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Preparation of a modified flue gas desulphurization residue and its effect on pot sorghum growth and acidic soil amelioration

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ABSTRACT

A modified flue gas desulphurization residue (MFGDR) was prepared and its effects on sorghum growth and acidic soil amelioration were evaluated in this paper. The MFGDR was prepared by calcining a mixture of dry/semi-dry flue gas desulphurization (FGD) residue from a coal-fired power plant, sorted potash feldspar and/or limestone powder. The available nutrients from the MFGDR were determined with 4.91 wt% K^+, 1.15 wt% Mg^{2+}, 22.4 wt% Ca^{2+}, 7.01 wt% Si^{4+} and 2.07 wt% $SO_4{}^{2-}$–S in 0.1 mol L^{-1} citric acid solution. Its pH value was held at 9.60 displaying slightly alkaline. The results of sorghum pot growth in both red and crimson acidic soil for 30 days indicated that adding the MFGDR at a dosage of 2 g kg^{-1} in total soil weight would increase the growth rate of biomass by 24.3–149% (wet weight basis) and 47.3–157% (dry weight), the stem length and thickness increase by 5.75–22.1% and 4.76–30.9% in contrast with CK treatment for two test cuttings, respectively. The effect on sorghum growth was attributed to the increase of available nutrients, the enhancement of soil pH value and the reduction of aluminum toxicity in acidic soil due to the addition of the MFGDR. The experimental results also suggested that the MFGDR could be effectively used to ameliorate the acidic soil which is widely distributed throughout the southern China.

1. Introduction

Coal-fired power plants are a major energy supplier in China, accounting for about 67% of the primary energy consumption [1]. To minimize the air pollution due to SO_2 generation from the coal-fired plants, flue gas desulphurization (FGD) devices have been installed in the power plants over the past decade, resulting in the collection of significant amount of FGD residue. By the end of 2005, the capacity of power plants installed with FGD devices in China has risen to about 53 GW, with the annual FGD residue production exceeding 6.5 million tons [2]. Up to the end of 2010, the FGD residue production will be estimated to attain 42 million tons. Based on desulphurization processes, the FGD residue can be divided as wet FGD byproducts (FGDBs) and dry/semi-dry FGD residue [3–5]. The former is produced from wet FGD scrubber such as the limestone-gypsum process; the later is generated in desulphurization processes of Circulating Fluid Bed (CFB), Limestone Injection into the Furnace and Activation of Calcium oxide (LIFAC), Spray Dryer Absorber (SDA), etc. The FGDBs has been found extensive applications in construction and cement industries to manufacture wallboards, flowable filling materials, cement additives, and autoclaved concrete blocks [4]. The dry/semi-dry FGD residue generally contains FGD byproducts $CaSO_4{\cdot}2H_2O$ and $CaSO_3{\cdot}1/2H_2O$, unreacted calcium-based absorbents limestone ($CaCO_3$), dolomite ($CaMg[CO_3]_2$), calcium hydroxide ($Ca(OH)_2$) and dead-burnt calcium oxide (CaO), and a little coal fly ash [3,6,7]. How to handle the dry/semi-dry FGD residue is still posing huge challenges due to its constituent complexity. Although a small fraction of them has been utilized to make roadbed materials, dam bed materials, stall backfill materials, and ever flowable fill [8], most of them is simply disposed of in cultivated land as industrial solid waste, which will lead to secondary environmental pollution. Therefore, it is an urgent task to develop highly efficient and convenient techniques to fully utilize dry/semi-dry FGD residue. Among all the techniques currently under development, one of the most promising techniques is the application of dry/semi-dry FGD residue to agriculture [9].

Guangdong Province, PR China, is located in southern China, where serious soil acidification as well as allitization occurs universally, due to relatively high air temperature and heavy rainfall [10]. Particularly, the soil acidification has been exacerbated by the frequent occurrence of acid rain during the recent years [11–13]. Nearly 90% of cultivable lands, especially the hillside lands distributed in the northern and western regions of Guangdong Province, exhibit the characteristics of acidic soil, in which the soil

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Abbreviations: FGD, flue gas desulphurization; MFGDR, modified flue gas desulphurization residue.

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nutrients such as potassium (K), calcium (Ca), magnesium (Mg), silicon (Si), and sulfur (S) elements are seriously deficient. For instance, the deficiency of them could be as high as 90%, 50%, 22%, 22% and 54%, respectively [14]. It has been found that dry/semi-dry FGD residue contain some nutrients necessary for plant growth, including calcium, magnesium and sulfur elements. Particularly, its alkalinity can serve to neutralize soil acidity to further adjust soil physicochemical properties and prevent aluminum toxicity [9,15–18]. However, when used alone as a soil amendment, the dry/semi-dry FGD residue could also present some adverse side effects due to more enhanced pH value and calcium sulfite ($CaSO_3$) containing in it to damage plant roots. In order to solve these problems and increase nutrients of dry/semi-dry FGD residue, a modified FGD residue (MFGDR) was prepared with adding potash feldspar and/or limestone powder into dry/semi-dry FGD residue and calcing the mixture at the certain temperature under oxidized circumstance.

It is the objectives of this paper to introduce the modified flue gas desulphurization residue (MFGDR) preparation process and evaluate its effects on pot sorghum growth and acidic soil amelioration, and to provide fundamental data for ameliorating acidic soils that are widely distributed throughout the southern China.

2. Materials and methods

2.1. Materials and test methods

The dry/semi-dry FGD residue was collected from Hengyun Power Plant, Guangzhou, PR China, using a semi-dry desulphurization technology called Spray Dryer Absorber system. This residue was abbreviated to SDA residue. The potash feldspar was derived from Shandong Province, PR China, which was crushed to about 0.5 mm in diameter and some impurities such as quartz, magnetite and hematite was manually picked out from ore under a microscope and the sorted potash feldspar was then ground to 200 meshes (about 74 μm in diameter). Other chemicals limestone ($CaCO_3$) was also sieved to 200 meshes. These material compositions were analyzed using X-ray Fluorescence (XRF) spectrometer (PANalytical Axios). The $SO_3{}^{2-}$–S content in the SDA residue could be determined by iodimetry method [19,20]. Meanwhile, $SO_4{}^{2-}$–S content in the residue could also be calculated with subtracting $SO_3{}^{2-}$–S content from total S content detected by XRF method. The heavy metals Cd, Cr, Ni, Cu, Zn, Co, and Pb in the SDA residue were detected by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES, PerkinElmer, Optima 5300DV) after US EPA3050B-2000 treatment, but As was detected by Atomic Fluorescence Spectrophotometer (AFS0-830) respectively. The nutrients K, Ca, Mg, Si and S in the MFGDR were detected with Atomic Absorption Spectrophotometer (AAS, Z-5000) and Ion chromatograph (ICS-1000) after being dissolved in water or 0.1 mol L^{-1} citric acid solutions. The simultaneous Thermogravimetry (TG) and Differential Scanning Calorimetry (DSC) in the temperature range from room temperature to 1050 °C were performed on STA449C, Netzseh, Germany. Its heating atmosphere was air and the heating rate was 10 K/min. Their particle sizes and specific surface area were measured by Size Distribution Analyzer (Horiba LA-920).

Table 1
The major content of the SDA residue and the potash feldspar powder (g kg^{-1}).

Ions types	SDA residue	Potash feldspar powder
$SO_4{}^{2-}$–S	16.4	–
$SO_3{}^{2-}$–S	86.0	–
Ca^{2+}	268	0.07
Al^{3+}	41.4	81.6
Si^{4+}	46.2	328
Fe^{3+}	7.27	0.98
Mg^{2+}	33.0	0.66
K^{+}	1.33	107
Na^{+}	1.63	6.31

Table 2
Comparison between control standards of concentrations of heavy metals in fly ash for agricultural use (GB8173-87) and our measured value in the SDA residue (μg kg^{-1}).

Elements	Control standards in acidic soil	Measured value in the SDA residue
Total cadmium	5	0.12
Total arsenic	75	1.30
Total molybdenum	10	1.20
Total selenium	15	2.55
Total nickel	200	5.87
Total chromium	250	6.40
Total copper	250	12.6
Total lead	250	20.4
pH value	10.0	10.6

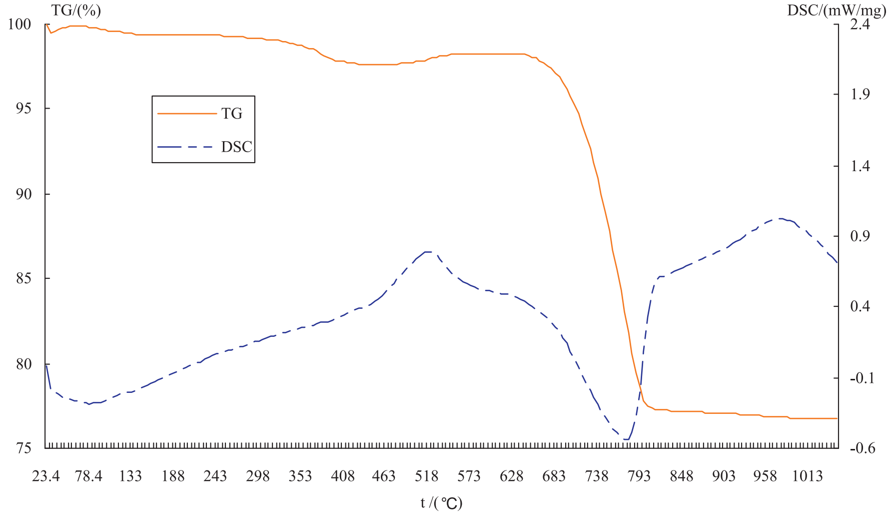

Fig. 1. TG-DCS curve in the process of the MFGDR preparation.

2.2. Soil and test methods

Two types of soil, located in hillside land regions in Guangdong Province, PR China, known as red and crimson soil, were collected from Langtian Town, Baiyun District, Guangzhou (Latitude 23°23′7″N, Longitude 113°24′22″E) and Luotan Town, Lechang City, Guangdong Province (Latitude 25°9′33″N, Longitude 113°28′1″E) respectively. Air-dried soil samples from the two regions were crushed and sieved through a 2 mm prior to their characterization and use in subsequent experiment. In the whole planting seasons, the soil bulk density was measured using cutting ring method, while the field water capacity was measured by Wilcox method. The major elements content in soil was detected by XRF methods as described above, the content of active aluminum dissolved in the soil was determined using the methods of chemical analysis to measure forest soil water content (LY/T1257-1999). The content of organic matters in each soil samples was determined by means of potassium dichromate titration. The nutrient availabilities of N, P and K were also measured using Stal-2 type soil analyzer. The pH value (1:1 soil and distilled water proportion by weight) was measured with PHS-25 type acidity instrument.

Table 3
The nutrients content of the MFGDR (wt%).

Nutrients	Water solubility	Citrus solubility (0.1 mol L^{-1})
K^+	4.91	5.05
Mg^{2+}	0.02	1.15
Ca^{2+}	1.32	22.4
Si^{4+}	0.05	7.01
$SO_4{}^{2-}$–S	2.02	2.07

Table 4
The physicochemical properties of the red soil and crimson soil used in the study.

Soil types	Red soil	Crimson soil
Organic matter/%	0.51 ± 0.09 a	0.24 ± 0.07 b
Alkali-hydrolyzable nitrogen/mg kg^{-1}	21.1 ± 1.4 a	13.0 ± 2.4 b
Phosphorus/mg kg^{-1}	2.40 ± 0.25 a	2.90 ± 0.16 a
Potassium/mg kg^{-1}	22.9 ± 1.7 b	63.9 ± 1.5 a
Bulk density/g cm^{-3}	1.52 ± 0.09 a	1.31 ± 0.10 b
Water field capacity/%	14.9 ± 0.4 b	19.8 ± 2.2 a
pH value	4.90 ± 0.1 a	5.10 ± 0.1 a

Values followed by the same letter in the same column are not significantly different at the 0.05% level.

2.3. Pot growing design and test methods

Sorghum (the Variety Xiong Yao 253), supplied by Guangdong Academy of Agriculture, was selected as the plant species for pot incubation test. The MFGDR dosage of 2 g kg^{-1} in total soil weight was added into the wet soil inside the pot. The effect on sorghum plant growth and soil amelioration was recorded and analyzed. All data were evaluated and compared with those not treated using any soil amendment (CK), or treated using a 2 g kg^{-1} dosage of lime hydrate. The pot growing design was described as follows: approx-

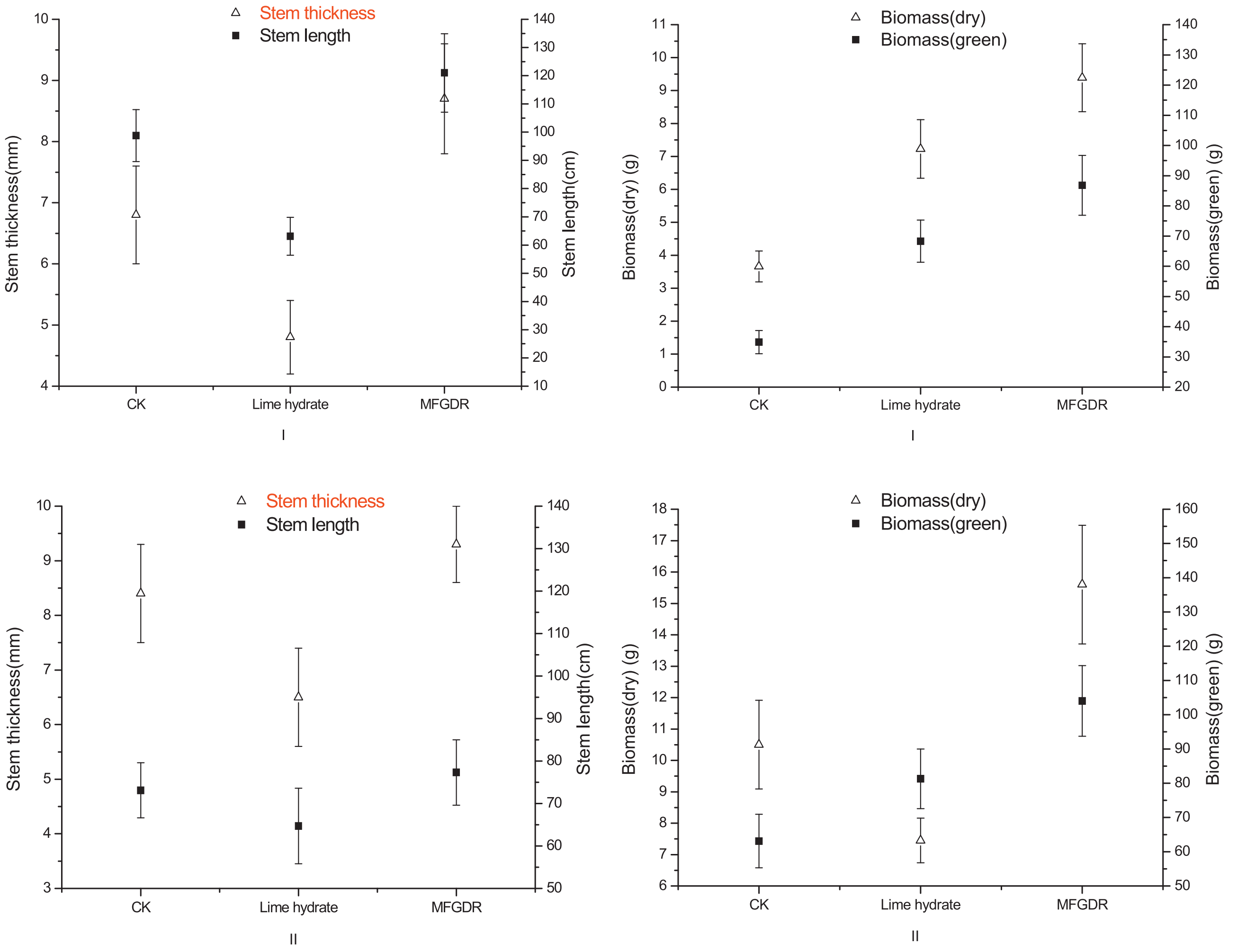

Fig. 2. The sorghum growth indices after 30 days in the red soil for two test cuttings (I and II).

imately 7.50 kg soil was transferred into each round pot (30 cm upper diameter, 21 cm bottom diameter, and 22 cm height), and treated with 0.75 g:0.75 g:0.75 g mass ratios of N, P and K fertilizers, including 0.16 g of carbamide, 3.20 g of diammonium phosphate and 1.43 g of potassium chloride. Three treatments were carried out in this study: (1) CK/NPK (without any soil amendment); (2) lime hydrate/NPK (a 2 g kg^{-1} dosage of lime hydrate amending with soil); (3) MFGDR/NPK (a 2 g kg^{-1} dosage of the MFGDR amending with soil). The procedure of fertilizer addition was as follows: first, 3.20 g of diammonium phosphate and 1.43 g of potassium chloride were well mixed with 7.50 kg of acidic soil. Then, one-third of the treated soil mixture was placed at the bottom of each pot, while the remaining soil was well mixed with either lime hydrate or the MFGDR, except those for CK/NPK treatment. These soil mixtures were transferred to the upper layers of appropriate test pots. An additional fertilizer of 0.16 g carbamide was also applied to all pots in two stages. In the first stage, an aqueous solution containing 0.05 g carbamide fertilizer was sprayed onto the plant foliage, while in the second stage, the remaining 0.10 g carbamide fertilizer was divided into five equal portions and dissolved into water, and then sprayed for three times over a period of 15 days. Two planting tests have been carried out in sequence over a 60-day period. In each test, sorghum was grown for 30 days. Six sprouted sorghums were planted in each pot, and five pots were arranged for the same treatment. The indices of sorghum pot growth, including biomass, stem length, and stem thickness were measured using conventional methods, and the resulting data were statistically analyzed using Statistical Analysis System after the sorghum seeds were planted for 30 days in two successive cuttings [21]. The physiochemical parameters of both soils were determined by methods illustrated in Section 2.2 before and after the pot experiment.

3. Results and discussion

3.1. Physicochemical properties of the SDA residue and the potash feldspar

The major content of the SDA residue and the potash feldspar powder was illustrated in Table 1. In the SDA residue, major ions included $SO_4{}^{2-}$–S, $SO_3{}^{2-}$–S, Ca^{2+}, Al^{3+}, Si^{4+} and Mg^{2+}. While in the potash feldspar powder, the major ions included K^+, Al^{3+}, Si^{4+} and Na^+. The K^+ content of 107 g kg^{-1} in the potash feldspar powder indicated that the purity of potash feldspar attain 75.5%. The concentrations of heavy metals in the SDA residue are illustrated in Table 2. As seen in Table 2, the concentrations are much lower than the value of control standards in fly ash for agricultural use (GB8173-87) in acidic soil, indicating that the SDA residue can be applied safely as soil amendment. The residue appeared off-white and loose powder under dry conditions with an average particle diameter of 11.8 μm and the bulk density of 0.67 g cm^{-3}.

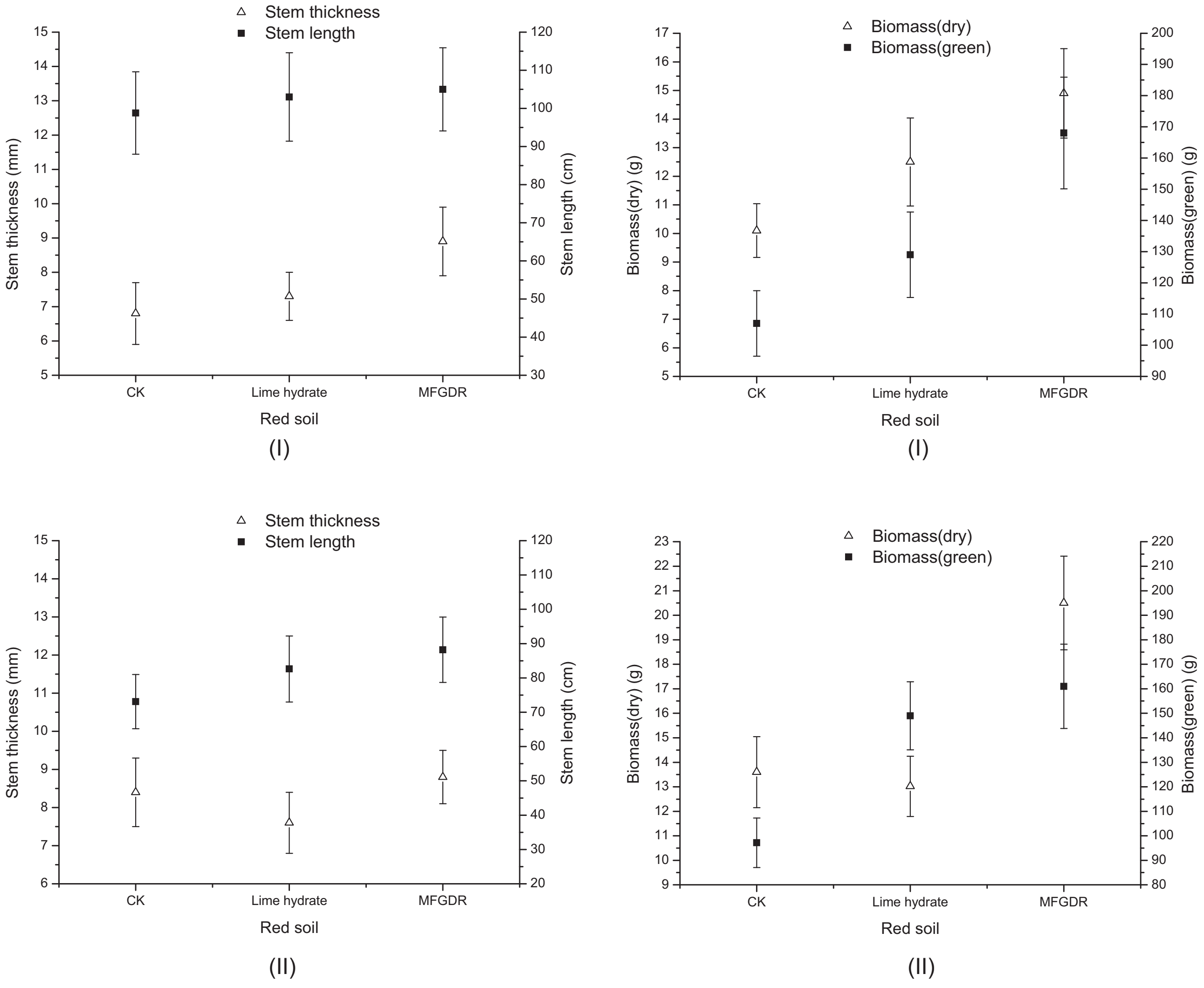

Fig. 3. The sorghum growth indices after 30 days in the crimson soil for two test cuttings (I and II).

Its BET surface area and pH value were 2.76 $m^2 g^{-1}$ and 10.6, respectively.

3.2. Preparation of the MFGDR

The MFGDR was prepared by calcing a mixture of the SDA residue, the sorted potash feldspar, and/or chemicals limestone powder $CaCO_3$. The raw materials were first dried at 105 °C in an oven until a constant weight was obtained. Each material was then weighed and added into the mixer based on their molar ratio according to the following equation:

$$2KAlSi_3O_8 + CaSO_4 + 14CaO = K_2SO_4 + Ca_3Al_2O_6 + 6Ca_2SiO_4 \quad (1)$$

In the SDA residue, the total molar quantity of calcium sulfate was calculated based on gypsum ($CaSO_4{\cdot}2H_2O$) and $CaSO_3{\cdot}1/2H_2O$ and the total molar quantity of $CaCO_3$, $Ca(OH)_2$ and $CaMg[CO_3]_2$ in the SDA residue was calculated as CaO. If total molar quantity of CaO was insufficient, a small amount of limestone powder ($CaCO_3$) should be added into the mixture to meet the material equilibrium of Eq. (1). Sufficiant water, about 40 wt% of total raw material, was also added into the mixer to allow adequate stirring. The resulting mixture was then processed into spherical agglomerates with a diameter of 2 cm at a semi-plastic stage. The spherical agglomerates, after being dried, were then calcined for 1.5 h at 1000 °C in a muffle furnace.

In the process of the MFGDR preparation, TG-DCS test was also conducted and the result was shown as in Fig. 1. When temperature was in the range from room temperature, 23.4 °C–450 °C, the TG curve appeared a slight downtrend, which was probably attributed to free water evaporation at about 100 °C, and then dehydration of $CaSO_4{\cdot}2H_2O$ forming $CaSO_4{\cdot}1/2H_2O$, also known as calcined gypsum, in the temperature range of 109–130 °C, and finally completely losing all crystal water to form II-type $CaSO_4$ at above 205 °C [22]. In the temperature range from 450 to 580 °C, however, the TG curve turned to be almost flat, indicating the oxidation of $CaSO_3$ to $CaSO_4$ with slight weight increment. This explanation can be verified from DSC curve where an exothermic reaction occurred obviously. In the mean time, $Ca(OH)_2$ was decomposed into CaO and water vapor at about 580 °C. The summation is the reason that the TG curve remained a nearly horizontal line until 650 °C. Theoretically, $CaCO_3$ should be decomposed into CaO and CO_2 at 897 °C. In the temperature range from 650 to 820 °C, nevertheless, a sharp fall occurred in the TG curve with a total material weight loss of about 22%, which implied that $CaCO_3$ was decomposed into CaO and CO_2 at a lower temperature (about 780 °C) with an endothermic reaction shown in DSC curve because of constituent complexity. Simultaneously, unreacted $CaMg[CO_3]_2$ in the SDA residue was also dessociated into CaO, MgO and CO_2 in a temperature range of 740–900 °C. Consequently, the exothermic reaction (1), calcining the mixture of all raw materials, occurred at 960 °C resulting in the target product.

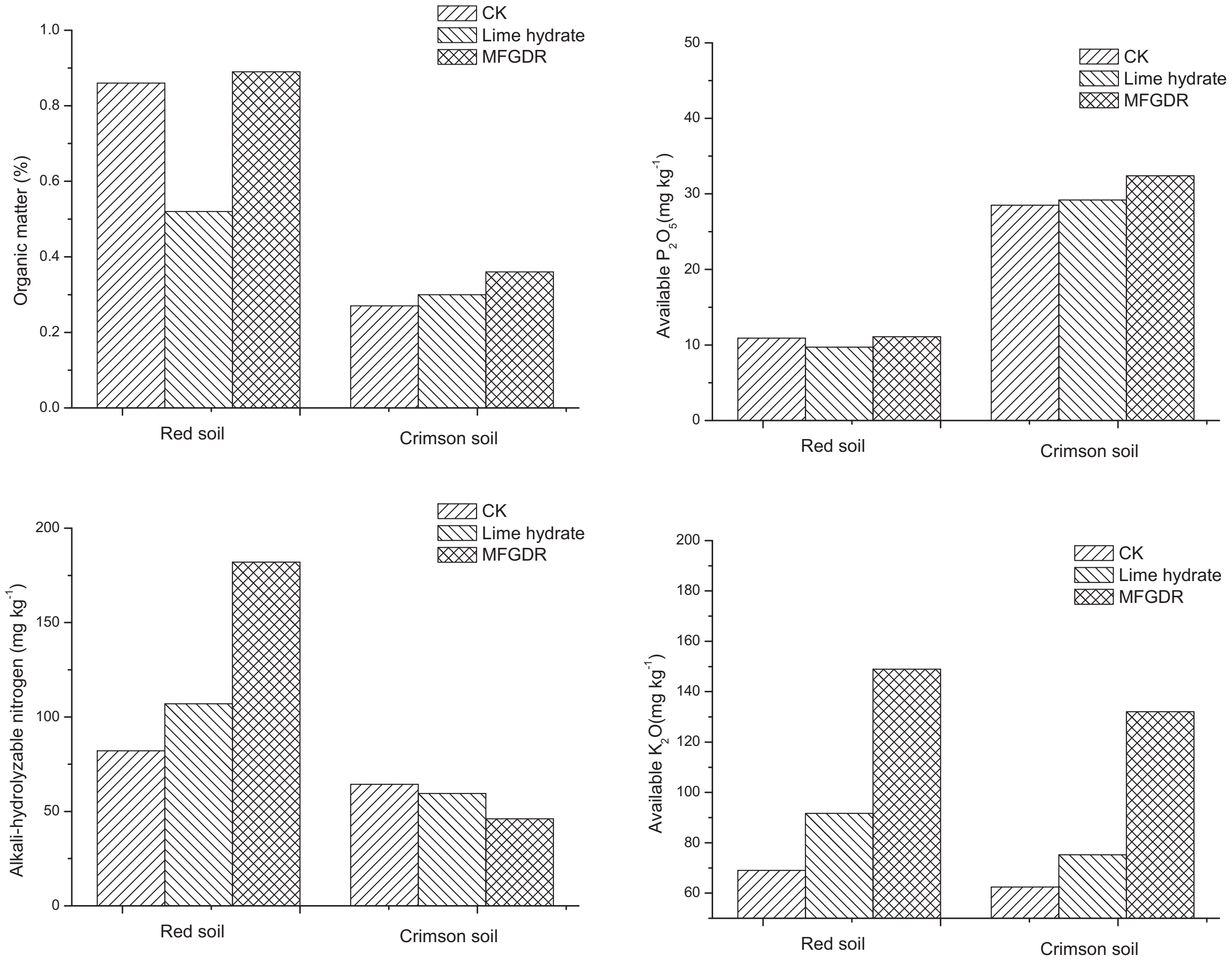

Fig. 4. The physicochemical properties of the planted soil after amelioration.

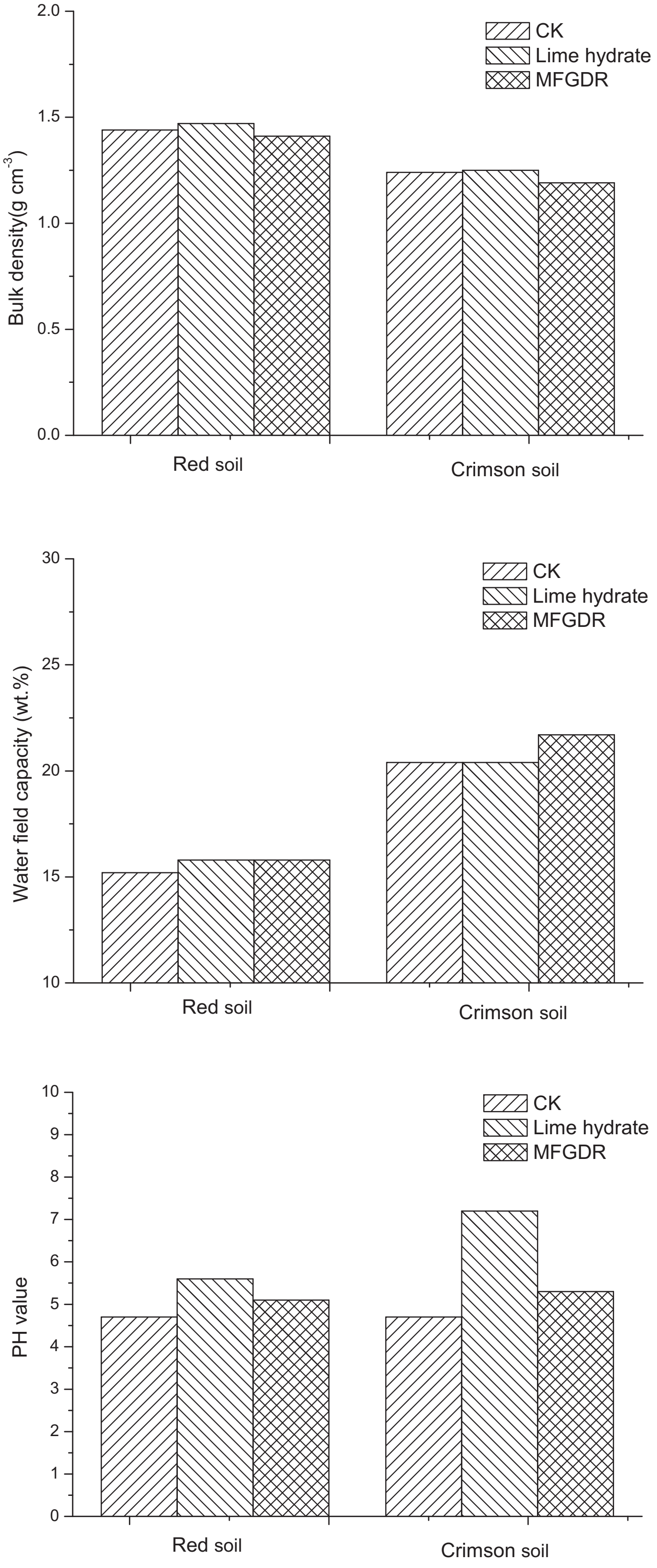

Fig. 4. (*Continued*).

The purpose of calcination was to decompose the potash feldspar into K_2SO_4 and active SiO_2 with the aid of the SDA residue and/or limestone powder. The optimal operating conditions of the reaction process have been reported in our previous paper [23], and the content of nutrients in the MFGDR was shown in Table 3. The target product, the MFGDR, contained 4.91 wt% K^+, 1.15 wt% Mg^{2+}, 22.4 wt% Ca^{2+}, 7.01 wt% Si^{4+} and 2.07 wt% $SO_4{}^{2-}$–S measured by dissolving it in 0.1 mol L^{-1} citric acid solution. Both the nutrients and its alkalinity (pH 9.60) could make up for the nutrients deficiency and neutralize acidity of the soil in the southern China effectively.

3.3. Sorghum growth

Two types of soil, red soil and crimson soil, were applied for sorghum growth test. The physicochemical properties of both soils were summarized in Table 4. The content of organic matter in red soil or crimson soil is only 0.51% and 0.24%, which is much lower than 1% of the critical value to inhibit plant growth [24]. The content of alkali-hydrolyzable nitrogen, phosphorus and potassium in soil also appears serious deficiency by contrast with critical values 100, 30 and 80 mg kg^{-1} to inhibit plant growth [24]. Both soils had lower pH value (pH 4.90 and 5.10), suggesting the serious soil acidification and allitization.

The sorghum growth indices after 30 days were shown in Fig. 2 and Fig. 3 for two test cuttings. The growth rate was calculated by:

$$\text{Growth rate\%} = \frac{[\text{the growth amount of treated sorghum} - \text{the growth amount of the control}]}{[\text{the growth amount of the control}]} \times 100\% \qquad (2)$$

*The growth amount includes stem length, thickness, and biomass (green/dry).

As seen from Figs. 2 and 3, the sorghum treated with the MFGDR grew the best, followed by the sorghum treated with the lime hydrate, while sorghum growth in the CK treatment was the poorest. Specifically, the growth rate of the stem length and the stem thickness increased by 5.75–22.05%, and 4.76–30.9%, while the growth rate of biomass, during two successive cuttings, substantially increased by 24.3–149% (wet weight basis) and 47.3–157% (dry weight) respectively after the seeds have been planted for 30 days. Particularly, the increase in sorghum growth rate was more significant in the red soil than in the crimson soil. Further, the growth rate during the cutting (I) was more evident than that during the cutting (II) seen in Fig. 2 and Fig. 3. This is probably due to the fact that the content of available nutrients in the MFGDR was the highest, containing significant amount of nutrients of K, Ca, Si, Mg and S, while the content of these nutrients in lime hydrate and CK was much lower or even negligible. And it can be seen that the content of available nutrients in cutting (I) was higher than those in cutting (II).

3.4. Acidic soil amelioration

The physicochemical properties of acidic soil after amelioration were summarized in Fig. 4. The content of organic matter, alkali-hydrolyzable nitrogen and soil bulk density in the red soil was relative higher than those in the crimson soil. But the content of available P_2O_5 and water field capacity in the red soil was much lower than those in crimson soil. The content of available K_2O and pH value in both type of soil was almost identical. The most distinctive amelioration was obtained by applying the MFGDR in comparison with that of CK and lime hydrate. The content of organic matter, alkali-hydrolyzable nitrogen, available P_2O_5 and K_2O increased significantly after it was treated by the MFGDR. For example, the content of alkali-hydrolyzable nitrogen and available K_2O in the MFGDR treated red soil was over 2-fold than those in CK treated. This achievement can be attributed to the significant amount of nutrients K, Ca, Si, Mg, and S existing in the MFGDR and the enhancement of soil pH value. Active calcium containing in it could promote the enrichment of phosphate anion in soil and prohibit available P_2O_5 from running off. The enhanced pH value after the MFGDR treatment could greatly improve acidic soil microenvironment and gradually increase the content of organic matter. However, the amelioration effects in the crimson soil were less effective than that in red soil. This could be due to the relatively higher content of organic matter and alkali-hydrolyzable nitrogen and much lower pH value in the red soil. Nevertheless, the content of organic matter in both soils was still lower than 1% of critical value to inhibit plant growth. Hence, in order to further improve plant growth, some organic fertilizer should be applied to some extent. In addition, the content of alkali-hydrolyzable nitrogen in the crimson soil decreased from 64.3 to 59.5 and to 46.0 mg kg^{-1} respectively after applying lime hydrate and the MFGDR. This drop could be construed as the loss of alkali-hydrolyzable nitrogen when soil pH value enhanced a little after amelioration.

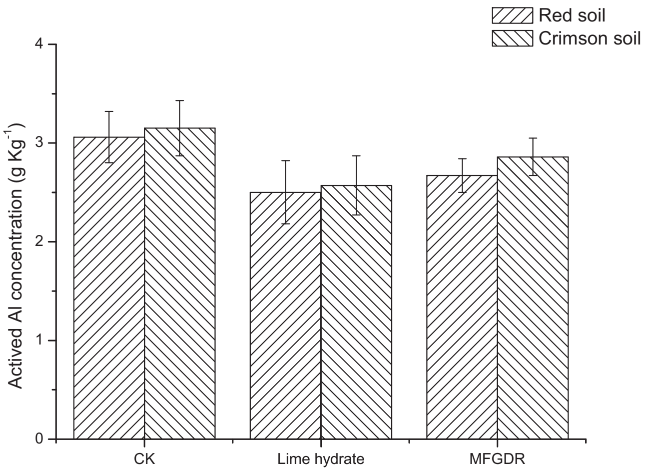

Fig. 5. The active Al concentrations in the soil after the addition of the soil amendments.

In southern China, the most soil has a lower pH value and this inhibits the plant growth. As shown in Fig. 4, the pH values of both red and crimson soils were lower, exhibiting the characteristics of acidic soil. However, after the MFGDR amelioration, the pH values of both soils increased to 5.10–5.30 from the original value of 4.90–5.10, demonstrating the ability of appropriate amelioration to neutralize soil acidity. The bulk density of the soils decreased by 2.08–4.03% while the field water capacities increased by 3.94–6.52%. Generally, a lower bulk density makes the soil looser and more porous, thereby, facilitating the transport and migration of water and available nutrient, air and heat flow, and consequently it promotes plant root growth. And higher field water capacity can be beneficial to plant growth and can improve the production of crops. On the whole, the physicochemical properties of acidic soil after the MFGDR amelioration have enormously improved in both soil types.The active aluminum could release from soil at lower soil pH value. The dissolved aluminum would cause serious problems during plant growth, such as the inflation of plant root tip, the reduction of lateral roots and root hairs. As a result, it may lead to the root defection and even cause root death. However, it can be noticed from Fig. 5 that the situation could be improved by applying the soil amendment to acidic soil. The active aluminum was observed to decrease by 9.12–12.7% after the addition of the MFGDR, thereby decreasing the toxic effects of aluminum on plant growth. This effect is mainly attributed to the enhancement of pH value and $SO_4{}^{2-}$ content upon the addition of the MFGDR forming $AlSO_4{}^+$ complex and thereby decreasing the level of toxic aluminum in plant root zone [16–18].

4. Conclusions

The FGD residue is an industrial solid waste derived from SO_2 pollution control of coal-fired power plants. A novel technique to prepare the MFGDR was reported in this work by calcining a mixture of dry/semi-dry FGD residue, potash feldspar and/or chemicals limestone powder. The effects of sorghum growth with adding the MFGDR into acidic soil were evaluated. The pot experiments indicated that the MFGDR exhibited positive effects on sorghum growth, and on ameliorating the nutrients deficiency and acidity of these soils that are widely distributed throughout the southern China. The main conclusions were drawn as follows:

1. The prepared MFGDR contained nutrients of 4.91 wt% K^+, 1.15 wt% Mg^{2+}, 22.4 wt% Ca^{2+}, 7.01 wt% Si^{4+} and 2.07 wt% $SO_4{}^{2-}$–S determined after dissolving in 0.1 mol L^{-1} citric acid solution and emerged slightly alkaline characteristics (pH 9.60).
2. The concentrations of heavy metals in the SDA residue were far lower than the value of control standards in fly ash for agricultural use (GB8173-87) in acidic soil, which indicated that the SDA residue can be applied as soil amendment safely.
3. The results of sorghum pot growing in both the red and crimson acidic soil for 30 days indicated that adding the MFGDR at a dosage of 2 g kg^{-1} in total soil weight would increase the growth rate of biomass by 24.3–149% (wet weight basis) and 47.3–157% (dry weight), the stem length and thickness increase by 5.75–22.0% and 4.76–30.9% in contrast with CK treatment for two test cuttings, respectively.
4. By applying the MFGDR, the acidity of the red and crimson soil caused by weathering and leaching, and chronic acid rain in southern China can be neutralized or balanced, the amount of organic matter, available nutrients and field water capacity were observed to be increased, the soil bulk density was also greatly decreased, and the toxic effects of aluminum on plant growth can be alleviated effectively.

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