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Long-term performance of flue gas desulfurization gypsum in a large-scale application in a saline-alkali wasteland in northwest China

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ABSTRACT

Flue gas desulfurization (FGD) gypsum has been used as an amendment to reduce soil salinization and alkalinization worldwide. However, the effective and safe use of FGD gypsum in agricultural land is still debatable in some countries, although many studies have reported its beneficial effects on soil management. Therefore, a study was conducted on wasteland (600 ha) close to the Yellow River in Inner Mongolia, China. The main aim of this research was to evaluate the long-term effects of FGD gypsum application on soil salinity and sodicity, crop production and heavy metals in soils and crops. The results showed that soil pH and exchangeable sodium percentage (ESP) in topsoil (0–20 cm) decreased dramatically during the first year, while a substantial reduction of electrical conductivity (EC) occurred during the second year after FGD gypsum application. Four years later, the EC, pH and ESP levels in reclaimed soils were 58.3%, 92.2% and 95.2% lower, respectively, than those in the initial soils. In addition, the FGD gypsum application altered the major water-soluble ion composition of dissolved salts, showing high Ca^{2+} and $SO_4{}^{2-}$ concentrations and low concentrations of $HCO_3{}^{-}$, $CO_3{}^{2-}$ and other water-soluble ions. After reclamation, the crop yields gradually increased over time, and the sunflower and corn yields reached more than 90% of the levels of local production of these crops. Moreover, the heavy metal (Cd, As, Pb, Hg and Cr) contents of the FGD gypsum-reclaimed soils and crops was far lower than the established standards and below detectable limits. This study provides convincing evidence of the benefits of the large-scale use of FGD gypsum to reclaim saline-alkali soils.

1. Introduction

Flue gas desulfurization (FGD) gypsum is a by-product of the wet FGD process of coal-fired power plants (Chen et al., 2001). Its main content is $CaSO_4$ or a mixture of $CaSO_3$ and $CaSO_4$. To meet clean air standards, almost all coal-fired power plants are required to be equipped with a desulfurization facility to remove SO_2 from the flue gas (Wang et al., 2017). As a result, large amounts of FGD gypsum are being produced and stored in landfill plots and/or mountains (Clark et al., 2001). In China, for example, the annual production of FGD gypsum was 6.5 Mt in 2005 and increased to 75.5 Mt in 2013, according to the China Electricity Council (Pan et al., 2015). As regulations of SO_2 emissions limits become increasingly strict (SEPA, 1997), increasingly greater quantities of FGD gypsum will be produced in the future. This solid waste is able to create environmental problems and undesirable legacies for future generations (Clark et al., 2001). However, a reasonable utilization of FGD gypsum may shift the value of this waste material and harness and improve its surroundings (Wang et al., 2017).

FGD gypsum can be used as a substitute for mined gypsum in many applications, e.g., construction, food and agriculture (Clark et al., 2001; Wang et al., 2008), due to its relatively high content of $CaSO_4$ and smaller particle size (Dontsova et al., 2005). Surveys conducted annually by the American Coal Ash Association on coal combustion products and use showed that 60% of FGD gypsum was being used beneficially in 2008 (Baligar et al., 2011). In the US, approximately 98% of FGD gypsum was used in wallboard products for residential and commercial buildings, as an ingredient in Portland cement, and as a filler ingredient in some foods and toothpaste; in contrast, only

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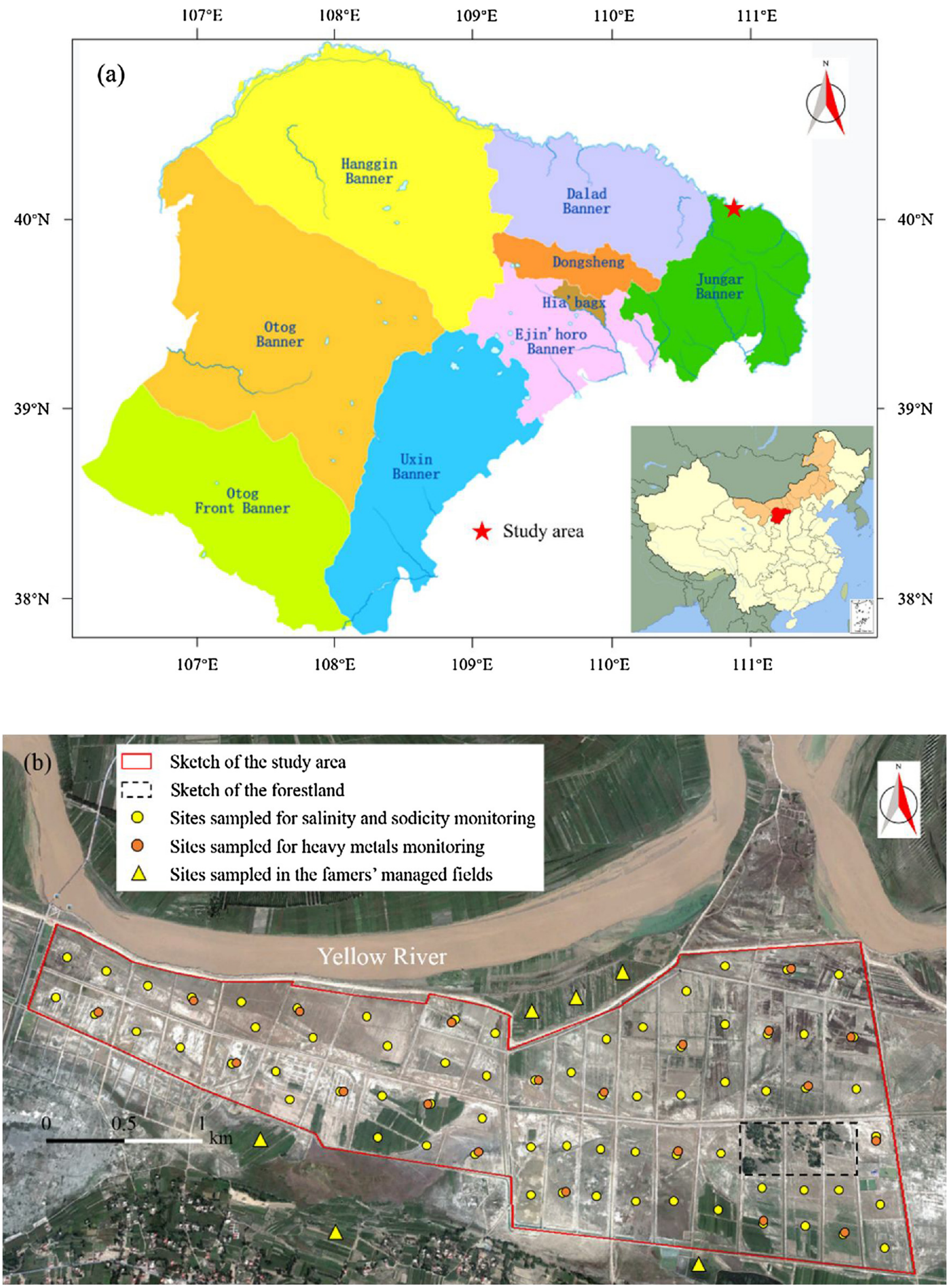

Fig. 1. Location of the study area (a) and distribution of sampling sites (b).

approximately 2% was used in agriculture (US EPA, 2008). In China, there is a much lower proportion of agricultural use, regardless of the relatively high comprehensive utilization ratio of FGD gypsum over the past decade (approximately 69%) (Li et al., 2015). For most uses, FGD gypsum must be purified and dehydrated because it contains large amounts of moisture and ash (Wang et al., 2008). In comparison, soils have large buffering and diluting effects on FGD gypsum (Clark et al., 2001); thus, it can be used directly in agriculture. In addition, it can provide mineral nutrients (Ca, S, K and B) that are essential to plants (Clark et al., 2001). Consequently, FGD gypsum has gradually come into use on agricultural land. However, extreme rainfall events and high rates of runoff or non-suitable land management could induce high losses of downslope (Martínez-Hernández et al., 2017; Rodrigo-Comino et al., 2017; Serpa et al., 2017).

Previous studies have provided a good review of the agricultural application of FGD gypsum (Clark et al., 2001; Dick, 2006; Wang et al.,