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Influence of compost on the mobility of arsenic in soil and its uptake by bean plants (*Phaseolus vulgaris* L.) irrigated with arsenite-contaminated water

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A B S T R A C T

The influence of compost on the growth of bean plants irrigated with As-contaminated waters and its influence on the mobility of As in the soils and the uptake of As (as $NaAs^{III}O_2$) by plant components was studied at various compost application rates ($3\cdot10^4$ and $6\cdot10^4$ kg ha^{-1}) and at three As concentrations (1, 2 and 3 mg kg^{-1}). The biomass and As and P concentrations of the roots, shoots and beans were determined at harvest time, as well as the chlorophyll content of the leaves and nonspecific and specifically bound As in the soil.

The bean plants exposed to As showed typical phytotoxicity symptoms; no plants however died over the study. The biomass of the bean plants increased with the increasing amounts of compost added to the soil, attributed to the phytonutritive capacity of compost. Biomass decreased with increasing As concentrations, however, the reduction in the biomass was significantly lower with the addition of compost, indicating that the As phytotoxicity was alleviated by the compost. For the same As concentration, the As content of the roots, shoots and beans decreased with increasing compost added compared to the Control. This is due to partial immobilization of the As by the organic functional groups on the compost, either directly or through cation bridging. Most of the As adsorbed by the bean plants accumulated in the roots, while a scant allocation of As occurred in the beans. Hence, the addition of compost to soils could be used as an effective means to limit As accumulation in crops from As-contaminated waters.

1. Introduction

Arsenic (As) is commonly encountered in ground water in different parts of the world due to natural processes as well as from anthropogenic activities (Mohan and Pittman, 2007; Smedley and Kinniburgh, 2002). Arsenic can occur in the environment in several oxidation states (−3, 0, +3 and +5) but in natural waters is mostly found in inorganic form as oxyanions of trivalent arsenite (As^{III}) or pentavalent arsenate (As^{V}). In neutral oxygenated waters, As^{V} is the thermodynamically favored form, whereas As^{III} is stable under reducing conditions. Arsenite is 25–60 times more toxic and mobile than As^{V}; arsenite mainly arises from its state as H_3AsO_3 at pH $<$ 9.0, whereas As^{V} is present as the charged species ($H_2AsO_4^-$ and $HAsO_4^{2-}$) which predominate in a wide pH range (Frankenberger, 2002; Mahimairaja et al., 2005; Smedley and Kinniburgh, 2002).

Arsenic-contaminated ground water, in addition to being a source for drinking water is also widely used for the irrigation of crops. People drinking As-contaminated waters and/or eating As-contaminated foods over prolonged periods often show typical arsenical toxicity symptoms such as lesions (spotted keratosis, melanosis, dolsal keratosis, hyper pigmentation, hyper keratosis and gangrene) (USDHHS, 2000). To effectively remediate As-contaminated soils, thereby reducing the uptake of As by plants, and consequently lower the health risk to humans consuming these As-contaminated crops requires information regarding the soil-to-plant transfer of As (Meharg and Hartley-Whitaker, 2002).

Arsenic is also found to be toxic toward plants, severely affecting crop production. Elevated As levels in irrigation water were found to inhibit seed germination and seedling establishment of rice

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(Abedin and Meharg, 2002). The presence of As in plants inhibits their principal metabolic processes, such as photosynthesis, thereby inhibiting growth and often leading to death (Marques and Anderson, 1986; Tu and Ma, 2002). Arsenic is accumulated mainly in the root system and causes physiological changes and damages to the plant tissues (Marin et al., 1992). Reported ranking of relative sensitivity to As to plants are (in order of increasing sensitivity): asparagus, tomato, potato, carrot, tobacco, grape, raspberry < strawberry, sweet corn, beet, squash < bean, onion, pea, cucumber and alfalfa (Wauchope, 1983). The ability of specific plants to survive in As-contaminated systems has been related to a variety of mechanisms of tolerance or detoxification, which includes chelation, compartmentalization, biotransformation and cellular repair (Gonzaga et al., 2006). Arsenite (As^{III}) compounds are generally more phytotoxic than As^{V} compounds (Abedin et al., 2002; Schat et al., 2002).

Arsenic uptake by plants is mainly influenced by its phytoavailability in soils. Several factors seem to play an important role on As mobility in soils, such as: a) the pH; b) the redox potential; c) the organic matter content; d) the texture and clay mineralogy; e) the content of iron, aluminum and manganese oxides; f) the presence of inorganic (particularly phosphate) and organic (humic and fulvic acids and roots exudates) ligands, and; g) microbial activity (Violante et al., 2005).

Application of organic amendments (e.g., compost) to soils increases their fertility by improving their physical and chemical properties, supplying nutrients such as nitrogen and phosphorus and augmenting microbial activity (Peterson et al., 1999; Roe et al., 1993). Furthermore, the addition of organic matter to soils seems to play an important role on the mobility of inorganic contaminants such as As in the soil-plant-microorganism system. Gadepalle et al. (2008) and Liu et al. (2009) reported that the addition of compost to soils resulted in the complexation/adsorption of As with the humic substances, decreasing the mobility and phytoavailability of As in the soils, thus permitting the re-establishment of vegetation on As-contaminated sites. Cao and Ma (2004) observed that compost addition to soils with elevated As levels reduced the uptake of As in carrots and lettuce due the sorption of As by the organic matter. In materials (e.g., mine spoil, Fe-oxides) with low or no organic matter, the addition of compost increased the dissolved organic matter (DOM) in the systems, increasing the amount of leachable As due to competition for the sorption sites on the inorganic materials (Hartley et al., 2009; Mench et al., 2003; Xu et al., 1991). Cao et al. (2003) observed that compost additions to an As-contaminated soil increased the uptake of As by the hyperaccumulator *Pteris vittata* L. by increasing the soil water-soluble As, while the compost reduced As uptake from a non-contaminated soil spiked with As due to As adsorption to the compost. Hence, insufficient information is available on the response of food plants such as beans to compost application when irrigated with As-contaminated water. Therefore, in the present work we studied the influence of the compost added to soils on the: i) growth of bean plants irrigated with As^{III}-contaminated waters; ii) As uptake by bean plant components (roots, shoots and beans); and iii) mobility and phytoavailability of As in the composts enriched soil. We have also examined the phosphorus (P) status of the bean plants, because it seems to be intimately linked to As sensitively (Cao et al., 2003).

The bean plant was selected for this study as it is a low-cost protein source and a staple food in many Countries around the world and because it is grown in several As-contaminated areas and suffers from As toxicity. Arsenite was chosen as the As source because it is more toxic and mobile in soil environments than As^{V}.

2. Materials and methods

2.1. Compost characterization

The compost used in this experiment was from GeSeNu srl (Perugia, Italy). The starting material consisted of urban organic wastes (50%), plant trimmings (40%), and tobacco and aromatic plant residues (10%), which were composted and stabilized for 120 days.

The compost was characterized by ^{13}C Cross Polarization Magic Angle Spinning (CPMAS), Nuclear Magnetic Resonance (NMR) spectroscopy (Pane et al., 2011). The ^{13}C NMR spectrum was obtained in the solid state (CPMAS), using a Bruker AVANCE™ 300, equipped with a 4 mm Wide Bore MAS probe, operating at a ^{13}C resonating frequency of 75.475 MHz. The compost was also characterized by NCS Elemental Analyzer (NA 1500 Series 2) and, after digestion with concentrated HNO_3, by inductively coupled plasma atomic emission spectroscopy (ICP-AES, Varian, Liberty 150).

2.2. Soil preparation and characterization

The soil used in this experiment was collected from the subsurface layer (10–30 cm) of a grassland in Portici, Naples, Italy. The soil was classified as a Calcari-Vitric Cambisol according to the soil classification of FAO World Reference Base for Soil Resources. After air-drying, the soil for bean cultivation and chemical analysis were passed through 5 and 2 mm sieves, respectively.

Soil fractions (sand, silt and clay) were separated using the pipette and sieving method following pretreatment with H_2O_2 to oxidize organic matter, and dispersion was aided by sodium hexametaphosphate (Indorante et al., 1990). Soil pH was measured by potentiometry in distilled water (1:2.5 soil/water ratio). The soil organic C content was determined by wet digestion using the modified Walkley-Black procedure (Nelson and Sommers, 1982). For determination of CEC, the soil was extracted with 1 M NH_4OAc at pH 7.0. The total soil N was determined using a NCS Elemental Analyzer (NA 1500 Series 2). Available P concentration was determined by the colorimetric method using 0.5 M $NaHCO_3$ as the extractant (Olsen et al., 1954). The initial As concentration in the soil was determined by extracting the soil with concentrated HNO_3 and HF at 5:1 ratio. The concentration of the total As was determined as discussed below in Section 2.7.

2.3. Experimental design

Borlotto Nano bean plants (*Phaseolus vulgaris* L.) were cultivated in an unheated greenhouse. Bean plants were seeded into a polystyrene alveolar seedbed consisting of 90 holes (25 mm diameter, 40 mm depth), filled with soil mixed with commercial potting soil (having a low organic carbon content, classifiable as a Cambisol) (70% (*v*/*v*) soil in the final mixture). Two weeks after germination, seedlings were transplanted into pots containing 8 kg of the soil (one seedling per pot). At transplanting, 0, 60 and 120 g of a commercial compost (GeSeNu srl, Perugia, Italy) (equivalent to an application in open field of 0 (C 0), $3 \cdot 10^4$ (C 3), $6 \cdot 10^4$ (C 6) kilograms of compost per ha) was added to the pots, and mixed thoroughly with the soil. Bean plants were irrigated with water for the first 5 days after transplanting, and thereafter irrigated with water containing sodium arsenite ($NaAs^{III}O_2$) at four different concentrations: 0 (As 0), 1(As 1), 2 (As 2) and 3 (As 3) mg As L^{-1}, until the beans were ripe. The range of As concentrations was chosen to encompass the concentrations occurring in ground waters of the As affected areas of the world (Smedley and Kinniburgh, 2002). Treatments were replicated five times and the experimental design was completely randomized and rearranged every 3 days. The