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ORIGINAL PAPER

Organic amendments: effects on cereals growth and cadmium remediation

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Abstract Cadmium (Cd) is one of the toxic metals that adversely affect plant growth. Organic amendments may not only enhance nutrient status of soil, but they may also form complexes with Cd and reduce its availability to plants. This experiment was conducted to determine whether organic amendments (compost and biogas slurry) could stabilize/extract Cd and alleviate the adverse effects of Cd on the growth of two cereals, wheat and maize. Organic amendments along with four varying levels of Cd (0, 5, 20, 50 mg kg^{-1} soil) were prepared with soil. Effect of these amendments on tolerance indices, root/shoot dry biomass, tissue Cd concentration, Cd uptake and translocation were studied. Biogas slurry caused maximum increase in tolerance indices of wheat and maize (100–112 and 117–133 %, respectively, as compared to control), whereas compost caused significant increase in their dry biomass. Negative correlation between root dry biomass of wheat ($r = -0.37$) and maize ($r = -0.53$) to Cd revealed its suppressive effects. Dry biomass of plant correlated with organic amendments in wheat ($r = 0.83$–0.98), whereas weak correlation was observed in maize ($r = 0.30$–0.40). Compost significantly reduced Cd uptake in wheat and maize; however, it increased Cd translocation in plants. Based on the results of this study, root was the major sink of Cd when soil was amended with or without organic amendments. Biogas slurry removed 97 % Cd from artificially polluted water after 13 h at pH 6. The additions of compost in soil and biogas slurry in wastewater are recommended to stabilize/extract Cd.

Keywords Bioremediation · Cadmium stress · Biosorption · Compost · Biogas slurry · Wheat · Maize

Introduction

The steadily growing population is increasing the production of municipal waste, which contains both organic and inorganic pollutants including heavy metals. The heavy metals are accumulated in soil through pedogenic and anthropogenic activities (Taghinia et al. 2010; Conceição et al. 2013; Moaref et al. 2014). The problem of heavy metals is associated with the proliferation of industry. Most of the waste generated by industries ultimately ends its journey in soil and water. Some of such industries causing metals build up in soil include textile, paint, electroplating, paper, mining and tannery industry (Azzaoui et al. 2002; Vutukuru 2003; Taghinia et al. 2010). Industrial effluents discharged from these industries are irrigating chunk of agricultural soils that causes problem of metal pollution. The untreated industrial effluents are the main source of metal pollution of peri-urban soils in developing countries (Mahmood 2010). It has also been reported that Cd is an inveterate toxicant and is easily passed through plants. Cadmium shows many deleterious effects in humans when they consume it through food (Vassilev et al. 1998). Therefore, it is a dire need to develop effective technology to curtail Cd contamination from soil.

Organic manures (compost, biogas slurry) are known to improve soil structure and soil fertility status by adding essential nutrients, and enhance microbial community of

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soil (Oldare et al. 2008, 2011). Application of organic manures is a common practice worldwide to enhance nutrient status of soil, and as a result, more production of crops is obtained (Muhammad et al. 2007). Compost produced from crop leftovers has been used as a nutrient source and also as a soil conditioner since the ancient times to improve growth and yield of crops (Hussain et al. 2001; Sarwar et al. 2007). Biogas slurry (BGS) being used as organic manure is produced from dung waste after methane (NH_4) generation. It has also been evaluated as a good nutrient source in various countries including Pakistan. Very recently, Shahbaz et al. (2014) reported increased fruit set and nitrogen use efficiency of okra with the addition of BGS to soil medium.

Most of the work done by several research groups focuses on organic manures (compost and BGS) as a way to improve soil fertility, but they may also be exploited for metal remediation from polluted soil and water. Addition of these organic amendments to soil is a way of enhancing natural mechanisms such as precipitation, complexation, adsorption and absorption, which reduces the bioavailability of the pollutants (Pérez-de-Mora et al. 2007). Moreover, these organic amendments provide a facility to establish plants on polluted soil by binding pollutants, increasing nutrients and stimulating native microbial community (Oldare et al. 2011; Zaniewicz-Bajkowska et al. 2007; Pérez-de-Mora et al. 2006, 2007). The revegetation of metal-contaminated soil could be possible by the application of compost prepared from municipal solid waste (Farrell and Jones 2010; Walker et al. 2004). Furthermore, compost is converted into a final stable product of humus that can reduce metal availability in soil by the formation of stable complexes (Walker et al. 2003).

Biosorption is a cost-effective, environment-friendly technology, which can be exploited for numerous pollutants irrespective of their toxicity. Furthermore, it takes less time to remove pollutants from wastewater without producing any toxic secondary metabolites. Natural products are being used to adsorb metals and slack down their concentrations from wastewater. El-Said et al. (2010) used rice husk ash to sorb metals from metal-contaminated aqueous solution. Use of a biological source to sorb contaminant from wastewater is an emerging technology, and scientists are interested to apply such low-cost materials to bind metals from wastewater (Sari and Tuzen 2009; El-Said et al. 2010). Although some work has been conducted on organic manures, there is still a need to explore the role of compost and BGS to stabilize/extract Cd and to improve cereal growth by mitigating Cd stress. Therefore, the present study was conducted to answer the following questions: (1) Can compost and BGS improve cereal growth by alleviating Cd stress and which one is more effective? (2) Can these organic amendments stabilize or sorb Cd from soil or solution?

Materials and methods

Collection and analysis of manures

The compost produced from fruit peels was collected from the locally fabricated unit at Institute of Soil & Environmental Sciences, University of Agriculture Faisalabad, Pakistan. Biogas slurry was collected from the biogas plant located at Rissalawala village in Faisalabad and then air-dried and crushed in a crushing unit to the final grain size of 5 mm. The pre-analysis of organic amendments was carried out to determine total metal concentration, total nitrogen, electrical conductivity (EC) and pH (Table 1). Total metal concentration in organic manures was determined through dry ashing (Isaac 1998). Briefly, 1 g of manure sample weighed in crucibles and converted into ash in a muffle furnace at 550 °C for 4 h. The crucibles having ash were cooled in a desiccator for 1 h. Then, the ash was dissolved in 10 mL HCl, transferred it to a 100-mL volumetric flask, and made the final volume with distilled water. The material was stored in plastic bottles and used for the determination of Cd, Pb, Cr, Ni, Zn, and Fe in manures using an atomic absorption spectrophotometer (PerkinElmer, 100 Analyst, Waltham,

Table 1 Characteristics of compost and biogas slurry used in the experiments

	Units	Compost	Biogas slurry	Permissible limits‡	
				EU range	USA
$pH_{1:2}$	–	7.65	7.1	5.5–7.0	6–7
$EC_{1:2}$	dS m^{-1}	3.15	2.98	–	–
Organic matter	%	56	45	>20	>30
Total N	%	2.12	1.65	–	–
Total Cd	mg kg^{-1}	2.13 ± 0.31†	1.94 ± 0.11	0.7–10	39
Total Pb	mg kg^{-1}	ND√	ND	70–1,000	300
Total Ni	mg kg^{-1}	10.48 ± 4.47	17.35 ± 4.45	20–200	420
Total Cr	mg kg^{-1}	ND	ND	70–200	1,200
Total Zn	mg kg^{-1}	46.57 ± 2.64	81.82 ± 4.50	210–4,000	2,800

† data presented as mean ± SD

√ not detected

‡ standard limits of heavy metals, pH, organic matter for compost, and biosolids (Brinton 2000)

USA). Total nitrogen contents were determined using the Kjeldahl apparatus (Jackson 1962). Organic manures (compost and BGS) to water ratio 1:2 was made to determine pH and EC with the help of pH meter (Jenway Model-671P) and EC meter (Kent EIL Model 7015). Organic matter contents of compost and BGS were determined according to loss on ignition method using equation (Eq. 1).

$$\text{Organic matter }(\%) = \frac{\text{Dry weight at }105\,^{\circ}\text{C} - \text{Dry weight at }450\,^{\circ}\text{C}}{\text{Dry weight at}105\,^{\circ}\text{C}} \times 100. \quad (1)$$

Seed material

The seed of wheat (cv. Inqlab-91) was obtained from the Wheat Section, Ayub Agricultural Research Institute (AARI) Faisalabad, Pakistan, whereas that of maize (Pioneer Hybrid-3068) was purchased from a local supplier of Pioneer Seed Company Sahiwal, Pakistan. Before sowing, seeds were surface sterilized with 5 % sodium hypochlorite solution for 5 min following 3–4 washings with distilled water.

Cadmium treatment

Cadmium chloride ($CdCl_2.H_2O$) salt of high purity (98 %) was purchased from Merck Chemicals, Germany, and used to prepare desired Cd concentrations (5, 20, 50 mg kg^{-1} soil) along with control in which distilled water was used without Cd contamination.

Experimental conditions

Jar experiments were conducted to evaluate the effect of organic amendments (compost and BGS) on dry biomass of cereals and Cd uptake. Organic amendments (compost at the rate of 10 and 15 Mg ha^{-1} for wheat and maize, respectively, while BGS at the rate of 15 Mg ha^{-1} for both cereals) weighed and thoroughly mixed in sand (400 g for wheat and 500 g for maize depending upon the size of jar). The desired Cd levels [2, 8, and 20 mg/jar for wheat; 2.5, 10, and 25 mg/jar for maize equal to 5, 20 and 50 mg Cd kg^{-1} soil, respectively] were prepared with sand and left for 2 weeks to homogenize Cd. The surface sterilized seeds of each crop cultivar were placed in each jar with the help of a sterilized pincer at uniform depth. Light and dark periods were adjusted at 10 and 14 h, respectively, while a temperature of 25 ± 2 °C and light intensity of 275 µmol m^{-2} s^{-1} were maintained during the whole growth period. Treatments were structured in a completely randomized design in factorial arrangement (CRD factorial) with three replicates. At harvesting, tolerance indices (Eq. 2), root/shoot dry biomass, and Cd uptake were calculated.

$$\text{Tolerance indices }(\%) = \frac{\text{mean root length in Cd or organic amended soil}}{\text{mean root length in control (no Cd or organic amendments)}} \times 100. \quad (2)$$

Shoot and root Cd

Shoot and root Cd contents were determined following the method described by Ahmad et al. (2013). Briefly, the diacid mixture consisting of concentrated nitric acid and perchloric acid in 3:1 ratio was used to digest maize and wheat samples on hot plate until the material became colorless. De-ionized water was added to the flasks and filtered through Whatman # 40, and the volume made up to 50 mL. The resultant extract was stored in plastic bottles and used for the determination of Cd on atomic absorption spectrophotometer (PerkinElmer, 100 Analyst, Waltham, USA). Cd uptake in plant tissues (root, shoot, and total plant) and translocation in plants (root to shoot) was calculated using Eq. 3 and Eq. 4 respectively.

$$\text{Cd uptake (mg kg} - \text{1dry weight)} = \text{Cd concentration in plant tissues} \times \textit{respective dry weight} \quad (3)$$

$$\text{Translocation factor (TF)} = \frac{\text{Cd concentration in shoot}}{\text{Cd concentration in root}} \quad (4)$$

Cadmium removal efficiency of organic manures

This study was conducted to support the hypothesis that "organic material binds Cd from soil or solution" and thus reduces its bioavailability to plants. The effect of loading rate of Cd and pH at a fixed rate of organic manures (1 %) was studied. Two Cd levels (20 and 40 mg L^{-1}) were developed using salt $CdCl_2.H_2O$. One gram each of compost or BGS was added to 100 mL of each Cd level adjusted to pH 6 and 8 in the 250-mL conical flask. Conical flasks were placed in a mechanical shaking incubator at 28 ± 2 °C and 100 rpm. The samples were drawn after 1, 6, and 13 h from respective flasks to quantify Cd in solution using an atomic absorption spectrophotometer (PerkinElmer, 100 Analyst, Waltham, USA). Cd removed from artificially polluted water by the application of organic amendments was determined following Eq. 5.

$$\text{Removal efficiency }(\%) = \frac{\text{Cdi} - \text{Cds}}{\text{Cdi}} \times 100. \quad (5)$$

where Cdi: Initial Cd concentration (mg L^{-1}), Cds: Cd concentration at the time of sampling (mg L^{-1}).

Statistical analysis

Two-way analysis of variance (ANOVA) was carried out to analyze the data using the STATISTIX (version 8.1). The experiment was arranged according to CRD-2 factor factorial design. It comprised of two factors [Factor A: Cd with 4 levels 0, 5, 20, and 50 mg kg^{-1} soil; Factor B: organic amendments with 3 levels, i.e., control, compost, and BGS]. Post hoc HSD Tukey test was used to determine significance between treatment means at $p \leq 0.05$. Correlation of Cd and organic amendments with different parameters was determined to estimate their relationship at $p \leq 0.01$ and $p \leq 0.05$.

Results and discussion

Physicochemical characteristics of organic amendments

Table 1 shows analytical results of compost and BGS used in this study. Organic amendments showed slightly higher pH, while the organic matter and mineral contents of nitrogen and heavy metals were within the range of quality standard prescribed by the European and American councils (Brinton 2000).

Effect of organic amendments on wheat and maize

Tolerance indices

Tolerance indices of wheat decreased sharply (99–86 %) in response to Cd, but in contrast to this, application of organic amendments increased it (100–112 %) under Cd-stressed conditions (Fig. 1). It was shown from the results that the maximum tolerance indices (112 and 103 %) were observed with the application of BGS and compost at 5 and 50 mg kg^{-1} soil, respectively. Similarly, Fig. 1 shows positive influence of organic amendments on tolerance indices of maize, which was increased (116–133 %), as compared to treatment receiving no Cd, and organic amendments (control). Soil amended with BGS showed maximum tolerance (133 and 117 %) to Cd applied at the rate of 5 and 50 mg kg^{-1} soil, respectively, as compared to the control. Our previous study reported inhibitory effects of Cd on tolerance indices of wheat (Ahmad et al. 2012). However, increased tolerance indices by the application of organic amendments in normal and Cd stress conferred their positive effect on root growth of studied crops. Likewise, the growth promoting effects of organic amendments in metal-contaminated soil have also been reported earlier (Farrell and Jones 2010; Medina and Azcón 2010).

Plant dry biomass

The interactive effects (Cd × organic amendments) were significant on shoot and total plant biomass (root + shoot), but nonsignificant on root dry biomass of wheat (Table 2). Dry biomass decreased with increasing concentration of Cd. Organic amendments significantly increased shoot, root, and plant dry biomass of wheat in normal and Cd-contaminated soils as compared to their respective controls. However, in normal soil, only the application of BGS increased root dry biomass of wheat significantly as compared to its respective control. The highest shoot (42 mg $plant^{-1}$), root (19 mg $plant^{-1}$), and plant biomass (59 mg $plant^{-1}$) was obtained with the application of BGS in the treatments receiving 50, 0, and 0 mg Cd kg^{-1} soil, respectively.

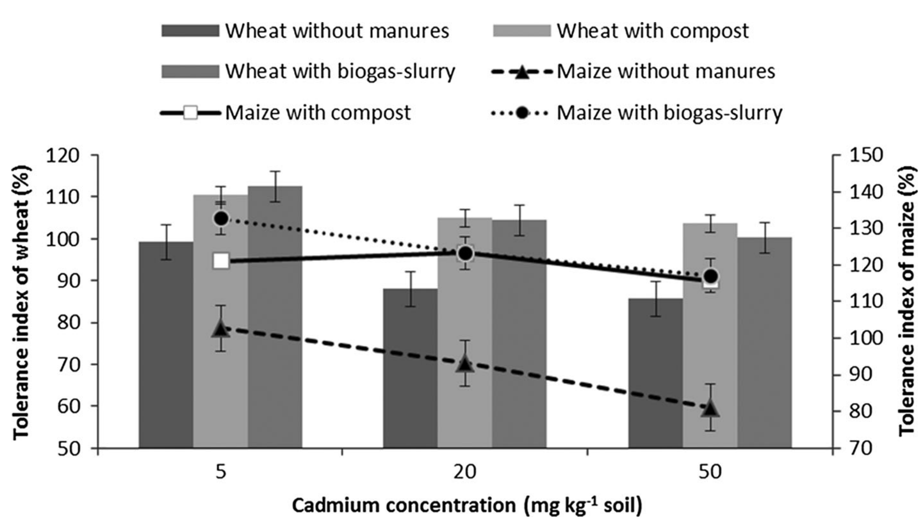

Fig. 1 Tolerance indices of wheat and maize affected by organic amendments under Cd stress. *Bars* show means ± standard errors

Table 2 Effect of organic amendments on dry biomass and tissue Cd concentration of wheat

mg kg^{-1} soil	Mg ha^{-1}	dry weight (mg plant^{-1})			Cd conc. (mg kg^{-1} dwt)			Cd uptake (mg kg^{-1} dwt)			TF
Cd levels	Org. amendments	Shoot	Root	Plant	Shoot	Root	Plant	Shoot	Root	Plant	
0	Control	22^{d}	15.5^{cd}	37.6^{c}	ND	ND	ND	ND	ND	ND	ND
	Compost	33^{c}	$16.8^{a–c}$	50.1^{b}	ND	ND	ND	ND	ND	ND	ND
	Biogas slurry	41^{ab}	18.5^{a}	59.0^{a}	ND	ND	ND	ND	ND	ND	ND
5	Control	22^{d}	14.6^{de}	36.9^{c}	0.27^{d}	0.79^{d}	1.06^{e}	6.14^{d}	11.55^{d}	39.46^{e}	$0.37^{b–d}$
	Compost	32^{c}	16.5^{bc}	49.0^{b}	0.14^{d}	0.35^{d}	0.46^{e}	3.69^{d}	5.84^{d}	22.83^{e}	0.32^{cd}
	Biogas slurry	39^{b}	17.4^{ab}	56.7^{a}	0.07^{d}	0.41^{d}	0.48^{e}	2.68^{d}	7.16^{d}	27.02^{e}	0.17^{de}
20	Control	21^{d}	13.1^{e}	33.7^{d}	2.64^{c}	4.81^{c}	7.45^{d}	54.11^{c}	63.32^{c}	251.1^{d}	$0.55^{a–c}$
	Compost	31^{c}	$16.3^{b–d}$	47.7^{b}	2.26^{c}	3.57^{c}	5.84^{d}	71.26^{c}	58.52^{c}	279.2^{cd}	0.64^{ab}
	Biogas slurry	41^{ab}	17.4^{ab}	58.5^{a}	2.23^{c}	3.91^{c}	6.14^{d}	91.86^{c}	67.80^{c}	359.0^{c}	$0.57^{a–c}$
50	Control	20^{d}	13.6^{e}	33.8^{d}	7.51^{a}	9.26^{a}	16.77^{a}	151.99^{b}	125.9^{b}	566.9^{b}	0.82^{a}
	Compost	32^{c}	$16.0^{b–d}$	47.8^{b}	5.11^{b}	6.75^{b}	11.85^{c}	162.71^{b}	108.2^{b}	567.7^{b}	0.76^{a}
	Biogas slurry	42^{a}	16.5^{bc}	58.6^{a}	5.11^{b}	9.04^{a}	14.12^{b}	215.37^{a}	149.2^{a}	829.3^{a}	$0.56^{a–c}$
Cadmium† (df = 3)		ns	*	*	*	*	*	*	*	*	*
Organic amendments† (df = 2)		*	*	*	*	*	*	*	*	*	*
Interaction† (df = 6)		*	ns	*	*	*	*	*	*	*	ns

Compost was applied at the rate of 10, while biogas slurry at the rate of 15 Mg ha^{-1} to wheat; control was without organic manures. Means, in each column, sharing same letters differ nonsignificantly at ($p > 0.05$) according to post hoc HSD Tukey test. Values presented in table are means of three replicates

df degree of freedom, *dwt* dry weight, *ns* nonsignificant, *ND* not detected, *TF* translocation factor

† Asterisk shows significant main and interactive effects at ($p \leq 0.05$)

In contrast to wheat, the interactive effects (Cd × organic amendments) were not significant in maize dry biomass, but the main effects were significant in relation to shoot, root, and total plant dry biomass (Table 3). In normal soil, application of compost showed significant increase in shoot, root, and total plant dry biomass of maize; however, BGS also increased total plant dry biomass significantly as compared to their respective controls. The significant increase in shoot and total plant dry biomass of maize was recorded on application of compost at all levels of Cd contamination as compared to their respective controls. Neither compost nor BGS showed any significant improvement in root dry biomass of maize at all levels of Cd contamination as compared to their respective controls.

Similar to our findings, Farrell and Jones (2010) observed that application of different types of compost increased above and below ground biomass of plant in contaminated soil, with maximum biomass produced by the application of peat-based compost. In this study, the plant species-specific response of organic amendments was observed, as BGS produced maximum increase in dry biomass in wheat, while compost in maize (Tables 2, 3). However, these organic amendments sharing one similarity that shoot dry biomass of both cereals was affected more significantly than root dry biomass with the addition of these amendments. This might be due to improved soil structure, nutrient, and water-holding capacity of soil in response to organic amendments, as similar effects on soil properties after the addition of compost and BGS were observed earlier by Oldare et al. (2011). Organic amendments increased biomass of studied crops in Cd-contaminated soil, which is in line with Farrell and Jones (2010) and in contrast with Rosario et al. (2007). This alleviation of phytotoxicity in response to organic amendments may be credited to improved physical health of soil and nutrient availability (Oldare et al. 2011; Abubaker et al. 2012). However, the added organic amendments may also bring new organisms (bacteria, fungi, actinomycetes etc.) that may increase nutrient cycling, produce hormones, and establish symbiosis with plants to enable better stress tolerance. It was reported earlier that soil microbial activity increased upon addition of compost (Lejon et al. 2007). Moreover, BGS enhanced indigenous microbial activity (Oldare et al. 2008, 2011) and prevented crop diseases (Yu et al. 2006). Our results are consistent with those of Tiwari et al. (2000) who reported that crop performance was increased by the application of BGS might be due to increased ammonium nitrogen in digested BGS (Monnet 2003). This study clearly demonstrates the positive effects of organic amendments on restoration of contaminated land and successful establishment of green cover in the form of plants. A large amount of waste produced during agricultural activities can be converted into compost and biogas

Table 3 Effect of organic amendments on dry biomass and tissue Cd concentration of maize

mg kg^{-1} soil	Mg ha^{-1}	dry weight (mg $plant^{-1}$)			Cd conc. (mg kg^{-1} dwt)			Cd uptake (mg kg^{-1} dwt)			TF
Cd levels	Org. amendments	Shoot	Root	Plant	Shoot	Root	Plant	Shoot	Root	Plant	
0	Control	223^{cd}	$150^{b–d}$	373^{cd}	ND	ND	ND	ND	ND	ND	ND
	Compost	330^{a}	193^{a}	523^{a}	ND	ND	ND	ND	ND	ND	ND
	Biogas slurry	$280^{a–c}$	183^{ab}	463^{ab}	ND	ND	ND	ND	ND	ND	ND
5	Control	230^{cd}	143^{cd}	373^{cd}	0.27^{bc}	0.70^{d}	0.97^{d}	60.8^{b}	100.8^{c}	362^{c}	0.39^{cd}
	Compost	327^{a}	$180^{a–c}$	507^{a}	0.11^{bc}	0.32^{d}	0.43^{d}	35.1^{b}	57.5^{c}	216.9^{c}	0.34^{cd}
	Biogas slurry	$257^{b–d}$	$167^{a–d}$	423^{bc}	0.13^{bc}	0.39^{d}	0.52^{d}	35.3^{b}	64.1^{c}	222.5^{c}	0.34^{cd}
20	Control	200^{d}	130^{d}	330^{d}	2.92^{b}	4.12^{c}	7.04^{c}	586.4^{b}	534.9^{b}	2322.6^{b}	0.72^{bc}
	Compost	313^{ab}	$163^{a–d}$	476^{ab}	2.22^{bc}	2.81^{c}	5.03^{c}	694.5^{b}	457.4^{b}	2400.5^{b}	$0.82^{a–c}$
	Biogas slurry	237^{cd}	$153^{b–d}$	390^{cd}	2.55^{bc}	2.97^{c}	5.52^{c}	605.4^{b}	443.3^{b}	2139.1^{b}	$0.91^{a–c}$
50	Control	200^{d}	137^{d}	337^{d}	10.35^{a}	7.62^{a}	17.97^{a}	2062.9^{a}	1038.5^{a}	6036.9^{a}	1.38^{a}
	Compost	317^{ab}	$157^{a–d}$	473^{ab}	8.17^{a}	5.87^{b}	14.04^{b}	2586.2^{a}	922.1^{a}	6652.9^{a}	1.38^{a}
	Biogas slurry	227^{cd}	143^{cd}	370^{cd}	8.71^{a}	6.75^{ab}	15.46^{ab}	1993.3^{a}	972.8^{a}	5725.7^{a}	1.30^{ab}
Cadmium† (df = 3)		*	*	*	*	*	*	*	*	*	*
Organic amendments† (df = 2)		*	*	*	ns	*	*	ns	ns	ns	ns
Interaction† (df = 6)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Compost and biogas slurry both applied at the rate of 15 Mg ha^{-1} to maize; control was without organic manures. Means, in each column, sharing same letters differ nonsignificantly at ($p > 0.05$) according to Post hoc HSD Tukey test. Values presented in table are means of three replicates

df degree of freedom, *dwt* dry weight, *ns* nonsignificant, *ND* not detected, *TF* translocation factor

† Asterisk shows significant main and interactive effects at ($p \leq 0.05$)

and may be applied to restore contaminated site. Likewise, it has also been suggested that organic amendments can also be used to extract and stabilize organic and inorganic pollutants present in the soil and may be used successfully to establish plants (Farrell and Jones 2010; Tejada et al. 2008).

Tissue Cd concentration and translocation

Results in Table 2 demonstrate tissue Cd concentration and its uptake in wheat plant [root, shoot, and total plant (root + shoot)] in amended and non-amended soil. The main and interactive effects were significant, which means that the exogenous application of Cd and organic amendments both influenced tissue Cd concentration and its uptake in wheat. Tissue Cd concentration of wheat decreased in amended soil at all levels of Cd contamination, but the results were significant only at higher Cd level. Compost significantly decreased shoot, root, and total plant Cd concentration, while BGS significantly decreased shoot and total plant Cd concentration of wheat at 50 mg Cd kg^{-1} soil as compared to their respective controls. Likewise, Cd uptake in wheat decreased at lower Cd level (5 mg Cd kg^{-1} soil), but increased at higher Cd level (20 mg Cd kg^{-1} soil) upon addition of organic amendments in comparison with respective control, although these differences were not significant. Cd uptake increased significantly at 50 mg Cd kg^{-1} soil in soil amended with BGS as compared to its respective control. Cd translocation from root to shoot was increased with increasing exogenous application of Cd; however, organic amendments nonsignificantly reduced Cd translocation in comparison with control. BGS application caused 2.17- and 1.46-fold reduced translocation in wheat at 5 and 50 mg Cd kg^{-1} soil as compared to their respective controls (Table 2; Fig. 2).

Tissue Cd concentration and uptake in maize (shoot, root, and total plant) was directly proportional to Cd applied in soil which was significantly higher with each other except shoot Cd, which showed nonsignificant differences at 5 and 20 mg Cd kg^{-1} soil (Table 3). Application of compost showed significant decreased Cd concentration in root and total plant as compared to their respective controls. None of the organic amendment showed significant differences in root, shoot, and total plant Cd uptake of maize. Cd translocation from maize root to shoot was directly related to its concentration in soil. Organic amendments nonsignificantly decreased/increased the Cd translocation from root to shoot depending on Cd concentration in soil (Table 3; Fig. 2).

Tissue Cd concentration in wheat and maize was greatly reduced in the presence of organic amendments; however, it can be seen from the results that tissue Cd concentration and its uptake depends upon plant species and its concentration in soil (Tables 2, 3). Addition of organic

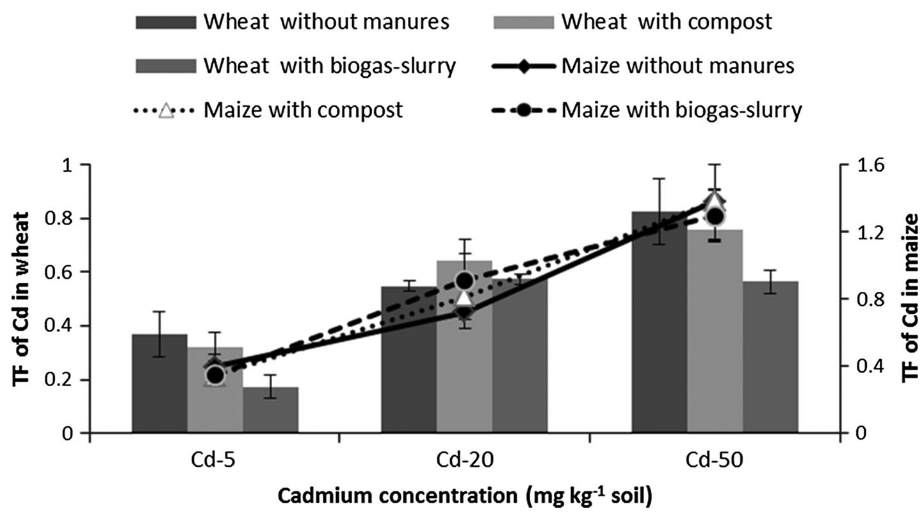

Fig. 2 Effect of organic amendments on translocation factor (TF) of Cd in wheat and maize. *Bars* show means ± standard errors

amendments can immobilize or stabilize Cd in soil by forming stable metalo-organo complexes that might have restricted Cd uptake in aerial part of plants. Dourado et al. (2013) reported that immobilization of Cd in soil is one of the mechanisms for increased plant biomass in metal-contaminated soil. Further, they argued that Cd immobilization may be helpful to reduce its toxicity on root proliferation; thereby, plants may uptake better nutrients in normal and stressed conditions. In this study, dry biomass of plants (wheat and maize) significantly increased in Cd-contaminated soil, which might be due to immobilization of Cd in amended soil (Tables 2, 3). Businelli et al. (2009) reported reduction in the bioavailability of metals in soil amended with organic matter, while Rajaie et al. (2006) reported highest metal availability in soil after addition of organic matter to soil. Bioavailable fraction of metals depends upon soil characteristics, climatic conditions, and the native microbial activity that converts compost and other organic material into mineral form (Clemente et al. 2006). Moreover, the reduction in Cd concentration could have occurred due to progressive binding of Cd to added organic amendments which are known for numerous metal-binding sites (Wang and Staunton 2006; Sebastia et al. 2008; Businelli et al. 2009). In this study, addition of compost had the most promising effect on Cd stabilization as compared to BGS. This suggests that Cd phytoavailability to plants may possibly be decreased with the application of compost. Concurrent to this Cd reduction, it has been reported that compost induced a gradual alkalinization of soil which would induce precipitation of Cd as hydroxides and carbonates making it less bioavailable to plant (Kumpiene et al. 2007). Our results show that Cd translocation was higher in maize (TF = 1.38 at 50 mg Cd kg^{-1} soil) than wheat (TF = 0.82 at 50 mg Cd kg^{-1} soil); this implied that Cd translocation from root to shoot depends upon plant species and the concentration of Cd applied in soil. Organic amendments were shown to decrease Cd translocation significantly only in wheat (Table 2; Fig. 2). According to classification reported by Zhang et al. (2002) and Fayiga and Ma (2006) plant would be hyperaccumulator if TF values >1 and excluder if TF values <1. According to this classification, wheat plant does not qualify for hyperaccumulator, while maize plant qualifies based on TF values at higher Cd level (50 mg Cd kg^{-1} soil). Cd uptake in plants significantly increased in soil amended with BGS, which may be due to increased biomass of the plant (Tables 2, 3). Moreover, Cd uptake depends upon transpiration rate of plant species (Mobin and Khan 2007), and it may also differ in plant species and genotypes (Metwally et al. 2005). Our results reported similar findings that Cd uptake was higher in maize than wheat (Tables 2, 3). This study did not report Cd effect on physiology and antioxidant activities; however, these may be included in future research to better understand the mechanism of Cd uptake in plants from soil amended with organic manures.

Correlation between parameters

Table 4 shows the relationship of Cd and organic amendments with different wheat and maize parameters. A strong correlation was found between exogenous application of Cd and its accumulation in the roots, shoots, and total plants of wheat and maize. However, addition of organic amendments inhibited Cd accumulation in aerial and underground parts of both cereals, but the results were nonsignificant. The negative sign showed that Cd significantly decreased dry biomass of plant, particularly root; however, addition of organic amendments significantly increased dry biomass of both cereals, particularly wheat. Organic amendments showed strong correlation with growth parameters of wheat ($r = 0.98$ for shoot dry weight and $r = 0.83$ for root dry weight) as compared to maize ($r = 0.30$ for shoot dry weight and $r = 0.40$ for root dry weight), indicating that their effects were species dependent (Table 4). This strong relationship may possibly be due to significant reduction in Cd at higher level of Cd contamination in wheat as compared to maize in organic amended soil (Tables 2, 3). This immobilization of Cd may be due to enhanced microbial activity in organic amended soil because it has been reported that high organic matter contents can favor native microbial community, which may stabilize Cd in soil (Farrell et al. 2010). In this study, microbial dynamics in organic amended soil were not studied in the presence of trace metals, but it would be beneficial to investigate such relations to better understand the metal–microbe–organic matter relationship.

Table 4 Correlation between different parameters of wheat and maize with Cd and organic amendments

Parameters	Wheat		Maize	
	Cadmium	Org. amendments	Cadmium	Org. amendments
Shoot dwt	-0.02^{ns}	0.98^{**}	-0.24^{ns}	0.30^{ns}
Root dwt	−0.37*	0.83^{**}	-0.53^{**}	0.40^{*}
Plant dwt	-0.09^{ns}	0.98^{**}	-0.36^{*}	0.36^{*}
Root Cd conc.	0.94**	-0.05^{ns}	0.93^{**}	−0.09
Shoot Cd conc.	0.89**	-0.12^{ns}	0.87^{**}	−0.06
Plant Cd conc.	0.92**	-0.08^{ns}	0.91^{**}	−0.07
Root Cd uptake	0.94**	0.05^{ns}	0.94^{**}	-0.05^{ns}
Shoot Cd uptake	0.90**	0.13^{ns}	0.87^{**}	-0.01^{ns}
Plant Cd uptake	0.91**	0.13^{ns}	0.91^{**}	-0.03^{ns}

Asterisk shows significant differences at $p \leq 0.01^{**}$ and $p \leq 0.05^{*}$
dwt dry weight, *ns* nonsignificant

Cadmium removal efficiency of organic amendments

The effectiveness of compost and BGS to remove or sorb Cd affected by the application of varying doses of Cd (20, 40 mg L^{-1}) at two pH levels (6, 8) and various time intervals (1, 6 and 13 h) was also investigated. Both organic amendments (compost and BGS) showed promising results in terms of their capacity to remove Cd from solution (Fig. 3). Both organic amendments showed 70–95 % Cd removal efficiency under varying conditions. Another important factor is pH, which can also influence Cd uptake. It was noted that two units increase in pH of the solution influenced Cd uptake in solution. It observed that pH 8 favored more Cd removal from solution as compared to pH 6. Cadmium removal by organic amendments was also influenced by time. In the current study, Cd removal by organic amendments depended on time; it was also found that maximum Cd removal occurred after 13 h of exposure. The compost removed 71 and 73 % Cd (initial concentration 20 mg L^{-1}) from solution after 1 h while 83

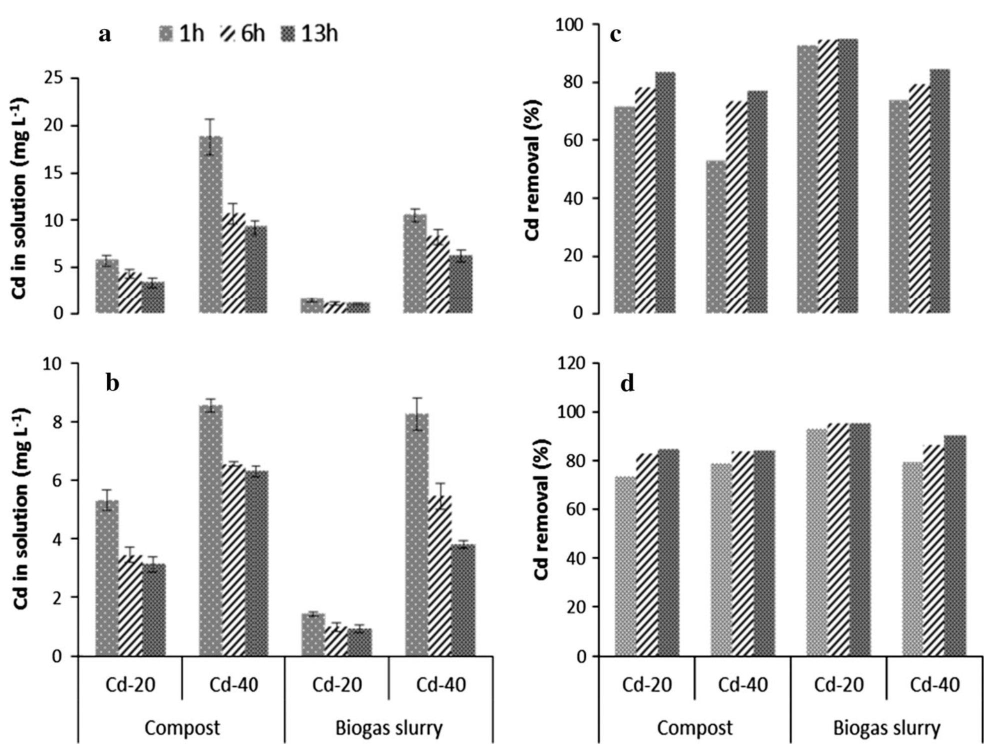

Fig. 3 Cadmium removal from solution at pH 6 (a, c) and pH 8 (b, d), effects of different cadmium loading rates (20, 40 mg L^{-1}), contact time (1, 6, 13 h), and organic amendments (compost and biogas slurry at fixed rate of 1 %). *Bars* show means ± standard errors

and 84 % after 13 h at pH 6 and 8, respectively. Biogas slurry removed 93 and 95 % Cd (initial concentration 20 mg L^{-1}) from solution after 1 and 13 h, respectively, at both pH (6 and 8). However, at increasing Cd concentration (40 mg L^{-1}) compost removed 77–84 %, whereas BGS 84–90 % at different pH values. Moreover, with the changing pH conditions, dramatic changes in Cd removal were observed. Overall, the BGS was more effective in Cd removal from artificially Cd-polluted water as compared to compost. The results of the study inferred that the organic amendments are capable of remediating artificially Cd-polluted water depending upon time, concentration of the pollutant, and pH of the media.

The acidity and alkalinity of solution have great impact on biosorption of metals. It happens because most of the metals are frequently available under acidic conditions. The capacity of different biomaterials to sorb metals varies at different pH levels, while maximum biosorption of metals was reported to occur at pH 6 (Sari and Tuzen 2009). In contrast to this, our results inferred that pH 8 was ideal for Cd removal from solution. Moreover, at higher pH, the biomaterial surfaces have most of negatively charged groups (hydroxyl, carboxyl, amino, and amide) that form complexes with the available cation (Cd^{2+}). Thus, biosorption might occur between adsorbate and adsorbent (Sari and Tuzen 2009; Rahaman et al. 2008). The results of this study showed that Cd might have bound to applied organic amendments that helped in 95 % Cd removal after 13 h from artificially Cd-polluted water. We cannot neglect the effect of time, pH, and metal concentration in the removal of Cd, because increased contact time may have enhanced Cd removal depending on the pH and actual metal concentration in the solution.

Conclusion

Results demonstrated that organic amendments may not only be used as soil conditioner, but these are also capable to stabilize Cd in soil. Organic amendments (compost and BGS) are effective soil amendments to increase plant biomass in normal and Cd-contaminated soil. Compost can stabilize Cd in the presence of plants; however, BGS can be used for removal of Cd from wastewater. Further, research should focus on the effect of organic amendments on physiology of wheat and maize in relation to its uptake in plants in metal-contaminated soil. These results provide good preliminary data and provide ground for further exploitation of organic amendments (compost and BGS) to remove other inorganic and organic pollutants from soil and water based on kinetic, laboratory, and field-oriented studies.

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