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Research article

Minimizing the risk to human health due to the ingestion of arsenic and toxic metals in vegetables by the application of biochar, farmyard manure and peat moss

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A B S T R A C T

Mining activity releases toxic metals (TMs) into the soil ecosystem and creates serious problems for the environment and human beings due to their adverse eco-toxilogical impacts. Currently, several remediation techniques can be used to immobilize TMs within contaminated soil. The present study focuses on the application of different organic amendments biochar (B), farmyard manure (FYM) and peat moss (PTM) – at different application rates (1%, 2% and 5%) in mining-impacted agricultural soil to immobilize TMs (Ni, Cr, As, Zn, Cd and Pb) and minimize their bioaccumulation in pea (*Pisum sativum*) and chili (*Capsicum annuum*) and the associated human health risk. Among the organic amendments, the treatments at the 5% application rate of B, FYM and PTM significantly ($p \leq 0.001$) reduced the bioavailability of TM concentrations in amended soil and increased pea and chili plants' and fruits' biomasses when compared with the control. Moreover, risk assessments showed that B, FYM and PTM decreased the daily intake and health risk associated with the consumption of vegetables effectively for individual TMs compared with the control. The highest application rate of 5% significantly ($p \leq 0.001$) reduced the average daily intake of TMs and their health risk, as compared to 1% and 2%, for both adults and children. The health risk index (HRI ˂ 1) values were lower (and within safety limits) for adults and children consuming vegetables grown on organic-amended soils. The results indicate that the B5% treatment of this mining-impacted agricultural soil was the most efficient at increasing plant and fruit biomasses and reducing the bioavailability, bioaccumulation and daily intake of TMs and their potential health risk through consumption of vegetables such as pea and chili, as compared to FYM, PTM and the control treatment.

1. Introduction

Contamination of the soil ecosystem with toxic metals (TMs) is currently considered to be a major global environmental issue. TMs such as arsenic (As), lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni) and zinc (Zn) are released into the environment by natural (weathering of parent rocks and volcanic eruptions) and manmade sources (mining, energy, electroplating, fuel production, intensive agriculture, use of fertilizers and pesticides, smelting, power transmission, the dumping of sludge, and wastewater irrigation) (Nawab et al., 2015, 2016a,b,c; Wei and Yang, 2010; Khan et al., 2017). Due to their persistent nature, TMs remain in soil for long periods and accumulate within food crops, which further negatively affects the growth of these plants and their productivity (Paz-Ferreiro et al., 2014; Chehregani et al., 2005). Also, TMs enter into food chains through the accumulation or uptake by food crops from natural soil, which directly (and often severely) affects human health (Adriano, 1992; Dong et al., 2011). Arsenic is a highly toxic

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carcinogenic element that creates many health-related problems, including cardiovascular and neurological disorders and infertility (IARC, 2004). Elevated concentrations of Pb, meanwhile, are associated with kidney damage, nerve damage, abdominal pain and cancers (stomach and lungs) (Jarup, 2003; Steenland and Boffetta, 2000). Like Pb, high levels of Cd can also cause numerous health problems, such as cancer, diabetes, high blood pressure and skeletal damage (Satarug and Moore, 2004). Long-term exposure of Cd can also lead to renal dysfunction due to its slow release from the body (Horiguchi et al., 2013). Mining-impacted soils are characterized as poor and unstable in their structure, and unsuitable for farming due to the presence of TMs (Nawab et al., 2016b,c; Mench et al., 2010). Such highly degraded soils contain high concentrations of TMs, which reduce the productivity and quality of crops because of their toxicity and lower quantities of organic matter and essential nutrients (Zhuang et al., 2009; Lange et al., 2012; Mendez and Maier, 2008).

Organic amendments have been used by many researchers worldwide to immobilize TMs within contaminated soils (Nawab et al., 2016b; Walker et al., 2004; Khan et al., 2015; Ok et al., 2015). Organic amendments such as biochar (B) reduce the bioaccumulation of TMs within food crops and their mobility within the soil (Waqas et al., 2014; Ahmad et al., 2017). In many studies, the use of B has been found to enhance crop growth in less fertile soil, improve aeration and the retention of water, and increase the soil pH and cation exchange capacity (Khan et al., 2014; Hussain et al., 2017; Qi et al., 2017). Another organic amendment, peat moss (PTM), can remediate TM concentrations in contaminated soils effectively, and transform TMs from exchangeable and soluble fractions to the organic matter, residual and carbonate-bounded fraction, thus leading to the immobilization of TMs such as Cu, Zn, Pb and Cd in contaminated soils and the reduction of TM content in vegetables (Walker et al., 2003; Angelova et al., 2010). Studies have also shown that farmyard manure (FYM) can significantly increase plant biomass by increasing the availability of essential nutrients; plus, most FYM contains considerable quantities of nitrogen (N), which enhances the buffering capacity of the FYM-amended soil (Clemente et al., 2007; Stewart et al., 2000). In summary, FYM and other organic amendments improve the availability of soil organic material, which enhances the binding capacity of TMs and reduces their mobility in the soil (Liu et al., 2007).

In this study, organic amendments (B, FYM and PTM) were used at different application rates (1%, 2% and 5%) in mining-impacted agricultural soil where TM concentrations were known to be high. The application of these amendments may immobilize TM in the amended soil through different mechanisms including pH decrease, formation of insoluble metal complexes upon release of salts, phosphates and carbonate minerals from organic matter (Walker et al., 2003) and microbial activity in the soil (Medina et al., 2006). Being a carbonaceous materials, B has strong sorption capacity due to its unique chemical composition, high porosity and large surface area which helps to reduce TM bioavailability and accessibility to microorganisms (Rhodes et al., 2008). B addition also improves soil water retention and its aeration which help to enhance crop growth and soil pH (Beesley et al., 2010; Khan et al., 2014; Ahmad et al., 2017; Qi et al., 2017). Like other organic amendments, FYM also improves the soil organic matter content and reduces the TM mobility by increasing the metal binding capacity of the amended soils (Liu et al., 2007).

In Pakistan, most mining sites are in hilly and rural areas where people are poor, illiterate and unaware of the adverse effects of mining. The open dumping of mining-related waste is common practice, which further impacts agricultural soils during rainfall, landslides and the erosion of hilly areas in Pakistan. Thus, we hypothesized that the addition of organic amendments may assist in reclaiming these mining-impacted agricultural soils and contribute towards sustainability in the agricultural sector. In view of the potential effects of organic amendments on mining-impacted soils and their minimization of associated human health risks, the present study aimed to investigate the influence of B, FYM and PTM (at application rates of 1%, 2% and 5%) on (1) mining-impacted agricultural soil, (2) pea and chili plant and fruit biomass, (3) the bioaccumulation of TMs in chili and pea plants and fruits, and (4) the daily metal intake (DMI) and health risk index (HRI) associated with the consumption of TMs in pea and chili plants. The results of this research are not limited to the health risk associated with the consumption of vegetables grown in mining-impacted agricultural soils; the role played by different organic amendments in mining-impacted soil properties and how they immobilize TMs to minimize their bioavailability to vegetables grown in contaminated soil were also investigated. Furthermore, how organic amendments reduce the human health risk in the context of vegetables grown in mining-impacted soil was also studied. On the basis of this research, and against the background of sustainable farming practices, suggestions and recommendations can be made with respect to the organic amendments studied to reduce TM accumulation in food plants grown in mining-impacted areas.

2. Materials and methods

2.1. Plants, organic material and chemicals

Certified seeds of *Pisum sativum and Capsicum annuum* were obtained from the Agriculture Research Centre (ARC), Takhtaband Swat, Pakistan. Different types of organic amendments, i.e., B, FYM and PTM, were used in experiments at different application rates (1%, 2% and 5%). FYM was easily available and locally produced; PTM was purchased from the ARC, and B was provided by the Institute of Urban Environment, Chinese Academy of Sciences, Xiamen, China. The chemicals used in the experiments were of analytical grade, purchased from Merck (Merck KGaA, 64271 Darmstadt, Germany).

2.2. Soil collection and preparation

Using a stainless-steel auger, soil samples were randomly collected from different mining-contaminated agricultural sites in Khyber Pakhtunkhwa, Pakistan. The collection of mining-impacted agricultural soil is not a restricted activity in Pakistan, and so no permission was required from any government or regulatory authority. Mining-impacted agricultural soil samples were selected because of their known high TM concentrations. The soil samples were air-dried, sieved (2 mm) and then homogenized. The soils were stored in paper bags at room temperature, in the dark, for chemical analysis.

2.3. Experimental design

Different pot experiments were carried out in a greenhouse environment for four months at the ARC. The selected organic amendments (B, FYM and PTM) were mixed with mining-impacted soil at different application rates of (1%, 2% and 5%) on a dry-weight basis. The 10-g, 20-g and 50-g amendments were mixed in the soil for each pot at application rates of 1%, 2% and 5%, respectively, and each plastic pot was filled with 3 kg of amended soil. Soil without amendment (the control treatment) was also included in the pot experiments. A total of 63 pots, including the amended and control soils, was prepared in triplicate. The pots were kept in the greenhouse environment under control conditions and irrigated with deionized water for two weeks (Khan et al., 2014). The subsamples