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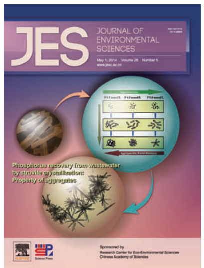

Growth and metal uptake of energy sugarcane (*Saccharum* spp.) in different metal mine tailings with soil amendments

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ABSTRACT

A pot experiment was conducted to investigate the feasibility of growing energy sugarcane (*Saccharum* spp.) in three different metal mine tailings (Cu, Sn and Pb/Zn tailings) amended with uncontaminated soil at different mixing ratios. The results indicated that sugarcane was highly tolerant to tailing environments. Amendments of 20% soil to Sn tailings and 30% soil to Cu tailings could increase the biomass of cane-stem for use as the raw material for bioethanol production. Heavy metals were mostly retained in roots, which indicated that sugarcane was useful for the stabilization of the tailings. Bagasse and juice, as the most valuable parts to produce bioethanol, only accounted for 0.6%–3% and 0.6%–7% of the total metal content. Our study supported the potential use of sugarcane for tailing phytostabilization and bioenergy production.

Introduction

Mining activities can produce huge amounts of mine tailings. Without proper storage and rehabilitation, the tailings may leach into soil and water bodies (Kien et al., 2010), resulting in environmental contamination and then human health concerns. Furthermore, mine tailings threaten natural vegetation owing to their lower pH and a composition consisting of mostly silt or sand-sized particles, lacking water retention capacity and fertility (Mendez et al., 2007; Rosario et al., 2007; Ye et al., 2002). In China, mining activities have generated about 3.2 Mha wasteland, and the area impacted is still increasing at a rate of 46,700 ha per year (Li et al., 2007). Gejiu City of Yunnan Province in south-west China is rich in tin and other mineral deposits, including lead/zinc and copper mines. It produced 223 Mt mining waste and destroyed a total of about 1671 ha land area as of 2002 (Li, 2006), which seriously affected the sustainable socio-economic development of the region. Obviously, there is an urgent demand for proper management of mine tailings.

Conventional technologies for the remediation of mine tailings such as soil excavation, landfilling or soil washing mainly involve physical and chemical methods. However, owing to the large quantity of mine tailings, decontamination by such conventional methods appears to be unfeasible due to the high cost and secondary pollution involved. In the long run, the establishment of vegetation cover is recognized as a sustainable approach that can fulfill the objectives of stabilization, pollution control and visual improvement (Wong, 2003). However, usually the ecological restoration of mining-impacted land is a big challenge.

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Suitable substrate amendment and selection of suitable plant species for planting on mine wastes are critical steps for revegetation practice. Covering the mine tailings with topsoil from an un-mined site is a commonly accepted strategy for the successful establishment of vegetation cover. Plants selected should be tolerant to specific metals, drought or infertile conditions (Wong, 2003), and growth of edible crops on mine tailings should be avoided owing to health risks to humans. Alternatively, planting energy crops which can adapt to adverse conditions is considered to be a good choice, as it could potentially mitigate the soil contamination and the gradual reduction of fossil fuels at the same time (Olivares et al., 2013). As seen in reports, several researchers have postulated this new strategy of cultivating energy plants, including rapeseed, wheat, corn, castor bean, vetiver grass and willow in metal-contaminated soils for bioenergy production (Hargreaves et al., 2012; Liu et al., 2012; Luu Thai et al., 2011; Van Danh et al., 2007; Witters et al., 2012).

As an important crop in the tropics and subtropics, sugarcane (*Saccharum* spp.) belongs to the Hatch-Slack crop type and fixes solar energy efficiently. It is regarded as one of the three largest biomass energy crops worldwide. Its annual output amounts to 40–120 tons/ha and the dry shoot weight can reach 12.8 tons/ha, with superior growth compared to most other crop species (Alexander, 1973). The Brazilian National Company of Food Supply estimated that 432 Brazilian mills and distilleries crushed a total of 625 million tons of sugarcane and produced 27 billion liters of bioethanol in 2010 (Amorim et al., 2011). Such productivity led Brazil to become the second largest ethanol producer in the world, responsible for 37% (2.4×10^7 m^3) of the global annual production (6.56×10^7 m^3) (Souza et al., 2012). Moreover, sugarcane has a vigorous root system with the maximum root depth exceeding 6 m, which can extract water and nutrients from considerable depths and make use of water up-flow from water tables (Smith et al., 2005). As a result, it can combat adverse conditions and tolerate dry, salty, or contaminated environments (Wahid, 2004; Wahid et al., 1997). Sugarcane plantlets were able to tolerate up to 100 mmol/L of copper in nutrient solution for 33 days, with no significant reduction in fresh weight and accumulating 45 mg/kg Cu on a shoot dry weight basis (Sereno et al., 2007). Xia et al. (2009) also investigated the growth and heavy metal accumulation of sugarcane that grew on artificially contaminated soil with different concentration of Cd, and found sugarcane had a high ability to tolerate and accumulate Cd with its large biomass. The feasibility of adopting edible sugarcane for restoration of manganese mining sites has been investigated, and it was found that Cd and Pb concentrations were higher than the safety limits in the edible parts of sugarcane. Researchers mentioned that such a product was unacceptable as food and this agricultural restoration pattern should be carefully reconsidered (Li et al., 2007). Alternatively, sugarcane could potentially serve as reclamation species for mine tailings owing to its outstanding biomass production, robust root system and strong adaptability to the adverse environment.

Despite the fact that energy sugarcane could adapt to certain adverse conditions and be efficient in bioethanol production, its heavy metal tolerance and potential for phytoremediation when growing in mine tailings have not been examined. Here we carried out a pot experiment to test the feasibility of growing energy sugarcane on three different metal mine tailings (Cu, Sn and Pb/Zn tailings). To assist successful planting, soil amendment was also considered. The objectives of the study were therefore to (1) investigate the metal accumulation and tolerance of sugarcane in different mine tailings; (2) examine the need for soil amendments to support plant growth; (3) evaluate whether sugarcane could serve as an energy crop in mining areas.

1 Material and methods

1.1 Experimental material

Cu, Sn and Pb/Zn mine tailings were collected from an ore-dressing plant of Gejiu City, Yunnan Province. Uncontaminated soil for amendment was collected from a paddy field in the Sugarcane Research Institute of Yunnan Agricultural Academy of Sciences. The total heavy metal concentrations in different tailings and soil (digested by a mixture of concentrated HNO_3, HCl and $HClO_4$) and DTPA-metal available concentrations (Lindsay and Norvell, 1978) are listed in **Table 1**. The physico-chemical properties of uncontaminated soil and the three mine tailings are shown in **Table 2**. Soil chemical properties were determined by procedures recommended by Richards (1954). The pH value (1: 2.5 soil to water) of the mixture of different metal mine tailings with soil are listed in **Table 3**. The sugarcane cultivar selected was Funong 94–0403.

1.2 Experimental conditions

Mine tailings and soils were air dried and passed through a 2 mm sieve. Different mine tailings (Cu, Pb/Zn, Sn) were thoroughly mixed with soils at a mixing ratio of 7:3, 8:2 and 9:1 (*m*/*m*) respectively. Together with a control treatment with soil alone, there were a total of 10 treatments. Each treatment had four replicates. Black plastic pots having 30 cm in height, 38 cm in top and 28 cm in bottom diameter, were used as growth containers. Each container accommodated 20 kg of the mixed soil and mine tailings. Three bud sets of sugarcane were planted in each pot. The 10 g compound fertilizer (N-P_2O_5-K_2O of 14:15:16 (*m*/*m*)) was added 42 days after planting, and 5 g carbamide was added to each pot 92 and 147 days after planting. The pots were kept outdoors with a natural photoperiod of 12–13