15:89–97

Termorshuizen AJ, van Rijn E, Blok WJ (2005) Phytosanitary risk assessment of composts. Compost Sci Util 13:108–115

Tewari RK, Kumar P, Sharma PN, Bisht SS (2002) Modulation of oxidative stress responsive enzymes by excess cobalt. Plant Sci 162:381–388

Tripathi BN, Gaur JP (2004) Relationship between copper- and zinc-induced oxidative stress and proline accumulation in *Scenedesmus* sp. Planta 219:397–404

Uchimiya M, Lima IM, Chang KKT, Wartelle LH, Rodgers J (2010) Immobilization of heavy metal ions (Cu", Cd", Ni", and Pb") by broiler litter-derived biochars in water and soil. J Agric Food Chem 58:5538–5544

Van Zwieten L, Kimber S, Morris S, Chan KY, Downie A, Rust J, Joseph S, Cowie A (2010) Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant Soil 327:235–246

Warnock DD, Lehmann J, Kuyper TW, Rillig MC (2007) Mycorrhizal responses to biochar in soil—concepts and mechanisms. Plant Soil 300:9–20