Science of the Total Environment 576 (2017) 292–302

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Phytostabilisation potential of giant reed for metals contaminated soil modified with complex organic fertiliser and fly ash: A field experiment

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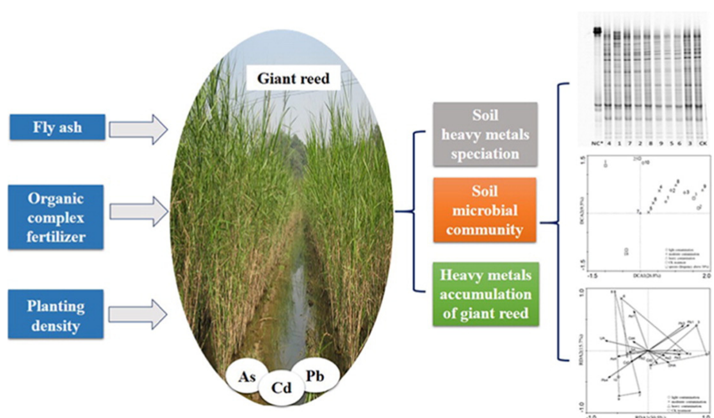
HIGHLIGHTS

- Both OCF and O&F increased biomass of giant reed and decreased available content of As, Cd and Pb in soil.
- Dominant bacteria communities were enriched with increased planting density of giant reed in contaminated soil.
- DHA was a reliable indicator of soil eco-environmental quality in phytoremediation with giant reed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 25 July 2016
Received in revised form 9 October 2016
Accepted 9 October 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Eco-remediation
Metals
Metalloids
Arundo donax
Soil microbial diversity
Soil enzyme activity

ABSTRACT

An orthogonal field experiment of giant reed (*Arundo donax*) modified with organic complex fertiliser (OCF), and OCF and fly ash (O&F), at different planting densities was carried out in metal-contaminated soil. The available percentage of arsenic (As) and lead (Pb) in soil decreased from 8.45% to 2.19% and from 29.6% to 13.5% by OCF, respectively, and that of cadmium (Cd) was reduced from 25.3% to 6.49% by O&F. The total biomass of giant reed was 631 g per individual following application of O&F in contaminated soil. The accumulation of As, Cd, and Pb in giant reed was 1.57, 4.06, and 11.25 mg per individual. Urease and sucrase activity were 87.4 NH_4-N μg/g d and 63.1 glucose mg/g d in response to the treatments modified using OCF, while the highest dehydrogenase activity was 101 TPF (triphenyltetrazolium formazan) μg/g d in the treatments modified using O&F. Dominant bacteria (frequency > 50%) were enriched with increasing planting density of giant reed. These results indicate that the phytostabilisation of metal-contaminated soil by giant reed could be improved by the application of O&F or OCF.

1. Introduction

Metal(loid) contamination of soil is a serious concern for ecology and human health (Marchiol et al., 2007). Phytoremediation, including phytoextraction, phytovolatisation, and phytostabilisation, is a promising alternative approach for the remediation of metal(loid)-

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http://dx.doi.org/10.1016/j.scitotenv.2016.10.065

contaminated soil (Farrag et al., 2011). Phytostabilisation is a method by use of vegetation to immobilise metals in the rhizosphere and reduce aboveground wind and water erosion (Gil-Loaiza et al., 2016). Two factors are considered when determining the suitability of plants with a large biomass for phytostabilisation: root accumulation and rhizosphere immobilisation (Sun et al., 2016).

To limit the effects of acidic conditions and high metal(loid) content on plant germination and growth, phytostabilisation is often assisted by the use of a chelating agent (Singh et al., 2016), organic fertiliser (Elouear et al., 2016), and inoculation with arbuscular mycorrhizal fungi (Kohler et al., 2015). Soil amendments and various planting practices are also used to remove pollutants from soil or decrease their toxicity in the phytoremediation process (Salt et al., 1995). Soil amendments, such as the application of fly ash, produced burning of coal, can decrease the concentrations of heavy metal in shoot tissues by increasing soil pH and physical adsorption (Su and Wong, 2004), and improve the physical, chemical, and biological qualities of soils by silt-sized particles, low bulk density (BD), high water holding capacity (WHC), favourable pH, and the presence of plant nutrients (Pandey and Kumar, 2013). Fly ash tends to be enriched in some potential contaminants, including salts and trace elements (Bednar et al., 2010), however, the toxic elements of concern are usually well-within the limits prescribed for soil application of waste materials (Sushil and Batra, 2006). Organic fertilisers, such as farmyard manure or organic manure, can promote biomass production and considerably reduce the solubility and mobility of metal(loid)s through the formation of complex compounds and precipitation reactions (Bolan et al., 2003), thereby reducing the bioaccumulation of metal(loid)s (Nawab et al., 2015; Song et al., 2012). Considering that the application of fly ash to soil must be very specific depending on the properties of both the fly ash and the soil, the performance of fly ash blended with organic materials is better than that with fly ash alone. Co-application of fly ash with organic fertiliser has been shown to increase plant biomass (Phunshon et al., 2002), decrease the bioavailability of toxic metals, enhance nutrient availability, and stimulate microbial activity (Belyaeva and Haynes, 2012).

Planting strategies, such as replanting (Luo et al., 2015), double cropping, sequential harvesting (Ji et al., 2011), crop rotation (Fumagalli et al., 2014), repeated harvest (Li et al., 2013) and planting density, can also affect the phytostabilisation of metal(loid)s in soil (Nsanganwimana et al., 2015). In previous phytostabilisation studies, phytoremediating soils with amelioration methods significantly increased bacterial biomass (Titah et al., 2013), soil live bacteria concentration (Fumagalli et al., 2014), and soil microbial diversity (Ram and Masto, 2014; Zhou et al., 2015).

The selecting of an appropriate plant species is important for successful phytostabilisation (Rizzi et al., 2004). Unlike phytoextraction, plants selected for phytostabilisation must be able to develop extended and abundant root systems, and translocate metals from roots to shoots at as low concentrations as possible (Mendez and Maier, 2008). Bioenergy crops grown on contaminated land offer real opportunities for the stabilisation of metal(loid)-contaminated soils, and the biomass produced can be used for fuel production (Chami et al., 2015). Giant reed (*Arundo donax*) and silvergrass (*Miscanthus sinensis*) genotypes are bioenergy crops well suited for the phytostabilisation of metal(loid)-contamination of dry land (Barbosa et al., 2015).

Giant reed is a perennial rhizomatous grass with a wide distribution in South China (Lewandowski et al., 2003), which exhibits limited translocation of metal from roots to shoots (Guo and Miao, 2010). Compared with silvergrass, giant reed has a higher biomass yield and can adapt to a broader range of environments (Ge et al., 2016). Giant reed has also exhibited rapid growth and generated high yields in soils polluted with multiple metals (Eid et al., 2016). When planted in dry land, the biomass of giant reed seedlings in red mud and a mud-soil mixture (control) increased by 40.4% and 47.2% over time, respectively, and decreasing the available Cd, Pb, Co, Ni, and Fe in soil (Alshaal et al., 2013). In pot experiments, the application of soil amendments, including acetic acid, citric acid, and ethylenediaminetetraacetic acid, improved the growth and phytoremediation potential of giant reed (Yang et al., 2012). Cultivation of giant reed at a density of 1 × 1 m per 140-m^2 (10 × 14-m plot) and harvesting giant reed at the appropriate time has led to favourable effects on soil quality, biomass quality and cropping system sustainability (Fagnano et al., 2015).

However, phytoremediation of giant reed in paddy soil has not been well studied. Considering that giant reed requires greater energy inputs than other phytoremediation species (Ge et al., 2016), interactions among different factors in giant reed phytostabilisation of metal(loid)s-contaminated soils should be studied in field experiments. The aims of the present study were as follows: 1) to evaluate giant reed growth and metal(loid) accumulation in metal(loid)-contaminated paddy field soils modified using different ameliorating agents in a gridded field experiment; 2) to determine the effectiveness of giant reed by analysing available metal(loid) contents; and 3) to investigate soil health, including enzyme activity and microbial diversity, following giant reed phytoremediation.

2. Materials and methods

2.1. Study area

The field experiment was performed in abandoned paddy soil, located at 27°52′23.13″N, 113°4′11.23″E near a Pb-Zn smelting plant in Hunan Province, China. The average annual temperature ranges from 15.5 to 25 °C, the annual accumulated temperature (>10 °C) ranges from 5000 to 9500 °C. The experiment was carried out from April to September. The average annual precipitation is dominated by the precipitation in summer, mainly acidic, in the range of 1250 to 1500 mm. The paddy soil was mainly contaminated by arsenic (As), cadmium (Cd), and lead (Pb) (Guo et al., 2014).

2.2. Experiment design

The field experiment arrangement was based on an orthogonal design of L_9 (3^3); each plot measured 18 m^2 (6 × 3 m) and was ploughed carefully to ensure the uniform content of metals in soil (Fig. 1). Light,

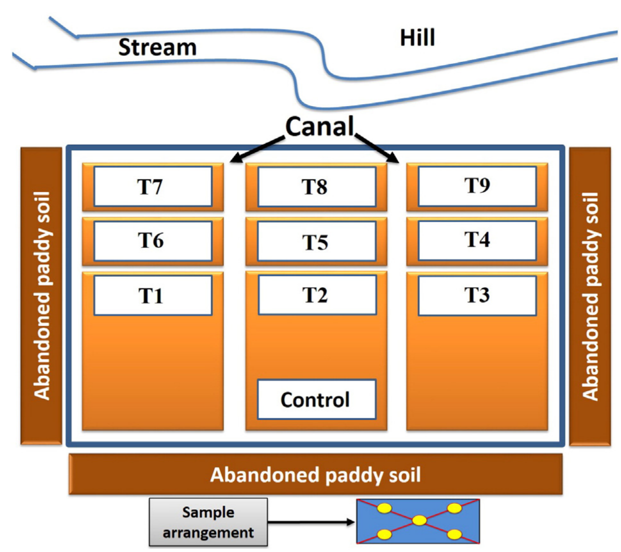

Fig. 1. Field orthogonal experiment design and sample arrangement. This orthogonal experiment was carried out in historical abandoned paddy soil cultivating rice for a long time. The arrangement of T1 to T9 treatments was shown in Table 1. The control was just the metal(loid)s contaminated soil further from the stream without any amendments. 2 kg mixed fresh surface soil (0–20 cm) samples and giant reed were collected from 5 holes in each plot as the sample arrangement.