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Amelioration of alkali soil using flue gas desulfurization byproducts: Productivity and environmental quality

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Flue gas desulfurization byproducts used to ameliorate alkali soils increased plant growth and did not contaminate soils and plants grown in the soil.

Abstract

In this study, flue gas desulfurization (FGD) byproducts are used to ameliorate alkali soil. The average application rates for soils with low exchangeable sodium percentage (ESP), mid ESP, and high ESP are 20.9, 30.6, and 59.3 Mg ha^{-1}, respectively. The experimental results obtained for 3 consecutive years reveal that the emergence ratios and yields of the crops were 1.1–7.6 times and 1.1–13.9 times those of the untreated control, respectively. The concentrations of Cr, Pb, Cd, As, and Hg in the treated soils are far below the background values stipulated by the Environmental Quality Standard for Soils (GB15618-1995). Their concentrations in the seeds of corn and alfalfa grown in the treated soils are far below the tolerance limits regulated by National Food Standards of China. The results of this research demonstrate that the amelioration of alkali soils using FGD byproducts is promising.

Keywords: Flue gas desulfurization byproducts; Alkali soil; Amelioration; Heavy metals; Environmental quality

1. Introduction

Wet flue gas desulfurization (FGD) is the dominant technology used in the control of SO_2 emissions from coal-fired power plants. The major byproduct of the process is $CaSO_4$ or a mixture of $CaSO_3$ and $CaSO_4$ (herein referred to as FGD byproducts). With the rapid development of the energy and power industries in China, the installed capacity of power plants with FGD devices, and therefore the amount of FGD byproduct, is expected to increase rapidly. By the end of 2005, the installed capacity of power plants in China with FGD devices was about 53 GW, and the annual production of FGD byproducts was about 6.5 million tons. According to the National Development Program of China, the installed capacity of power plants with FGD devices will be 200 GW by 2010, with an annual production of FGD byproducts of 40 million tons; by 2020, these figures will be 530 GW and 90 million tons. As FGD byproducts contain large amounts of moisture and ash, they can only be used as building gypsum after purification and dehydration; this represents an economic disadvantage compared with natural gypsum produced in China. If the FGD byproducts were to be directly disposed of without any utilization or treatment, a vast area of land would be required. Such an approach would be a waste of valuable land resources and represent a potential threat of secondary pollution to the environment.

Significantly, there are large areas of alkali soil in China. These soils are unsuitable for growing agricultural crops, and some such soils are unable to support any plant growth

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whatsoever. These barren lands severely limit agriculture production in China and have a negative impact on the ecosystem. According to statistics provided by the Ministry of Land and Resource in China, there are 346 000 km^2 (34.6 million ha) of alkali soils in the northwest, north, northeast, and coastal areas of China; of these areas, soils with heavy exchangeable sodium percentage (ESP) make up about 92 000 km^2. The amelioration of alkali soils over such an enormous area is one of the greatest challenges facing Chinese agriculture. Gypsum has been known to be an amelioration agent for alkali soil for more than 100 years; however, it has been used only rarely because of the high cost involved in the exploitation, transportation, and crushing of natural gypsum. Although the main component of FGD byproducts is $CaSO_4$, they also contain about 10% alkali material; however, it is uncertain as to whether FGD byproducts with a pH of 7.7–10.03 (Xu et al., 2005) are suitable for use in the amelioration of alkali soil. In fact, FGD byproducts have been used as a type of modifier for acid soil in the US and other countries (Chen et al., 2001; Li et al., 2004). Professor Matsumoto of Tokyo University firstly proposed the amelioration of alkali soils using FGD byproducts (Matsumoto, 1998).

The amelioration of alkali soil using FGD byproducts would make use of tens of millions of tons of FGD byproducts, thereby boosting the application of FGD technology and the development of the pollution-control industry. In addition, the huge extent of barren alkali soil ameliorated by the FGD byproducts would then be suitable for growing agricultural crops; this would be of significant benefit to both agricultural development and improvement to local ecosystems.

2. Materials and methods

Field studies were conducted on alkali soil upon the Tumochuan Plain, Huhhot, Inner Mongolia. There are 2 experimental fields. For the No. 1 experimental fields, the total area is about 2.67 ha; soil ESP ranges from 6.1 to 78.4%; and the soil pH is 8.5–9.77. For the No. 2 experimental fields, the total area is 6.67 ha; soil ESP ranges from 40 to 50%; and the soil pH is 9.4–9.5.

The concentrations of the main elements in the FGD byproducts were determined using ICP-AES, while the concentrations of certain heavy metals (Pb, Cd, Cr, Cu, Ni, and Se) were determined using ICP-MS, and As and Hg were determined using ICP-AES with a subsequent check using atomic fluorescence spectrophotometry (AFS). The chemical composition of the FGD byproducts is shown in Table 1.

The No. 1 experimental fields were divided into 3 types according to soil ESP: i.e. low ESP fields (soil ESP of 6.1–20%), mid ESP fields (soil ESP of 20–30%), and high ESP fields (soil ESP of 30–78.4%). The average application rates for the different types of fields are given in Table 2. The average application rates for No. 2 experimental fields were 33 Mg ha^{-1}. Control fields were also set for each of the three types of No. 1 experimental fields and No. 2 experimental fields. The treatments for the experimental and control fields were the same except for the application of FGD byproducts.

Table 1
Chemical composition of the flue gas desulfurization byproducts used to ameliorate alkali soil in the present study

Major elements (g kg^{-1})							
Ca	S	Si	Mg	Al			
269.1	205.4	10.1	4.5	3.3			
Trace elements (mg kg^{-1})							
Pb	Cd	Cr	As	Se	Ni	Cu	Hg
4.08	<0.05	9.70	1.08	0.84	7.82	11.4	0.658

Table 2
Average application rates of FGD byproducts to the No.1 experimentation fields

Experimental fields	Low ESP	Mid ESP	High ESP
Soil ESP	6.1–20%	20–30%	30–78.4%
Average application rates of FGD byproducts (Mg ha^{-1})	20.9	30.6	59.3

For No. 1 experimental fields, the FGD byproducts were added to the soil in a single application during the spring of 2001 and fully mixed with the surface (0–20 cm) soil. In 2001, mignonette was planted in the low ESP fields, forage corn was planted in the mid ESP fields, and the high ESP fields were left unplanted. Forage corn was planted in all types of fields in 2002, and food corn was planted in all types of fields in 2003. For No. 2 experimental fields, the FGD byproducts were added to the soil in a single application in July 2004 and fully mixed with the surface (0–20 cm) soil. Alfalfa was planted in the same year. The field treatments for both fields included fertilizing, weeding, and irrigation in accordance with local agricultural practices.

In October 2003, samples of soil and corn seed were collected from the No. 1 experimental fields and control fields with mid and high soil ESPs to determine the concentrations of heavy metals. In September 2005, samples of soil and alfalfa were collected from No. 2 experimental fields. For soil samples, total Pb and total Cd were determined using graphite furnace atomic absorption spectrophotometry according to National Standards for Soil Quality GB/T17141-1997, total Cd was determined using flame atomic absorption spectrophotometry according to GB/T17138-1997, total Hg was determined using AFS, and total As was determined using silver diethyldithiocarbamate spectrophotometry. For plant samples, Pb was determined according to GB/T5009.12-2003 (determination of lead in food), Cd was determined according to GB/T5009.15-2003 (determination of cadmium in foods), As was determined according to GB/T5009.11-2003 (determination of total arsenic and abio-arsenic in foods), Cr was determined according to GB/T5009.123-2003 (determination of chromium in foods), and Hg was determined using AFS.

3. Results and discussion

In 2001, the emergence ratio and yield of mignonette were 1.2 times and 4.2 times those of the untreated control, respectively, and the emergence ratio and yield of forage corn were 5.6 times and 7.6 times those of the untreated control (Table 3). In 2002, the emergence ratio and yield of forage corn were 1.1–7.6 times and 1.1–6.8 times those of the untreated control, respectively, and the emergence ratio and yield of food corn were 1.1–3.7 times and 1.6–13.9 times those of the untreated control, respectively, depending on the soil ESP. The emergence ratios and yields of crops in soils with varying ESP are presented in Figs. 1–4.

Table 3
Emergence ratios and yields for 2001

	Fields with low soil ESP		Fields with mid soil ESP	
	Emergence ratio (%)	Yields (kg ha^{-1})	Emergence ratio (%)	Yields (kg ha^{-1})
Control	65	1140	10.8	8600
Experimental	80	4782	60.3	65 500

Mignonette was planted in the low ESP fields, forage corn was planted in the mid ESP fields.