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Effects of biochar on the ecological performance of a subtropical landfill

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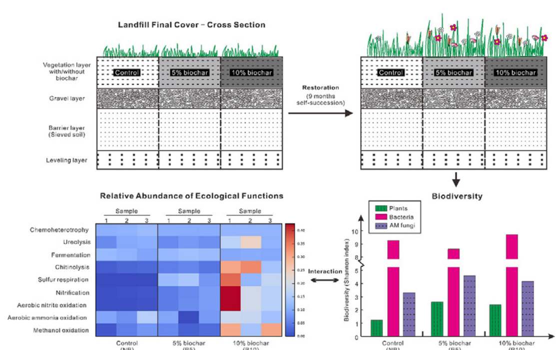
HIGHLIGHTS

- Effects of biochar on ecological restoration of disturbed lands are not clear.
- Biochar was added on landfill to study the ecological performance.
- Biodiversities (plant, bacteria and fungi) and ecological functions were studied.
- Biochar enhanced biodiversities (especially plant) and nutrient-cycling functions.
- Biochar amendment is a considerable approach for ecological restoration.

GRAPHICAL ABSTRACT



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ABSTRACT

Landfills commonly occupy large areas of land that may be ecologically important. Ecological restoration of landfill cover is a necessary approach to rebuild sustainable habitats. However, unfavourable soil conditions and invasion by exotic plants in certain regions hinder the restoration. In this study, the effects of biochar as a soil amendment on the restoration of a landfill cover were investigated under field condition. Topsoils of a landfill cover in the subtropical region (Shenzhen, China) were mixed with 0, 5 and 10% (v/v) of biochar. Soil pH, electronic conductivity, organic matter, total organic carbon, water content, total N and total P were enhanced by biochar amendment. After nine months of self-succession, plant productivity, species richness and diversity were enhanced by biochar. The structures of soil bacterial and arbuscular mycorrhizal (AM) fungal communities were changed, and species richness and diversity were moderately promoted. Enhanced plant growth and diversity were probably attributed to a number of enhanced bacterial functions related to nutrient cycling including aerobic ammonia oxidation, aerobic nitrite oxidation, nitrification, sulphur respiration, nitrate respiration, nitrogen respiration, ureolysis, chemoheterotrophy and fermentation. The higher abundances of bacteria *Streptomyces* sp. and *Pseudomonas* sp. in biochar treatments potentially enhanced the AM fungal diversity. The bacterial diversity was more related to the soil properties, especially pH, than AM fungi. Continuous monitoring is necessary to track the changes of species composition and ecological functions over time. This is the first comprehensive study on the effects of biochar on the ecological

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performance of a man-made ecosystem. In addition to agricultural application, biochar can be used for restoring degraded lands.

1. Introduction

Biodiversity loss has become a global concern since it will negatively influence ecosystem services that society depends on. Studies have demonstrated the importance of biodiversity in ecosystems (Delgado-Baquerizo et al., 2016; Isbell et al., 2015, 2011; Lefcheck et al., 2015; Perkins et al., 2014; Reich et al., 2001; Steudel et al., 2011; Wacker et al., 2009). For example, an ecosystem with a rich biodiversity is more sustainable when encounters climate extremes (Isbell et al., 2015). Plant diversity provides both resistance during and resilience after climate events (Isbell et al., 2015). An ecosystem with a higher plant diversity captures more carbon than an ecosystem with a lower plant diversity (Reich et al., 2001). During urbanization, land of ecological importance is often disturbed, for example, by converting large plots of land into a landfill. Ecological restoration is an important approach for the recovery and promotion of original biodiversity and ecological functions by active human intervention (Jordan et al., 1990). Plants (Isbell et al., 2011; Maestre et al., 2012), bacteria and fungi (Delgado-Baquerizo et al., 2016) are the key components functioning as a network within the ecosystems. The functioning largely relies on soil biota, especially bacteria and fungi (Wagg et al., 2014), which are essential for soil sustainability (Lehmann et al., 2017). Nutrient cycling, water balance, bioturbation, plant growth and trophic regulation (Nichols et al., 2008) are strongly related to biodiversity (Benayas et al., 2009; Ferguson and Friday, 1983) and the interaction between organisms and abiotic factors. The performance, biodiversity and community structure of plants and microbes are of great importance in ecosystems. Restored landfills can serve as habitats for improving biodiversity in urbanized areas (Do et al., 2013).

Ecological restoration in disturbed areas, especially on capped landfills (Chen et al., 2016a) and mine tailings (Cross and Lambers, 2017; Wong, 2003), is challenging due to the unfavourable soil conditions. The soil used for the restoration contains limited amounts of water content, organic matter and nutrients which limit the establishment of plants and the associated microbes. A number of studies investigated the plant and bacterial communities in the topsoil of a restored landfill, and showed that the landfill could not be restored similarly to the natural areas (Chen et al., 2016a, 2017; Wong et al., 2016). It could be caused by the initial selection of plant species (exotic species competing with native species) and unfavourable soil condition (e.g., low water content), which hindered the establishment of native species (Chen et al., 2016a). Enhanced diversity and evenness of native species are essential for a balanced and sustainable ecosystem (Andrén and Balandreau, 1999; Gamfeldt et al., 2008).

It has been proposed that biochar amendment in the landfill topsoil can be one of the strategies to enhance ecological performance (Chen et al., 2016b; Lehmann et al., 2011). Biochar is produced by pyrolyzing biomass with limited oxygen. Biochar has wide applications including carbon sequestration (Lehmann and Joseph, 2009), contaminants adsorption (Ahmad et al., 2014), positively affecting soil biota (Lehmann et al., 2011) and plant growth enhancement (Zhang et al., 2011). Biochar has been used to enhance plant performance in natural areas, and it strongly affected the composition of plant community and enhanced biological nitrogen fixation (van de Voorde et al., 2014). Results of a meta-analysis show that biochar influences the tree growth and forest restoration by enhancing soil nutrients (e.g., P, K and Ca) in the short term, and nutrients retention in the long term (Thomas and Gale, 2015). In general, adding biochar positively influences the ecosystem functions (Biederman and Harpole, 2012). In addition, the sorptive property of biochar restricts the uptake of soil contaminants (e.g., heavy metals in mine tailings) by plants (Brennan et al., 2014; Park et al., 2011).

Results of a laboratory experiment show that soil carbon and enzymatic activities were strongly enhanced due to biochar amendment, which is beneficial to saline soil restoration (Bhaduri et al., 2016). The root-associated bacterial community structure was altered by biochar-associated organic compounds, i.e. different soil bacterial phyla were observed in biochar-amended soil, compared with the control (Kolton et al., 2011). The abundance of *Bacteroidetes* (phylum) (especially the genus *Favobacterium*) increased from 12 to 30%, while *Proteobacteria* decreased from 71 to 47% (Kolton et al., 2011). On the other hand, biochar influenced the fungal gene abundance in a rice paddy (Chen et al., 2013). Biochar amendment alters the soil physico-chemical properties, affects other soil microbes, interferes plant-fungus signalling, detoxifies allelochemicals and provides refugia from fungal grazers (Warnock et al., 2007).

However, field studies applying biochar to promote biodiversity in man-made ecosystems are scarce. The effects of biochar application for landfill cover restoration focusing on plant, bacterial and fungal diversities remain largely unknown. Here, we applied biochar on the vegetation layer of a landfill cover to investigate its effects on influencing plant, bacterial and arbuscular mycorrhizal (AM) fungal communities, and ecological functions, compared with natural soil during early stages of ecological restoration.

2. Materials and methods

2.1. Site description and landfill final cover construction

The study site is located at the south boundary of the third phase of Xiaping landfill (E113°34′, N22°29′), Shenzhen, China (Fig. 1). Xiaping landfill is one of the largest sanitary landfills in China. The designed capacity is 4693 million m^3 for an operation period of 25 years. It started accepting domestic waste in 1997. The area is a typical south eastern natural area in China containing plant species such as *Trema tomentosa*, *Miscanthus* sp., *Lantana camara* (exotic), *Wedelia* sp. (exotic), *Ficus variegata*, *Mallotus paniculatus*, *Rhus chinensis*, *Musa paradisiaca*, *Desmodium heterocarpon*, *Laggera alata*, *Ipomoea nil* and *Dicranopteris dichotoma*. During 2016, the average annual precipitation was approximately 2000 mm. Relative humidity ranged from 76 to 80%. The annual average temperature was 22.4 °C.

The area of the study site is approximately 300 m^2 (Fig. 2a). An earthen final cover system was used to prevent water infiltration and landfill gas emission (Ng et al., 2015, 2016). Briefly, four layers were constructed directly above the waste: 1) a levelling layer using unsieved soil, 2) a barrier layer (thickness 0.8 m) using sieved soil (mesh 1.5 cm), 3) a drainage layer (thickness 0.4 m) using gravel, and 4) a vegetation layer (thickness 0.6 m) using unsieved soil mixed with or without biochar (Fig. 2b). The biochar treatment was applied during the construction of the landfill cover system. The vegetation layer was divided into three plots mixed with 0, 5 and 10% (v/v) of biochar, respectively (Fig. 2a). Ten percent biochar was selected as the maximum value because >10% can lead to deleterious effects on plant growth (Rillig et al., 2010). The biochar was obtained by pyrolyzing peanut shell and wheat straw (1:1, v/v) at 500 °C with limited supply of oxygen. Biochar was well-mixed with soil (Fig. S1) and compacted to ~90% of the maximum dry density (ASTM, 2012). The soils with and without biochar were compacted layer by layer (0.2 m each). The soil for construction