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Characteristics of biomass ashes from different materials and their ameliorative effects on acid soils

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ABSTRACT

The chemical characteristics, element contents, mineral compositions, and the ameliorative effects on acid soils of five biomass ashes from different materials were analyzed. The chemical properties of the ashes varied depending on the source biomass material. An increase in the concrete shuttering contents in the biomass materials led to higher alkalinity, and higher Ca and Mg levels in biomass ashes, which made them particularly good at ameliorating effects on soil acidity. However, heavy metal contents, such as Cr, Cu, and Zn in the ashes, were relatively high. The incorporation of all ashes increased soil pH, exchangeable base cations, and available phosphorus, but decreased soil exchangeable acidity. The application of the ashes from biomass materials with a high concrete shuttering content increased the soil available heavy metal contents. Therefore, the biomass ashes from wood and crop residues with low concrete contents were the better acid soil amendments.

Introduction

The increase in CO_2 emissions has led to an increase in global temperatures. It is widely accepted that biomass energy is a renewable power source that does not release net CO_2 during the combustion process (Mckendry, 2002; Cherubini and Strømman, 2011). Currently, biomass energy contributes 8%–15% of the world energy supplies, including heat, electricity and fuels, and the contribution is predicted to rise to 33%–50% by 2050 (Vassilev et al., 2013). In 2005, the generating capacity from biomass combustion in China was about 2.0 gigawatt (GW), which is expected to rise to 24 GW in 2020. It has been reported that 5%–10% on a dry weight basis forms ash during biomass combustion (Wang et al., 2011). As biomass energy becomes more wide spread, there will be increasing numbers of different biomass ashes produced. Hence, there is a need to reuse and manage biomass ash if the benefits to the economy, environment, and society brought about by biomass power generation are to be realized.

Previous studies have shown that biomass ashes from wood and crop straw not only contain some alkaline substances, but also contain high levels of nutrients, such as K, Ca, Mg, P, and trace elements (Etiegni and Campbell, 1991; Mozaffari et al., 2000). They could therefore be used to ameliorate soil acidity and increase soil nutrient contents (Muse and Mitchell, 1995; Nkana et al., 1998; Demeyer et al., 2001; Mozaffari et al., 2002; Park et al., 2005). However, these investigations just focused on the biomass ashes from single

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biomass fuel, such as wood ash, rather than from co-firing different bio-waste materials in biomass power plants. Biomass ashes showed clear variations in properties and composition due to the differences in the raw biomass materials (Werkelin et al., 2005, 2010; Vassilev et al., 2010). Thus, it is needed to study the various properties and composition of ashes how to affect their amelioration on acidic soils.

In the subtropical area of China, there is about 2.03 million km^2 of land covered in acid soils, which accounts for 22% of the total arable soil. Over recent decades, the acidification rate of the soil has been accelerated due to acid precipitation (Reuss and Johnson, 1986; Hu et al., 2007) and excess applications of NH_4^+ and R-NH_2 fertilizers to farmland (Bolan et al., 1991; Zhang et al., 2009; Guo et al., 2010). Aluminum (Al) toxicity and deficiencies of nutrients induced by soil acidification limit the growth of crops in acidic soils (Von Uexküll and Mutert, 1995). So, it would be a valuable and sustainable way if the plant ashes could be used as ameliorant for acid soils in southern China. On the other hand, it has also been reported that biomass ashes contain heavy metals to varying extents (Pastircakova, 2004; Wang et al., 2011; Williams et al., 2012; Vassilev et al., 2014; Saqib and Backstrom, 2015). To ensure environmental security of the ashes, the potential risk from these heavy metals has to be considered well when ashes were returned back to soils.

This study was designed to (1) examine the physicochemical properties of biomass ashes produced from different mixed biomass materials; (2) investigate the ameliorative effects of various biomass ashes on acid soils; and (3) evaluate the potential environmental risk of heavy metals in biomass ashes when they are applied as soil amendments. The results obtained in this study can provide practical, technical support for appropriate management programs, and will improve and increase the use of biomass ashes derived from the co-firing of mixed biofuels in power plants to ameliorate acidic soils.

1. Materials and methods

1.1. Soil samples and biomass ashes

Two acidic Ultisols were collected from Anhui and Guangdong Provinces. The soil samples were taken from the topsoil (0–15 cm), air-dried, and then ground to pass through a 2-mm sieve. The soils were then reserved for the incubation experiment. Some basic properties of the soils used are listed in Table 1. Soil pH was measured with Orion 720 pH meter (Orion Research Incorporated, Boston, Massachusetts, USA) in a 1:2.5 solid:water suspension. Soil exchangeable H^+ and Al^{3+} were extracted with 1.0 mol/L KCl and then titrated with 0.01 mol/L NaOH. Soil exchangeable base cations were extracted with 1.0 mol/L ammonium acetate. Ca^{2+} and Mg^{2+} in the extractants were measured with atomic absorption spectrophotometry (nov AA350, Analytik, Jena AG, Germany), and K^+ and Na^+ were measured using flame photometry (FP640, Aopu, Shanghai, China).

The ash samples were obtained from five power plants with circulating fluidized bed belonging to Sunshine Kaidi New Energy Group Co., Ltd. in China. Biomass ash-1 (BA-1), biomass ash-3 (BA-3) and biomass ash-5 (BA-5) were collected from power plants located in Chongqing, Hunan, and Hubei provinces, respectively, and biomass ash-2 (BA-2) and biomass ash-4 (BA-4) were collected from power plants located in Anhui Province. All samples are bottom ash, which were collected from ash pits. Each ash sample was collected from ten sites in the pit and mixed thoroughly. The biofuels burned were mainly a mixture of crop husks, woody byproducts and concrete shuttering. The same mixed waste biofuels were used during the total combustion process. The specific compositions of the ashes are shown in Table 2.

1.2. Analyses of the properties and compositions of the biomass ashes

The pH and electrical conductivity (EC) of the biomass ashes (BA) were measured in suspensions with a solid:water ratio of 1:5 by an Orion 720 pH meter (Orion Research Incorporated, Boston, Massachusetts, USA) and an EC 215 conductivity meter (Hanna instruments, Padova, Italy), respectively. The acid–base titration curves of the biomass ashes were measured using an automatic titrator (T50 Titrator, Mettler Toledo, Urdorf, Switzerland), which titrated a 60 mL suspension containing 0.250 g biomass ashes to pH 2.5 using 0.2 mol/L HNO_3. The acid consumptions down to pH 5.0 were regarded as the acid neutralization capacities (ANC) of the biomass ashes (Wong et al., 1998). The biomass ashes were digested in a mixture of HF–$HClO_4$–HNO_3 and dissolved by HNO_3 to determine the K, Na, Ca, Mg, Fe, Mn and P contents using inductively coupled plasma-atomic emission spectroscopy (ICP-AES, VISTA-MPX, Varian, Palo Alto, California, USA), and Cr, Pb, Ni, Cu, Zn, Co, Mo and Cd were analyzed by ICP-mass spectrometry (VGPQII Agilent 7500a, Agilent, California, USA). Mercury, arsenic and selenium levels in the biomass ashes were measured by atomic fluorescence spectrometry (AFS3300, Beijing Titan Instruments Co. Ltd., Beijing, China) after microwave digestion with HNO_3. To evaluate the solubility of nutritional ions in the biomass ashes, 0.200 g biomass ash was leached with 20 mL distilled

Table 1 – Basic properties of Ultisols used.

Location	Utilization	pH	OM (g/kg)	CEC	Exchangeable acidity	Exchangeable base cations ($cmol_{(+)}$/kg)				BS (%)
						K^+	Na^+	Ca^{2+}	Mg^{2+}	
Anhui	Farmland	4.6	18	14.3	4.59	0.31	0.34	3.16	0.63	49.17
Guangdong	Forest	4.56	11.9	8.1	3.19	0.02	0.17	0.15	0.1	12.12

OM: organic matter; CEC: cation exchange capacity; BS: base saturation.

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