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Short communication

Ameliorating effects of individual and combined application of biomass ash, bone meal and alkaline slag on acid soils

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ABSTRACT

Incubation experiments with biomass ash (BA), bone meal (BM) and alkaline slag (AS) applied alone and together were conducted to ameliorate acidity and increase nutrient contents of five Ultisols collected from four provinces of southern China. The results showed that the ameliorating effect of the combined application of three amendments on soil acidity was greater than that of BA + BM or their single applications. The combined application of BA, BM and AS increased the pH by 0.63–1.37 for five Ultisols. The most significant decrease of soil exchangeable acidity was also observed in the treatments of BA + BM + AS by 80.1–96.9% for five Ultisols. Meanwhile, the combined application of the amendments greatly increased the exchangeable potassium, calcium and magnesium of the five soils, respectively, by 0.4–3.8, 1.9–10 and 1.7–9.7 times. The contents of available phosphorus of the five soils were also increased significantly by 0.6–184 times due to the application of BA + HBM + AS. In general, the application of the amendments did not increase available heavy metals in the soils in this short-term incubation experiment, but the potential risk of the amendments applied should be further assessed under field conditions through long-term experiments.

1. Introduction

In southern China, there are 2.03 million km^2 of acid soils, representing about 22% of arable land in the country (Xiong and Li, 1990). In recent decades, soil acidification has been accelerated greatly due to various anthropogenic activities, such as serious acid deposition and excess application of ammoniacal nitrogen fertilizers (Guo et al., 2010). Aluminum (Al) toxicity and deficiencies of nutrients induced by soil acidification limit the growth of crops in acidic soils. Traditionally, lime has been applied to ameliorate soil acidity; however, its widespread application is limited by supply shortages and high costs, especially in many developing countries (Adams, 1984). Additionally, lime does not effectively increase contents of K, Mg and P (Sun et al., 2000).

Some researchers have turned their attention to industrial byproducts for the purpose of ameliorating acid soils (Li et al., 2010). Biomass ash (BA) is the byproduct of combusting biofuels in biomass power plants. It is reported that some BA, such as wood and straw ashes, not only contain an amount of alkalis, but also contain significant amounts of K, Ca, Mg and other nutritional elements (Mozaffari et al., 2000). Therefore, BA could ameliorate soil acidity and improve soil nutrient levels (Park et al., 2005). Bone meal (BM) is a byproduct of the bone rendering industry and has been authorized as a fertilizer for arable crops in regulation No. 181/2006 of the European Commission since 2006. It is regarded as an effective resource of P for crops due to the large amount of P in BM (Garcia and Rosentrater, 2008). Some studies were conducted to explore the effect of BM on soil fertility and crop yield, and showed that BM had positive effects on crops (Nogalska et al., 2012), but its amelioration on acid soils needs to be assessed. Alkaline slag (AS) is the waste of ammonia–alkali production of sodium carbonate, with sea salt and limestone as raw materials. Some studies suggested that application of AS can effectively alleviate acidity of topsoil and subsoil due to the high contents of alkaline substances and $CaCl_2$ (Li et al., 2010, 2015). Most researches just focus on the effect of a single amelioration material on soil acidity. However, it is difficult to thoroughly deal with soil acidity and nutrient deficiencies with any one of BA, BM or AS. While, combined application of BA, BM and AS may ameliorate soil acidity and improve soil fertility simultaneously.

A lab incubation experiment was conducted to investigate the effects of individual and combined application of BA, BM and AS on acidity and contents of K, Ca, Mg and P in several acid soils from southern China. The main objective of the present study is to

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develop low cost and efficient methods for ameliorating soil acidity and improving soil fertility through combined application of industrial byproducts.

2. Materials and methods

2.1. Soil samples and amendments

Five acidic Ultisols were used in the incubation experiment. Among them, three Ultisols were collected from Anhui Province, Hunan Province and Guangdong Province (Ultisol-AH, Ultisol-HN, and Ultisol-GD), and the other two Ultisols were collected from Zhejiang Province (Ultisol-ZJFA: Ultisol from farmland; Ultisol-ZJFO: Ultisol from forest). The soil samples were taken from the topsoil (0–15 cm), air-dried and then ground to pass a 2 mm sieve for incubation. Some basic properties of the soils used are listed in Table 1.

BA was produced by combined combustion of poplar bark, rice straw and wheat straw in a biomass power plant. BM was a byproduct of the manufacture of bone glue protein. AS was obtained from ammonia–alkali production of sodium carbonate. The chemical properties and compositions of the amendments and the related analysis methods were provided in supplementary data (Tables S1, S2 and Fig. S1).

2.2. Incubation experiment

In each experiment, 300 g of air-dried soil samples was mixed with byproducts thoroughly, and then placed in plastic beakers, wetted with deionized water to reach 70% of the field water-holding capacity. All beakers were covered by plastic film with a small hole kept for gas exchange but to avoid moisture loss. The incubation was conducted in an incubator with a constant temperature of 25 °C for 64 days. During the incubation, soil moisture was adjusted to a constant weight with distilled water at the end of every 3-d period.

Based on the preliminary study, nine treatments were set in the incubation experiment with the Ultisol-AH: control without amendment; 4 g kg^{-1} BA; 2 g kg^{-1} AS; 1 g kg^{-1} bone meal (LBM); 2 g kg^{-1} bone meal (HBM); BA + LBM; BA + LBM + AS; BA + HBM; and BA + HBM + AS. There were three replicates for each treatment. After incubation, the soil samples were air-dried and ground to pass a 2 mm and 0.25 mm sieve for measure their properties. Then, the incubation experiment with the treatments of BA + HBM and BA + HBM + AS was conducted using the other four Ultisols.

During the incubation, sub-samples were taken at specific intervals from each beaker to measure soil pH in a 1:2.5 solid:water suspension by an Orion 720 pH meter. After incubation, exchangeable protons (H^+) and Al^{3+} of the soils were extracted with 1.0 M KCl, and then titrated by 0.01 M NaOH. Soil exchangeable base cations were extracted with 1.0 M ammonium acetate at pH 7.0, and then Ca^{2+} and Mg^{2+} were measured by atomic absorption spectrophotometry (nov AA350, analytikjenaAG, Germany), K^+ and Na^+ were measured using flame photometry. The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable Al^{3+} and H^+ extracted by 1 M KCl and exchangeable base cations of Ca^{2+}, Mg^{2+}, K^+ and Na^+ extracted by 1.0 M ammonium acetate at pH 7.0 (Pansu and Gautheyrou, 2006). The content of available P was extracted by NH_4F-HCl solution and determined by ascorbic acid-NH_4-molybdate blue colorimetry at 700 nm (Bray and Kurtz, 1945). The available heavy metals of soil samples were extracted with 1 M HCl and measured by inductively coupled plasma-atomic emission spectroscopy (ICP-AES, VISTA-MPX, Varian, USA) (Rauret, 1998).

2.3. Statistical analysis

The SPSS 20.0 software package was used for statistical analysis. A one-way analysis of variance (ANOVA) was used to test the significant differences among the treatments. The means were compared by a least significant difference (LSD) test ($P < 0.05$).

3. Results and discussion

3.1. Properties and composition of BA, BM and AS

The properties and composition of the byproducts mainly depends on their raw materials and productive process. The highest pH of 12.28 was for BA, followed by AS, and the pH of BM was closest to neutral, however, their acid neutralization capacity (ANC) followed the order: AS > BA > BM (Table S1). Therefore, AS contains more alkaline substances than BA and BM. The content of K was 34.5 g kg^{-1} in BA, which was much higher than that in BM and AS (Table S1). The XRD spectra showed that there was 49% quartz and 30% calcite in the mineral composition of BA, and 63% calcium hydrophosphate and 35% calcite in BM (Fig. S1 and Table S2). Therefore, the contents of Ca and P in BM were as high as 283.0 and 124.2 g kg^{-1} (Table S2). The main mineral composition of AS was gypsum (83%), followed by calcite (17%) (Fig. S1). The content of Mg in AS was up to 59.3 g kg^{-1}, which was higher than in BA and BM (Table S1). The Ca content was 242.3 g kg^{-1} in AS, similar to that in BM.

The three byproducts also contained some heavy metals. BA was produced from the burning of crop straw, and more heavy metals were observed in BA than BM and AS. The contents of heavy metals in the three materials were all less than the standard limits for sewage sludge for application in agriculture soils either in China (GB4284-1984) or in European Community (Commission of the European Communities, 1986).

3.2. Ameliorating effects on an acid Ultisol from Anhui Province

During incubation, the pH of the Ultisol-AH decreased significantly until 20 d ($P < 0.05$) due to nitrification of NH_4^+ in

Table 1
Basic properties of Ultisols from Anhui (-AH), Hunan (-HN), and Guangdong (-GD) Provinces, and farmland and forest of Zhejiang Province (-ZJFA and –ZJFO).

Location	Utilization	pH	OM ($g\ kg^{-1}$)	pHBC ($mmol\ kg^{-1}\ pH^{-1}$)	CEC	Exch. acidity	Exchangeable base cations			
					($cmol_{(+)}\ kg^{-1}$)		K^+	Na^+	Ca^{2+}	Mg^{2+}
Ultisol-AH	Farmland	4.60	18.0	32.4	14.3	4.59	0.31	0.34	3.16	0.63
Ultisol-ZJFA	Farmland	4.20	14.3	32.7	15.1	6.79	0.45	0.08	3.30	0.74
Ultisol-ZJFO	Forest	4.52	14.5	31.7	12.4	4.07	0.72	0.12	2.28	0.69
Ultisol-HN	Farmland	4.23	11.2	28.9	11.5	5.15	0.25	0.12	1.67	0.24
Ultisol-GD	Forest	4.56	11.9	25.0	8.1	3.19	0.02	0.17	0.15	0.10

OM: organic matter; pHBC: pH buffering capacity; CEC: cation exchange capacity; Exch.: Exchangeable.