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Assisted phytoremediation of heavy metal contaminated soil from a mined site with *Typha latifolia* and *Chrysopogon zizanioides*

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ABSTRACT

Chemically assisted phytoremediation is fast gaining attention as a biotechnology to accelerate heavy metal removal from contaminated substrates, but how different chemical amendments affect the process remains an important research question. Here, bioaccumulation factor (BAF), translocation factor (TF), removal efficiency (RE) and uptake of Hg, As, Pb, Cu and Zn by cattail (*Typha latifolia*) and vetiver (*Chrysopogon zizanioides*) were quantified in a potted experiment to determine the effects of amendments on the phytoremediation success. Baseline concentrations of heavy metals within the studied mined site were determined. The experiment involved three soil treatments (each comprising 16 samples amended with 0.05 mol/L ethylene di-aminetetraacetic acid (EDTA), 3 g of aluminum sulfate [$Al_2(SO_4)_3$], and unamended control) transplanted with equal numbers of vetiver and cattail. Growth performance (height) of plant species was monitored every two weeks. Sixteen weeks after transplanting, heavy metal levels in plant and soil samples were quantified following standard protocols, and the biomass and root length measured for each plant species. Results indicated strong negative impact of mining activities on heavy metal levels of soil in the study area. Soil amendment considerably enhanced the BAF, TF, RE and uptake but the effect varied with plant species and heavy metal in question. The amendment also stimulated strong positive correlation between RE and BAF, TF and metal uptake, and generally did not show any negative effects on plant growth performance. In general, soil amendment aided the accumulation and translocation of heavy metals in the plant species studied, and could be explored for cleaning up contaminated sites.

1. Introduction

The mining industry plays an important role in the socio-economic and technological development of nations around the world (Amponsah-Tawiah and Dartey-Baah, 2011; Mobtaker and Osanloo, 2014). The sector contributes directly to export revenue, gross domestic product (GDP), corporate tax earnings and government revenue, and indirectly through the implementation of corporate social responsibility programmes, technology transfer and provision of employment to people (Aryee, 2012; Dorin et al., 2014). Nevertheless, the mining industry by its very nature is considered a “foot print industry”, and hence leaves significant environmental, social and economic footprints wherever it finds itself (World Bank Group Mining Department, 2002). Mining activities, for example, disturb the natural biogeochemical cycles of metals and subsequently contaminate soil, as well as ground and surface water resources with the mobilized heavy metals (Cobbina et al., 2013, Quarshie et al., 2011).

While most organic contaminants are biodegradable and pose no permanent risk to ecosystems, inorganic contaminants such as heavy metals are non-biodegradable and tend to persist in the environment (Ghosh and Singh, 2005). It has also been established that, though some heavy metals are essential to the function of living things, all metals can present serious health problems to humans and animals above certain threshold limits by causing oxidative stress to living cells (Ghosh and Singh, 2005; Malayeri et al., 2008; Singh et al., 2011). Environmental and health effects associated with heavy metal contamination become even more worrying given their tendency to accumulate and magnify along trophic levels.

Traditionally, these negative effects of heavy metal contamination in the environment have been mitigated with methods such as membrane filtration, electrochemistry, oxidation-reduction processes and soil washing (Hanif and Bhatti, 2015). However, some of these traditional processes sometimes prove too costly and environmentally unfriendly. Consequently, cost-effective and greener biotechnologies such as phytoremediation, which utilizes the natural abilities of plants to immobilize, degrade, reduce or remove heavy metal contaminants from the environment, have gained considerable research attention in recent years (Baker et al., 1994; Nowack et al., 2006). Studies shows that this

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technology can successfully and effectively remediate contaminated substrates such as industrial wastes, effluents, soil and water (Hegazy et al., 2011; Yeboah et al., 2015).

Nevertheless, application of this biotechnology in remediating heavy metals from soil can be challenging and less successful sometimes even with traditional phytoremediation plants (Raskin et al., 1994). This situation arises because heavy metals in soil are generally bound to organic and inorganic constituents, or are present as insoluble precipitates, and hence, are unavailable for phytoextraction (Raskin et al., 1994; Henry, 2000; Shahid et al., 2014). Reduced availability of heavy metals in soil reduces the efficiency of even traditional phytoremediation plants and also increases considerably the time required for phytoremediation (Ghosh and Singh, 2005; Shahid et al., 2014).

Methods aimed at increasing bioavailability of heavy metal contaminants in soil have therefore become vital for the success of phytoremediation of metal-contaminated soils (Ernst, 1996). Soil amendment with acidifiers, commercial nutrients or some chelates like ethylene di-aminetetraacetic acid (EDTA) and di-ethylene tri-amine-pentaacetic acid (DTPA) (Ebbs et al., 1997; Ali et al., 2013; Shahid et al., 2014) have been shown to disassociate heavy metals from soil compartments into soil solution, making them more available for remediation. Though chemically assisted phytoremediation has received considerable attention from researchers, it effects on the success of phytoremediation of different metals using different plant species is still poorly understood. Understanding the effectiveness of these chemical amendments on phytoremediation of heavy metal contaminated soils resulting from mining activities with different plants is thus essential in assessing the viability of the biotechnology for mitigating the environmental impacts associated with gold mining activities.

In Ghana, heavy metal contamination resulting from mining activities has a history as long as the liberalization of the gold mining sector in the mid-1980's and the subsequent use of extraction methods that invariably release mercury and other heavy metals into surrounding water sources and soil (Asante et al., 2007; Essumang et al., 2007; Armah et al., 2010; Obiri et al., 2010). This contamination and its impact on host communities have spurred numerous studies on phytoremediation mostly on the identification of local plants (e.g., Anning et al., 2013). However, studies on how to enhance this process through chemical amendment are lacking in the country. In this study, we evaluated the effects of soil amendments (EDTA and $Al_2(SO_4)_3$) on phytoremediation of Hg, As, Pb, Zn, Cu by cattail and vetiver. To this end, the effects of these soil amendments on bioaccumulation factor (BAF), translocation factor (TF), metal uptake (MU), removal efficiency (RE) and plant growth of vetiver and cattail were evaluated to ascertain their viability for enhancing phytoremediation. It was hypothesized that soil amendments would enhance the efficiency of phytoremediation depending on the plant species and heavy metal in question.

2. Materials and methods

2.1. Study area

The study was conducted at the concession of Mensin Gold Bibiani Limited, which is located in the Bibiani-Anhwiaso-Bekwai District of the Western Region of Ghana (Fig. A.1). It is located between latitude 6° and 3° N and 2° and 3° W and covers a total area of 873 km^2. The Bibiani-Anhwiaso-Bekwai district is among areas covered by the north-western part of the moist semi-deciduous forest of Ghana. Annual rainfall of the district averages between 1200 mm and 1500 mm. Average temperature throughout the year is 26 °C and relative humidity averages between 75% in the afternoons and 95% at nights and early mornings (BABDA, 2006).

The geology of the district is dominated by the precambrian metamorphic rocks of the Birimian and Tarkwaian formation, making mining a lucrative economic activity in the district (Kesse, 1985; BABDA, 2006). Heavy metal contaminated soil and uncontaminated soil (control) used for this study were obtained from the processing unit of the small-scale mining operations in Bibiani and an undisturbed forest behind the residential premises of Mensin Gold, respectively.

2.2. Study plants

Chrysopogon zizanioides (L.) Roberty (commonly called vetiver) of the Poaceae family and *Typha latifolia* L. (broadleaf cattail) of the Typhaceae family are the two high-biomass, metal-tolerant plants used for this study. Nomenclature of the plant species conforms to the online resource, The Plant List (2013). Both plant species were obtained locally from the re-vegetation nursery and raw water dam area of Mensin Gold Bibiani Limited. Vetiver and cattail possess massive and finely-structured deep root system and tolerate wide range of soil pH (3.0–10.5 for vetiver and 4.0–10.5 for cattail; Gucker, 2008; Danh et al., 2009; Al-Menaie et al., 2012). Moreover, vetiver is known to exhibit high tolerance for aluminum and manganese toxicity (Truong, 1999). These characteristics of the two plant species ensured that leaching, reduced pH and aluminum toxicity which were likely to result from soil amendment would not affect the outcome of this research.

2.3. Determination of baseline concentrations of heavy metal in the study area

To determine the level of plant available heavy metal concentrations in the study area, 35 plots each measuring 10 m × 10 m and comprising 25 from the mined sites and 10 plots from an unmined site (reference) were demarcated for sampling. Soil samples were then collected from 0 to 20 cm depth in five different locations in each plot and thoroughly mixed to form a composite sample. Levels of heavy metals (Hg, As, Pb, Cu, Zn) and pH were determined for each composite sample using EDTA extraction procedure (Kucak and Blanusa, 1999) and digital pH meter respectively. Hg determination was done by using the cold vapor technique, Pb and As by using the graphite furnace AAS and Cu and Zn by emission AAS (Page et al., 1982).

2.4. Potted experiment to determine the effects of soil amendments

Additional samples (five) of heavy metal-contaminated soil as well as samples (five) of all test plants (cattail and vetiver) were collected and analyzed to help estimate the initial concentrations of heavy metals (Hg, As, Pb, Cu, Zn) prior to their use for the potted experiment. Forty-eight pots were each filled with 1.5 kg of the thoroughly mixed heavy metal-contaminated soil and sorted into three groups with sixteen pots each. Soils in the first group of pots were amended (one time) with 3 g aluminum sulfate $Al_2(SO_4)_3$, and thoroughly mixed to reduce the initial pH from 7.18 to 5.0. Similarly, the second group of soil was amended with 100 ml of 0.05 mol/L of ethylenediamine tetra acetic acid (EDTA) dipotassium salt solution and thoroughly mixed, whilst the last group of soil remained unamended and served as control.

Young cuttings of vetiver (12 in.) and cattail (22 in.) were pruned, weighed and then transplanted into the pots (one plant per pot) such that for each group, eight pots had vetiver and the other eight had cattail. Each pot was tagged with unique identification number to allow for accurate data collection on individual plants. The transplanted plants were allowed a period of four weeks to grow and adapt to their new environment. Water with pH of 7–7.5 was added on daily basis to keep the soil moist. During the stabilization period, changes in the physicochemical parameters (pH) and physical performance of each plant were monitored. After the four weeks stabilization period, measurements of growth parameters such as height and leaf-area were monitored every two weeks from November 2016 to February 2017. Measurements were made using a tape measure. Final concentrations of Cu, Zn, Pb, As and Hg in plants (Jones and Cas, 1990) and soil samples after the sixteen weeks period were determined.