Effects of Biochar on Soil Quality and Heavy Metal Availability in a Military Shooting Range Soil in Korea

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Heavy metal remediation in shooting range soil is a challenge over the world. The excessive Pb accumulation in the soil can deteriorate soil quality and fertility. The objectives of this research were to evaluate the efficiency of biochar (BC) in improving the physicochemical and biological properties of the soil and to evaluate its effect on Pb availability in a military shooting range soil. Sandy loam soil was collected from shooting range of Gyeonggi Province, South Korea and was incubated for 30 days with different application rates (0-30% w w⁻¹) of BC. The results showed that the addition of BC increased aggregate stability, nitrogen (N) and phosphorus (P) contents, and enzyme activities in soil. Sequential extraction showed that residual and organic bound fractions in the soil amended with BC increased by 33.1 and 16.7%, respectively, and the exchangeable fraction decreased by 93.7% in the soil amended with BC, compared to the unamended soil. We concluded that the application of BC could not only improve physicochemical and biological soil qualities but also stabilize Pb in a shooting range soil.

Key words: Shooting range, Heavy metals, Biochar, Soil quality, Lead

Introduction

Shooting ranges are essential constructions around the world for weapons training and shooting activities. However, shooting activities produce the soil contaminated with heavy metals such as Pb from the used bullets (Dermatas et al., 2006). Nowadays, a huge amount of Pb is being deposited in the shooting range soil worldwide at an annual deposition rate of 200 to 60,000 tons (Craig, 1999; Mellor and McCartney, 1994). Shooting ranges are commonly considered as the second largest source of soil Pb after development of the battery industry (Cao et al., 2008). The contamination of shooting range soil with Pb is well documented (Cao et al., 2008; Dermatas et al., 2006; Grubb et al., 2009; Hashimoto et al., 2009a). Most of the studies indicated that Pb levels in the shooting range soils exceed 1% (Chen and Daroub, 2002; Hashimoto et al., 2010) resulting in degrading soil quality, decreasing soil microbial activities and threatening to living organisms (Belyaeva et al., 2005; Lee et al., 2002).

The remediation of shooting range soil has received great interest in the past due to its adverse effects. There are several remediation technologies for remediating heavy metal contaminated soils, such as excavation and landfill, thermal treatment, washing, electro-reclamation, and solidification/stabilization (Aboulroos et al., 2006; Shi and Spence, 2004; Singh and Pant, 2006). However, because of the high cost and low efficiency, these conventional methods are not effective (Aboulroos et al., 2006). The end use of the contaminated soil after remediation is an important factor, which controls the selection of remediation technology (Mulligan et al., 2001). Several soil amendments such as P containing materials and liming materials have been used to remediate the shooting range soil by converting highly mobile and available forms of Pb into less mobile and available forms (Cao et al., 2008; Hashimoto...
et al., 2009a; Li et al., 2009; Moon et al., 2010). However, phosphate-induced immobilization of Pb requires a high amount of available P to stabilize Pb that may result in the leaching of P into ground water and surrounding environment (Dermatas et al., 2008). On the other hand, rise in the soil pH (>8) induced by the lime-based materials for Pb stabilization is not favorable for soil biota.

Biochar (BC) is a charcoal produced from the pyrolysis of biomass at relatively low temperatures (< 700°C) (Lehmann and Joseph, 2009). BC has received great interest during the last few years, due to its beneficial role to mitigate CO2 emission and to improve soil quality (Major, 2010; Novak et al., 2009). Several studies have shown that BC can improve physicochemical and biological soil properties (Free et al., 2010; Novak et al., 2009; Yeboah et al., 2009). However, in our knowledge, BC has not been widely used so far as a soil amendment for shooting range soils. Additionally, only limited studies have reported on the effect of BC for heavy metal availability and stabilization in soil.

Recently, Cao et al. (2009) indicated that high content of P in the BC is mainly responsible for Pb stabilization in the aqueous solution due to the formation of stable phosphate minerals. Uchimiya et al. (2010) suggested several possible mechanisms for the stabilization of heavy metals in soil and water by using BC, such as cation exchange, coordination by π electrons of carbon (C) and precipitation. However, most of these studies applied BC to immobilize heavy metals in aqueous solutions or soils but only for a short incubation period (24 h). Therefore, the effectiveness of BC for the stabilization of heavy metals in soils has not been well explored.

In South Korea, there are more than 690 shooting ranges where 267 tons year−1 of Pb deposited annually (Ministry of Environment (MOE), 2010). However, little information is available for the soil and water contamination of these sites. Therefore, the objectives of this study are (i) to evaluate the efficiency of BC in improving soil quality related to physicochemical and biological properties, and (ii) to determine its performance on availability and stabilization of heavy metals in a military shooting range soil.

Material and methods

Soil collection A Pb contaminated surface soil was collected from the impact berm (200 m from the firing station) of a military shooting range in Gyeonggi Province, South Korea. Soil samples were air-dried and had all Pb-contained bullets removed passed through a 2-mm sieve, after which subjected to further analysis and the incubation experiment.

Biochar amendment Biochar material (BC250) or BC for short was obtained from University of Bayreuth, Germany, and comprised of 250-kg charcoal mixed with one ton of compost material (50% sewage sludge + 25% freshly chopped lop, grass and leaves + 25% of soil and coarse wood branches). Organic matter (OM) in BC was determined by loss on ignition method (Yerokun et al., 2007). The BC was ground to pass through a 0.5-mm sieve and used for the incubation experiment.

Incubation experiment A soil incubation experiment was conducted using BC at different application rates 0, 1, 3, 5, 10, 20 and 30% (weight basis of soil). Specifically, 100 g of shooting range soil was thoroughly mixed with BC in a high-density polyethylene (HDPE) container. The soil was hydrated to saturation in order to promote the reaction between metal ions and BC, and the hydrated conditions were maintained by periodically adjusting the weights of containers. Then, soil was incubated for 30 d at room temperature without direct sunlight exposure.

Soil analysis The particle size distribution was determined using a hydrometer method as described by Gee and Or (2002). The soil aggregate stability was determined using a wet sieving apparatus (Eijkelkamp, Netherlands). To ensure soil particle distribution, 4 g of 1- to 2-mm air-dried soil aggregate was pre-moistened with distilled water and then was sieved through 0.25 mm into 80 mL of distilled water for 3 min ± 5 s. The water was then evaporated in a dry oven at 110°C to get unstable aggregates. Meanwhile, the remaining soil aggregate was sieved into 80 mL of dispersing solution (2 g L−1 sodium hexametaphosphate for the soil with pH >7 or 2 g L−1 sodium hydroxide for the soil with pH <7) until only sand particles left on the sieve. Finally, the sample was evaporated and the stable aggregate fraction was calculated.

The soil pH and EC was determined at room temperature by following the 1:5 soil/water extraction methods (NIAST, 2000). Total organic carbon (TOC) content was determined using a Walkley-Black procedure (Nelson and Sommers, 1996), and total C (TC) and total nitrogen (TN) were measured using an elemental analyzer (Flash EA 1112,