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Original Research Article

The effect of pumice on reduction of cadmium uptake by spinach irrigated with wastewater

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A B S T R A C T

Increasing demand for irrigation water and scarcity of fresh water has caused significant increase in the reuse of urban and industrial wastewater throughout the world. Heavy metals in wastewaters are the main factors in the contamination of water and soil. The objective of this study was to evaluate the effect of application of pumice as soil amendment on the uptake of Cd by spinach (*Spinach oleracea* L.) under irrigation with wastewater (containing 10 mg/L Cd). The experiment was conducted as a completely randomized design in a greenhouse with 3 replications in the research station of Isfahan University of Technology. Different levels of pumice (0, 4% and 8% w/w soil) were added to the soil. Results indicated that the addition of 4% and 8% of pumice in soil, decreased 30.19% and 46.17% Cd uptake in plants, respectively. The transfer factor into roots and shoots of spinach were significantly reduced ($p < 0.05$) in pumice treatments compared to the control. The percentage of DTPA extractable Cd in soils amended with pumice significantly decreased ($p < 0.05$) and this resulted in lower Cd accumulation in plants. Irrigation with wastewater containing Cd decreased the yield in comparison to irrigation with freshwater. So, it seems that pumice, as a cost-effective adsorbent, poses potential for immobilization and reduction of phytoavailability of Cd in polluted soils.

1. Introduction

The water requirement is ceaselessly increasing in arid and semi-arid regions. Hence, water with lower quality or unconventional water resources are recommended for usage in irrigation (Kiziloglu et al., 2008). Urban or industrial wastewater is used for the crops irrigation, mostly in periurban ecosystems because of its good accessibility, potentially acceptable solution to disposal problems and shortage of fresh water. Mostly, wastewater contains considerable amounts of toxic heavy metals, that irrigation with wastewater is identified as a major cause of the increase of heavy metals in soils, which produce environmental problems (Arora et al., 2008). Natural soil contamination with heavy metals is a serious problem for plant quality, human health and quality of environment (Chen et al., 1996; Kabata-Pendias and Pendias, 2001). Cadmium has long been recognized as toxic to humans. In the 1960s, Cd caused the itai–itai disease in Japan (Kobayashi, 1978). Public concern about the potential toxicity of cadmium has been increasing in the past decade (Satoa et al., 2010). Nonbiodegradable nature of heavy metals, long biological half-lives and its potential to accumulate in different parts of human body makes them very harmful. Also because of solubility of most heavy metals they are very toxic. Whereas there is no good mechanism for removal of heavy metals from the body, they have pernicious effects on animals and human, even

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at low concentrations. The excessive usage of heavy metals in industrial practice has caused that heavy metals are present everywhere (Chen et al., 2005; Singh et al., 2004). The risk associated with soils contaminated with heavy metals, depends on soil characteristics (i.e. pH, clay content, sesquioxides and organic matter), climate factors (i.e. precipitation, temperature and wind speed), and environmental behaviors of the toxic contaminants (Filius et al., 1998; Zhou, 2003).

Heavy metals immobilization with the use of soil amendments is a promising technology to achieve a cost-effective remediation and environmentally secure solution (Gupta et al., 2007). Especially chemical immobilization, as a promising technique, can decrease the movability of toxic contaminants in the ecosystems. To reduce the solubility and bioavailability of toxic metals, by sorption and/or precipitation, chemical and mineralogical materials are added to the polluted soils (Lin and Zhou, 2009). For removal of metals from wastewater treatment at low cost, use of pumice as an adsorbent is well established. Pumice is an igneous volcanic rock that can be processed easily. It poses a light porous structure and a large surface area. Because of the large proportion of free silica sites at the grain surface, it has a negatively charged surface. Pumice has a skeleton structure with open channels that allow molecules and ions to reside and move throughout the framework (Akbal et al., 2000, reported by Yavuz et al., 2008). Pumice stone was used for removing of Cs, Sr, Th ions and also Cu, Cr and Fe from aqueous solutions (Bassari et al., 1996; Lale et al., 2005; Yavuz et al., 2008). The effectiveness of pumice for immobilization of heavy metals in the contaminated soils, in particular wastewater irrigated soils, has not been reported so far.

One of the main goals of ecohydrology as sustainability science is to increase the ecosystem potential, among other's through improvement of its resilience which in the same time enhances the carrying capacity of the ecosystem to sustain human population (Zalewski, 2015). The concept of enhanced ecosystem potential integrated with ecohydrological strategy to achieve sustainability is termed WBSR (w-water, b-biodiversity, s-ecosystem services, and r-resilience) and contains the four elements that should be taken into consideration while trying to improve the ecosystems potential.

Unfortunately many farmers in Asian, African and South American countries are illegally applying raw wastewater as irrigation water. Sometimes this wastewater is polluted with industrial wastewater and elevated amount of heavy metals (such as Cd, Cu,...) may be found in raw wastewater. Hence, we have tried to simulate this issue in the present research. So the objectives of the this study were (1) to evaluate the effects of pumice on the availability of cadmium in a soil treated with wastewater (extracted Cd with DTPA); (2) to evaluate the effects of pumice on the uptake of Cd by spinach (in the roots and shoots); and (3) to examine the toxic effect of Cd on spinach yield in greenhouse conditions. In this research we aimed to improve ecosystem resilience through reducing soil toxicity and improving water balance through irrigation with unconventional water.

2. Material and methods

This study was carried out in a greenhouse at the Isfahan University of Technology, Iran. Soil samples were air-dried and sieved through a 2 mm sieve before the physicochemical analysis. According to the hydrometer method (Gee and Bauder, 1986), the soil texture was sandy clay loam. The pH was measured using pH meter in a soil with distilled water ratio of 1:2.5. Determination of organic carbon was done by using the Walky and Black wet combustion method (Nelson and Sommer, 1982). Cation exchange capacity (CEC) was measured utilizing ammonium acetate (pH = 7.0) (Rhoades, 1982; Thomas, 1982). The physical and chemical properties of soil are shown in Table 1. Also, some soil elements characteristics extracted by DTPA (diethylene triamine pentaacetic acid) are shown in Table 2. Pumice was taken from Pumice Iran Company in Isfahan. Some properties of pumice were determined and given in Tables 3 and 4.

Analysis of water and wastewater were done for determination of EC, pH and concentration of some elements in waters. Amount of SAR (sodium adsorption ratio) were computed as follows:

$$SAR = [Na^+]/(([Ca^{2+}] + [Mg^{2+}])/2)^{1/2} \qquad (i)$$

where $[Na^+]$, $[Ca^{2+}]$, and $[Mg^{2+}]$ are the concentrations in meq/L of sodium, calcium, and magnesium ions in the soil solution.

2.1. Properties of irrigation waters

Some properties of water and wastewater as irrigation waters were determined and shown in Tables 5 and 6. All metals in wastewater had lower concentration than permissible concentration by FAO (Table 7), except Cd and Se, so the Cd concentration in wastewater was increased to 10 mg/L.

FAO permissible limits for pH of irrigations water is 6.5–8 (Ayers and Westcot, 1985). Water and wastewater used in this study did not exceed the limit for pH. The electrical conductivity (EC) of wastewater was 1.66 dS/m that was higher than water (0.48 dS/m). Compared to the FAO standard (Table 7), wastewater was classified as water with intermediate salinity. So application of this water

Table 1
The physical and chemical properties of soil.

Particle size fraction (%)			pH	EC (dS/m)	CEC[a] (cmol+/kg soil)	OC[b] (%)	Cd^{2+} (mg/kg)
Sand	Silt	Clay					
53.6	24.0	22.4	7.8	1.7	33	0.6	nd[c]

[a] CEC: cation exchange capacity.
[b] OC: organic carbon.
[c] nd: not detectable.

Table 2
Some soil elements concentration extracted with DTPA.

Element	Cu	Fe	Mn	Zn	Cd
(mg/kg)	0.51	5.51	15.81	0.57	nd