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Amendment with industrial and agricultural wastes reduces surface-water nutrient loss and storage of dissolved greenhouse gases in a subtropical paddy field

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ABSTRACT

Paddy fields are important ecosystems for supporting human life. They are frequently fertilized more than necessary for providing high yields of rice (*Oryza sativa*), so nutrients are lost by leaching into aquatic ecosystems, which become eutrophic. Rice production is also an important source of greenhouse gases (GHGs). Mitigation of the nutrient losses and GHG emissions from paddy fields is crucial both for the sustainability of rice production and the reduction of adverse environmental effects. We examined the effects of the application of biochar, steel slag, shell slag, gypsum slag and silicate and calcium slag (produced from steel slag) on water nutrient concentrations and dissolved GHGs in a paddy field in subtropical southeastern China, one of the most important areas of rice production in the world. The concentrations of total dissolved nitrogen (TN) and total dissolved phosphorus (TP) in the surface water were lower in plots amended with shell slag than the control plots. Mean porewater TN and TP concentrations, however, were higher, and the mean porewater dissolved CO_2 concentration was 68% lower in the plots amended with silicate and calcium slag than the control plots. Mean dissolved CH_4 concentrations were 92 and 70% lower in the plots amended with gypsum slag and silicate and calcium slag, respectively. Mean dissolved N_2O concentrations did not differ significantly among all plots. The concentrations of dissolved CO_2 and CH_4 were correlated with their production and emission. The concentration of dissolved CO_2 was negatively correlated with porewater concentrations of NH_4^+, NO_2^-, NO_3^-, TN, TP and Cl^-. The concentration of dissolved CH_4 was negatively correlated with porewater concentrations of NH_4^+, TN, TP, dissolved organic carbon (DOC), SO_4^{2-} and Cl^-. The concentration of dissolved N_2O was correlated positively with the concentrations of NO_2^-, NO_3^-, DOC and SO_4^{2-} and negatively with the porewater concentration of NH_4^+. These results support the use of these fertilizers alone or in combination for the mitigation of water nutrient losses and GHG production in rice agriculture and will provide a scientific basis for continuing the search for an easy, economical and optimum management of fertilization.

1. Introduction

Rice (*Oryza sativa*) is the most important cereal crop globally, currently feeding over 50% of the population (Haque et al., 2015). Rice production, however, needs to increase by 40% by the end of 2030 to cope with the increasing demand by a growing population worldwide (FAO, 2009). The leaching of nutrients from agricultural activities, though, contributes to the eutrophication of aquatic ecosystems and approximately 20% of the total emissions of atmospheric greenhouse gases (GHGs) (Hütsch, 2001).

Eutrophication is a major environmental concern (Sunda and Cai, 2012; Sardans et al., 2012; Peñuelas et al., 2012, 2013), with large impacts on water quality and human health (Svirčev et al., 2014). The causes of the sharp increase in water eutrophication driven by increases in nitrogen (N) and phosphorus (P) pollution (Lewis et al., 2011; Sardans et al., 2012) include both point-source (Kiedrzyńska et al., 2014) and nonpoint-source (Vilches et al.,

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2014) pollution. Agricultural nonpoint-source pollution is the direct cause of 60–70% of the global pollution of rivers and lakes (Zhu, 2006). Methods to minimize these environmental impacts of agricultural activities must be continuously improved. The rates of fertilizer application continue to rise, so the potential risk of nutrient loss from paddy fields and the consequent eutrophication are also increasing (Savci, 2012). Strategies of agricultural management, e.g. water management (Díaz et al., 2012) or the application of straw (Wang et al., 2014a), biogas slurry (Guo et al., 2014) or biochar (Liu et al., 2015), are being investigated and developed to both reduce environmental risks and achieve sustainable rice production. Different studies, however, have come to different conclusions, so further research is clearly warranted.

GHGs are produced by microorganisms and stored in porewater. Knowing the amount of GHG dissolved in porewater is therefore very important for evaluating the potential emission of GHGs (Jahangir et al., 2012; Pighini et al., 2015). N input (Jahangir et al., 2012), water chemistry (Whitfield et al., 2011) and salinity (Teixeira et al., 2013) are dependent on the dissolved concentrations of CO_2, CH_4 and N_2O. The relationships of porewater properties and dissolved GHGs with alternative crop amendments, however, have been little studied but would provide valuable information for improving the agricultural management to mitigate GHG emission.

Some studies have reported increases in rice production by the application of steel slag (Wang et al., 2014b, 2015), increasing the resistance against diseases (Ning et al., 2014) and increasing greenhouse gas emissions (Wang et al., 2014b, 2015). No data, however, are available for the effects of the application of steel slag or other urban-industrial wastes on dissolved GHGs and the dynamics of surface or porewater nutrients in rice croplands. Moreover, industrial and agricultural wastes are far less commonly applied in subtropical than temperate regions (Furukawa and Inubushi, 2002; Ali et al., 2008; Wang et al., 2014b). A better understanding of the effects of industrial and agricultural waste on paddy fields and the GHG dynamics of subtropical paddy fields is thus needed.

Sixty percent of the Chinese population depends on rice-based food (Zhu, 2006). The leaching of nutrients from rice croplands, however, accounts for 60–70% of the freshwater eutrophication in China (Zhu, 2006). Sixty to 65, 50–60 and 30–40% of the N, P and potassium applied in fertilizers, respectively, are drained and leached from paddy fields to freshwater (Cheng and Li, 2007). Ninety percent of the paddy fields in China are in subtropical regions, such as the provinces of Fujian, Jiangxi and Hunan. The development of valid and reliable methods for increasing soil fertility, reducing nutrient loss and sustaining rice productivity in Chinese paddy fields in subtropical regions is therefore important. We hypothesised that the amendment with biochar, steel slag, shell and gypsum slag, and a silicate and calcium fertilizer can improve soil fertility and prevent leaching losses by increasing the soil nutrient retention capacity as a result of the high adsorption capacity of these compounds. Moreover, their high contents of Fe^{3+} and SO_4^{2-} can make them to act as electron acceptors thus reducing the formation of CH_4 and N_2O and their potential effect on soil pH can lead to the precipitation of CO2 as carbonates. We aimed to test these hypotheses by measuring the effects on nutrients and greenhouse gas emissions in soil porewater and surface water after the application of various waste materials (biochar, steel slag, shell slag, gypsum slag and a silicate and calcium fertilizer produced from steel slag) to experimental paddy fields.

We aimed to: (1) determine the response of dissolved CO_2, CH_4 and N_2O to the application of various industrial and agricultural wastes in a paddy fields, and (2) assess the impacts of the applications on the availability of nutrients in soil porewater and (3) their loss to surface-water.

2. Materials and methods

2.1. Study site

Our study was conducted at the Wufeng Agronomy Field of the Fujian Academy of Agricultural Sciences in Fujian province, southeastern China (26.1°N, 119.3°E) (Fig. 1), during the early rice

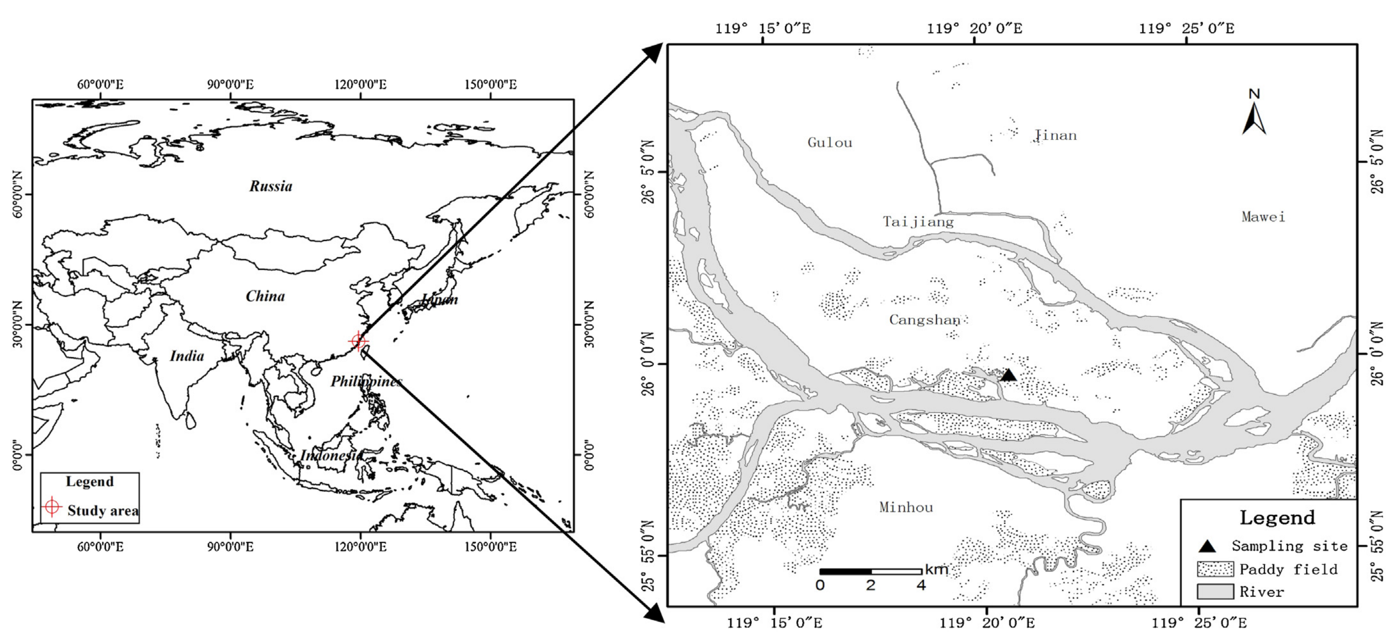

Fig. 1. The location of the study area and sampling sites (▲) in Fujian province, southeastern China.