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Effects of boron waste (BW) addition on the bioavailability of boron and magnesium during swine manure composting

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ABSTRACT

The improper disposal of boron waste (BW) would bring much trouble for environment, at the same time, BW with a higher content of boron (B) and magnesium (Mg) could be used as a fertilizer in B and Mg deficient soils. Therefore this study recommended a novel disposal method of BW by composting, and investigated the influence of BW additions (at rates of 2.5%, 5.0% and 7.5%, dry weight basis) on the bioavailability of B and Mg during aerobic swine manure composting. Results indicated that additions of BW increased the content of both B and Mg in different fractions. The proportion of B fractions in the final composted material supplemented with BW were: nonspecifically adsorbed B (NSA-B) > B occluded in Mn oxyhydroxides (MOH-B) > specifically adsorbed B (SPA-B) > residual B (RES-B) > B occluded in crystalline Fe and Al oxides (CRO-B) > B occluded in amorphous Fe and Al oxides (AMO-B). The addition of BW improved the bioavailability of B to plants and reduced the proportion of Mg in the exchangeable fraction. Spearman correlation showed that B and Mg bioavailability was associated with fulvic acid (FA; $P < 0.05$). This study suggested that the humification process changed bioavailable forms of B and Mg during co-composting.

1. Introduction

China has the sixth largest boron reserves, at approximately 1.50 million tons of boron (B) mined in 2010 with this amount increasing gradually since that time (Angulo, 2010). Because B is a low abundance mineral, 1 ton of B product can produce 3–4 tons waste using current technology (Boncukcuoglu et al., 2003). When large quantities of BW are piled up in environment, B compounds may be transported via runoff and leached into groundwater. At the same time, B deficiency may lead to nutritional deficiencies owing to it being one of the seven essential micronutrients. Indeed, 33×10^6 ha farmland is boron-deficient in China and about 54% of the soil in China should be supplied with varying rates of Mg (Liu et al., 1990). Boron deficiency in plants has been observed in China because about 60–99.7% of total soil B is found in the residual fraction (Jin et al., 1987; Xu et al., 2001). The BW have been recommended to be applied for fertility management because of high contents of B and Mg (Hou et al., 2014), however, the low bioavailability of Bin BW has limited its use as fertilizer.

Composting is a biological process in which aerobic thermophilic and mesophilic microorganisms use organic matter

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Table 1 – The characteristic of raw materials of composting.

	B (mg/kg)	Mg (g/kg)	EC (ds/m)	pH	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)
BW	6320 (232)	320 (3.78)	0.75 (0.27)	9.50 (0.27)	3.21 (1.01)	38.86 (0.95)	10.3 (0.51)
Manure	15.75 (1.32)	8.42 (1.27)	1.88 (0.37)	7.35 (0.11)	453.6 (2.33)	3401 (44.5)	3.00 (0.44)

(OM) as a substrate (Bustamante et al., 2008; Ouaqoudi et al., 2015). The agricultural application of compost is based on its degree of stability, contents, and biochemical forms of the metal present (Haroun et al., 2009). When properly executed, the aerobic composting of organic wastes can increase the exchangeable fraction of elements (Pare et al., 1999). Chemical characterization of metals is crucial for its bioavailability and mobility in soil–water–plant systems. In general, composting changes the proportion of exchangeable and labile fractions (i.e. carbonate fractions) for most heavy metals including Cu, Zn, Pb, and Cd during swine manure compost (Lu et al., 2014; Li et al., 2010; Singh and Kalamdhad, 2012). However, the effect of composting process on Mg and B fraction was reported rarely. In contrast to other trace elements, B transport in soil solutions and plant uptake occurs as neutral H_3BO_3 over a wide range of pH values (pKa: 9.24). Boron may be non-specifically and specifically adsorbed, occluded in Mn oxyhydroxides, or as amorphous and crystalline Fe and Al oxides. All of which have different availability patterns for plants (Tsadilas et al., 1994). Boron availability is influenced by several factors such as pH, texture, moisture, temperature, oxide minerals, clay mineralogy, calcium carbonate and organic matter (Xu et al., 2001). However, the distribution of B and Mg fractions during composting are scarce and it is fairly unclear that what would happen the bioavailability of B and Mg during composting.

Therefore, the aforementioned issues will be tracked in order to provide a comprehensive understanding factors and physicochemical processes controlling the bioavailability of B and Mg during composting. Specifically, objectives of this research were to (1) researched the change of fractions and evaluated the bioavailability of B and Mg under composting with different BW additions; (2) analyzed the correlation among chemical parameters and B and Mg fractions and identified the important factor controlling the fractions of B and Mg.

2. Materials and methods

2.1. Raw materials

Boron waste (BW) was collected from Jian County in Jilin province. The fresh swine manure came from Jilin University pig farm with a holding inventory of 1000 pigs. The rice straw was brought from the nearby farm and crushed to less than 5 mm size and then mixed with the swine manure. The chemical characteristics of the raw materials (swine manure and rice straw) have been reported previously (Lu et al., 2013).

2.2. Composting procedure

Swine manure and bulking agent (rice straw) were co-composted for adjusting the C/N ratio of the compost mixture to a value of 20. The compost mixture (about 30 kg each, fresh weight) was then mixed thoroughly with BW at 0 (control), 2.5%, 5.0%, and 7.5% (w/w, dry weight basis) using cylindrical plastic vessels of 50 cm height and 50 cm diameter (98 L). During composting, water was added at the time of sampling and stirred to achieve 60–70% moisture content. The co-compost was sampled in triplicates at 1, 7, 15, 23, 31, 39, and 49 days and thereafter stored at 4 °C for subsequent chemical analysis (Table 1).

2.3. Analytical methods

The temperature was recorded using a thermometer during the composting period. Organic matter was determined using the weight loss-on-ignition method at 550 °C for 8 h. The pH was measured in the suspension of samples and deionized water (1:10, w/v dry basis) with a pH meter (520M-01A Thermo Fisher, American).

Humic acid (HA) and fulvic acid (FA) were analyzed using a modified Ko's method. 2 g ground sample was dissolved in 100 mL 0.1 mol/L $NaOH/Na_4P_2O_7$ solution for 48 h at 65 °C. The supernatant solution was filtered through 0.45 μm filter and stored under N_2 at 4 °C. The humic acid (HA) was acidification with 25 mL extracts of 50% H_2SO_4 to separate from the FA. The FA was purified and resolubilized with 0.1 mol/L NaOH. The HA and FA was obtained by mineralization of 10 mL extracts with 5 mL of 2 N $K_2Cr_2O_7$ and 20 mL 96% H_2SO_4 for 10 min at 160 °C (Ko et al., 2008).

Total B (TB) was analyzed in an acidic mixture of HNO_3 and H_2O_2 (5:1). Boron in the compost material was fractionated as nonspecifically adsorbed plus water soluble B (NSA-B), the boron in solution or weakly absorbed by soil particle, specifically adsorbed B (SPA-B, the B specifically adsorbed onto clay surfaces or combined with OM), B occluded in Mn oxyhydroxides (MOH-B), B occluded in amorphous Fe and Al oxides (AMO-B), B occluded in crystalline Fe and Al oxides (CRO-B), and residual B (RES-B) using separate extraction procedures for different B fractions (Jin et al., 1987). The separate extraction method was as following: 5 g soil was extracted with 10 mL 0.02 M $CaCl_2$, 0.02 M mannitol in 0.02 M $CaCl_2$ shaking for 24 h at 25 °C as NSA-B and SPA; 5 g soil was extracted with 40 mL 0.1 M $NH_2OH{\cdot}HCl$ in 0.01 M HNO_3, shaking for 30 min at 25 °C as MOH-B; 1 g soil was extracted with 50 mL 0.2 M NH_4-oxalate, shaking for 2 h in the dark at 25 °C; 0.5 g soil was extracted with 20 mL DCB for 15 min in water bath at 80 °C twice as CRO-B. RES-B was digestion with the mixture of HCl, HNO_3 and HF. The suspensions were centrifuged, and B supernatant concentrations were analyzed by inductively coupled plasma spectroscopy (ICP-AES). Boron content in each fractions was calculated by subtraction of the B extracted in previous B fractions (Xu et al., 2001). Of the B fractions, NSA-B, SPA-B, and MOH-B are the most available forms to the plants. The B fraction occluded in Al and Fe oxyhydroxides is relatively unavailable (Jin et al., 1987; Lee et al., 2008). The sum of the NSA-B, SPA-B, MOH-B, and AMO-B represents the total concentration of the mobile fractions (MB). The bioavailability factor (BF) is defined as the ratio of MB to TB (Lechner and Smidt, 2003; Kota et al., 2012).

Total Mg content was digested in a mixture of HNO_3 and H_2O_2, and then determined by atomic absorption spectrophotometer (AAS) (GBC 932, Australia). The Mg was extracted with CH_3COOH (0.11 mol/L), $NH_2OH{\cdot}HCl$ (0.1 mol/L), H_2O_2