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Effect of limestone, lignite and biochar applied alone and combined on cadmium uptake in wheat and rice under rotation in an effluent irrigated field☆

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ABSTRACT

Cadmium (Cd) uptake and accumulation in crop plants, especially in wheat (*Triticum aestivum*) and rice (*Oryza sativa*) is one of the main concerns for food security worldwide. A field experiment was done to investigate the effects of limestone, lignite, and biochar on growth, physiology and Cd uptake in wheat and rice under rotation irrigated with raw effluents. Initially, each treatment was applied alone at 0.1% and combined at 0.05% each and wheat was grown in the field and then, after wheat harvesting, rice was grown in the same field without additional application of amendments. Results showed that the amendments applied increased the grain and straw yields as well as gas exchange attributes compared to the control. In both crops, highest Cd concentrations in straw and grains and total uptake were observed in control treatments while lowest Cd concentrations was observed in limestone + biochar treatment. No Cd concentrations were detected in wheat grains with the application of amendments except limestone (0.1%). The lowest Cd harvest index was observed in limestone + biochar and lignite + biochar treatments for wheat and rice respectively. Application of amendments decreased the AB-DTPA extractable Cd in the soil while increasing the Cd immobilization index after each crop harvest. The benefit-cost ratio and Cd contents in plants revealed that limestone + biochar treatment might be an effective amendment for increasing plant growth with lower Cd concentrations.

1. Introduction

Accumulation of non-essential elements in agricultural soils has mainly resulted due to anthropogenic activities (Nagajyoti et al., 2010; Adrees et al., 2015; Gill et al., 2015; Murtaza et al., 2015). Among non-essential elements, cadmium (Cd) is of primary concern due to its toxic effects on plants and humans (Gallego et al., 2012; Al Mamun et al., 2016; Rizwan et al., 2016a). The transfer of Cd from soil to crops and then crops to agri-food products is well documented (Ali et al., 2013a, 2013b; Khan et al., 2016; Qayyum et al., 2017; Yang et al., 2017; Zheng et al., 2017). Grain crops such as wheat (*Triticum aestivum*) and rice (*Oryza sativa*) fulfill the major food requirement of the whole world and are staple food for more than 50% of the world's population (FAO, 2014). However, as compared to other toxic metals, both wheat and rice could accumulate more Cd which may transfer to food chain (Song et al., 2015; Rizwan et al., 2016b). Cadmium is mainly taken up by plants from soil pore water, which is only a small fraction of the total Cd present in the soil (Al Mamun et al., 2016; Ahmad et al., 2017). The Cd uptake by plants can be reduced by decreasing the available Cd contents in the soil and this can be achieved by manipulating the soil cation binding sites (Simmler et al., 2013; Wu et al., 2016).

A large number of approaches have been employed to reduce the bioavailable Cd in the soil such as change in soil pH and increase in additional binding sites in the soil (Zhou et al., 2014; Younis et al.,

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2016). Studies showed that various organic (e.g. compost, manure, biochar etc.) and inorganic (e.g. gypsum, lime etc.) amendments can effectively reduce the bioavailability of Cd in the soil and its uptake by plants (Rehman et al., 2016; Wu et al., 2016; Qayyum et al., 2017; Yang et al., 2017). Monoammonium phosphate and gypsum decreased the bioavailable Cd in the soil and its uptake by wheat and rice (Rehman et al., 2015). Similarly, biochar application reduced the Cd uptake in plants (Chen et al., 2016; Younis et al., 2016) and nickel uptake in wheat (Rehman et al., 2016). In addition, lignite application in the soil reduced the Cd available fraction in the soil and its uptake to *Lolium perenne* (Simmler et al., 2013). Furthermore, limestone soil amendment has been shown to reduce Cd uptake in plants (Zhou et al., 2014; Wu et al., 2016).

To date, most of the previous work has been conducted on the individual impact of either organic or inorganic amendments on reducing metal uptake by plants including wheat and rice while ignoring the combined efficiency of different amendments (Cui et al., 2016; Rizwan et al., 2016a; Woldetsadik et al., 2016). In addition, very few field studies are conducted to evaluate the effects of organic and inorganic amendments on reducing metal uptake in plants, especially in soil with realistic metal concentrations (Rehman et al., 2015; Wu et al., 2016). Thus, this study evaluated the efficiency of limestone, lignite and biochar applied alone or combined in historically Cd-contaminated field on reducing Cd availability in soil and its uptake in wheat and rice under rotation irrigated with raw effluent.

2. Materials and methods

2.1. Site selection and soil characteristics

A field with historically Cd-contaminated soil was finalized for the present study in the periphery of Multan City (30° 14′58″ N, 71° 23′37″E and 215 m above the level of sea) of Punjab, Pakistan. Field have been irrigated with raw city effluents since last >30 years to grow different crops. The major portion of these effluents has been shared by different industries contributing a variety of heavy metals mainly Cd. Two soil depths (0–15 and 15–30 cm) were selected for soil sampling and collected samples were air-dried, sieved by passing through 2 mm and stored for further soil characterization. A method by Amacher (1996) was used to measure the pseudo-total trace element concentrations in the soil. Briefly, 10 mL of concentrated HNO_3 were added in 1.0 g soil sample and kept overnight, then the solution containing soil was heated to 200 °C and then cooled and added mixture of 1.0 mL HNO_3 and 4 mL $HClO_4$. After this, mixture was heated again to attain the temperature of 200 °C. On emergence of white fumes of $HClO_4$, assortment was cooled again and then added HCl in the ratio of 1:10 and again heated for 1 h at 70 °C. After cooling, a volume of 50 mL was made by using HCl solution of 1% and filtered the solution (Whatman, No. 42). AB-DTPA soil extraction was performed by taking 10 g of soil in 20 mL AB-DTPA solution of pH 7.6 and then bioavailable trace elements were determined in the soil extracts (Soltanpour, 1985). Soil particle size was determined by following the procedure of Bouyoucos (1962). Soil saturated paste was prepared for the measurement of soil pH (Jenway pH meter, Model 671P). Various soluble cations and anions in initial soil samples were measured by using standard procedures. Electrical conductivity (EC) value was measured by taking the saturated extracts of the soil and sodium adsorption ratio (SAR) was measured by using standard procedures (US Salinity Laboratory Staff, 1954; Page et al., 1982). Calcimeter method was used to measure calcium carbonate contents of the soil (Moodie et al., 1959) and Walkley-Black method was used to measure soil organic matter (OM) contents (Jackson, 1962). Physicochemical characteristics of the initial soil samples are present in Table 1.

2.2. Characteristics of raw city effluents

Both crops were irrigated with raw city effluents, as an alternate irrigation source for growing wheat and rice crops. Before irrigation of each crop, raw effluent was characterized for its physicochemical properties (Table 2).

2.3. Plant material and amendments

Wheat (*Triticum aestivum* L var. Lasani, 2008) and rice (*Oryza sativa* L. var. Super Basmati-515) crops were selected for the present study because these crops are mainly grown in the study area. First wheat was grown with the application of allocated amendments and then rice was cultivated in the same field without adding amendments.

Limestone, lignite, and biochar were selected for the experiment. Rice straw was used to prepare biochar at 450 °C for 2 h and was characterized as described previously (Qayyum et al., 2015). In brief, muffle furnace was used to measure both volatile and total ash contents by heating the samples at 450 °C and 550 °C respectively. Both pH and EC meters were used to measure the pH and EC of biochar (1:20, w/v, weight to distilled water ratio). Total hydrogen, carbon and nitrogen contents were measured by using elemental analyzer (Elementar, Germany). Biochar samples were digested in di-acid (HNO_3:$HClO_4$) mixture and then spectrophotometer was used to measure phosphorus (P) while potassium (K), and sodium (Na) concentrations were measured by using flame photometer. Ash content, volatile matter, EC, and pH values of biochar were 22.5%, 24%, 2.4 dS m^{-1}, and 10.0 respectively while carbon, nitrogen, P, K, and Na contents were 42.3%, 1.5%, 0.3%, 2.54%, and 1.1% respectively.

2.4. Experimental design

A field experiment was laid out having 7 treatments with four replicates having uniform size (9 m × 9 m) of each plot. The

Table 1
Initial physicochemical properties of the soil under field experiment.

Parameters	Unit	00–15 cm		15–30 cm	
Textural class		Loamy Sand		Loamy Sand	
Sand	%	80.12		82.23	
Silt	%	13.33		11.00	
Clay	%	06.55		06.77	
pH_s	–	7.23		7.54	
EC_e	dS m^{-1}	1.90		1.72	
Soluble ions					
CO_3^{2-}	$mmol_c$ L^{-1}	–		–	
HCO_3^-	$mmol_c$ L^{-1}	1.04		1.02	
Cl^-	$mmol_c$ L^{-1}	5.60		7.12	
[a]SO_4^{2-}	$mmol_c$ L^{-1}	12.36		9.06	
$Ca^{2+} + Mg^{2+}$	$mmol_c$ L^{-1}	7.98		6.14	
Na^+	$mmol_c$ L^{-1}	10.45		10.46	
K^+	$mmol_c$ L^{-1}	0.57		0.60	
SAR	$(mmol_c\ L^{-1})^{1/2}$	5.23		5.96	
CEC	$cmol_c$ kg^{-1}	3.93		3.85	
$CaCO_3$	%	1.79		1.75	
OM	%	0.91		0.73	
Metal concentrations		Total	[b]Available	Total	[b]Available
Cd	mg kg^{-1}	7.35	0.58	5.73	0.49
Pb	mg kg^{-1}	52.36	7.59	37.62	3.83
Zn	mg kg^{-1}	44.13	5.48	35.55	2.81
Cu	mg kg^{-1}	12.50	4.02	11.77	3.76
Mn	mg kg^{-1}	49.05	4.88	43.25	2.39
Ni	mg kg^{-1}	5.03	0.44	3.23	0.19
Fe	mg kg^{-1}	211.3	68.5	161.8	31.4

[a] By difference = TSS - (CO_3^{2-} + HCO_3^- + Cl^-).
[b] AB-DTPA extractable.