



Evaluation of potential effects of soil available phosphorus on soil arsenic availability and paddy rice inorganic arsenic content



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ABSTRACT

The transfer of arsenic from paddy field to rice is a major exposure route of the highly toxic element to humans. The aim of our study is to explore the effects of soil available phosphorus on As uptake by rice, and identify the effects of soil properties on arsenic transfer from soil to rice under actual field conditions. 56 pairs of topsoil and rice samples were collected. The relevant parameters in soil and the inorganic arsenic in rice grains were analyzed, and then all the results were treated by statistical methods. Results show that the main factors influencing the uptake by rice grain include soil pH and available phosphorus. The eventual impact of phosphorus is identified as the suppression of As uptake by rice grains. The competition for transporters from soil to roots between arsenic and phosphorus in rhizosphere soil has been a dominant feature.

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1. Introduction

Arsenic(As) distribution and toxicology in the environment is a serious issue, with millions of individuals worldwide being affected by As toxicosis (Bhattacharya et al., 2007). Sources of As contamination are both natural and anthropogenic and the scale of contamination ranges from local to regional. Along with contaminated groundwater (Acharyya et al., 1999; Roychowdhury et al., 2002; Williams et al., 2005, 2006), As contamination in rice has become a global concern as a potential dietary risk to human health. Rice is the predominant dietary staple in Southeast Asia with China being the world's foremost producer, accounting for over one-third of global supply (Zhu et al., 2008a). Paddy rice may contain large quantities of As and contribute significantly to the As intake of humans (Meharg and Rahman, 2003). In recent decades, millions of people in Southeast Asia have suffered from As poisoning from exposure to As contamination in rice (Mondal and Polya, 2008; Neumann et al., 2011; Zhu et al., 2008b), because paddy rice is particularly efficient at accumulating As (Zhao et al., 2010).

The transfer of As from soils to the edible parts of plants is deemed to be a key step in the route of As entry into the human

food chain. As uptake and translocation in rice plants are affected by a wide range of factors including soil As speciation and soil properties (Brammer, 2009; Fu et al., 2011; Lu et al., 2009; Norton et al., 2009; Zhao et al., 2009) and it is universally acknowledged that phosphorus plays a decisive role (Dani, 2011; Fu et al., 2011; Lu et al., 2010). As shares many physicochemical properties with P so that As can be taken up inadvertently by cells through the pathways for P. Smith et al. (2002) reported that phosphate and arsenate are chemically very similar. They, therefore, occupy the same sorption sites in soils and are both strongly adsorbed on Fe-oxides via ligand exchange mechanism. Therefore, there exists a competition between As and P in two processes which can cause two completely opposite effects. On one hand, P can restrain As uptake by plants, and on the other hand, it may promote the availability of As in soil. One aim of this paper is to explore the mechanism of action between the two elements under certain conditions.

The toxicity of arsenic is dependent on its speciation, with inorganic arsenite and arsenate thought to be more toxic than other species (Tamaki and Frankenberger, 1992). Most of previous studies focused on the total As in rice grain (Bogdan and Schenk, 2009; Fu et al., 2011; Lu et al., 2010) but little related to the inorganic As (As_i) directly. Most of the published papers on the As transfer from soil to plant referred to pot experiments or heavily As-contaminated soils. However, most of food consumption originates from crops grown in fields that are not heavily contaminated with As. Therefore, a regional-scale survey was performed to study the effects of soil

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properties on As transfer from uncontaminated soil to rice under actual field conditions.

In the present study, 56 rice and soil samples were collected in a typical red soil region of south China where no studies have reported the existence of As contamination. The possible relationships between rice As_i and soil As speciation, as well as some basic soil properties (pH, TOC, available P, available Fe) were discussed in order to characterize the contribution of these soil characteristics on As_i content of rice. This paper explores the effects of soil available phosphorus on As uptake by rice and, hence, may serve as a basis for comparison with future studies that seek to investigate the impacts of soil properties on the uptake of potentially toxic elements by plants.

2. Materials and methods

2.1. Study area and sampling

The study selected the Beibu Gulf economic zone (108°05' E–109°43' E, 21°31' N–22°10' N) as the study region, covering the area of 4200 km², located in the subtropical monsoon climate and rice is the dominant agricultural product in this area. According to Chinese soil taxonomy, ferralsol (laterite and latosolic red soil) and Anthrosols (paddy soil of subtropical China) are considered as the major soil orders in this area. So far, there have been no reports of soil As contamination in this region.

In the study area, all the rice belongs to the same variety (*Oryza sativa* L.), and the growth conditions for rice, such as climate and rainfall, are similar, as well as fertilization and irrigation. Shortly before harvesting (December 2010), 56 pairs of topsoil and rice grain samples at the same locations were collected by means of a random sampling method from the paddy fields in study area at sites located with the aid of a Global Positioning System (Fig. 1). At each site, 3–5 topsoil (depth: 0–20 cm) sub-samples were gathered (the sampling area of a sub-sample is 5 m × 5 m) using a stainless steel trowel, and mixed in a cloth bag. Meanwhile, the same number of matched rice grain sub-samples were collected and combined into a composite sample. All the soil samples were kept in plastic bags, double-sealed, coded, and then transferred to the laboratory. The rice grain samples were carefully rinsed with deionized water for removal of impurities, initially airdried at room temperature, and ground into fine particles, and then stored in polyethylene bags at ambient temperature for further analysis.

2.2. Analytical methods

All samples were analyzed in Geological Test Center of Anhui Province (China) after pre-treatment in strict accordance with the multi-purpose regional geochemical survey specification (CGS, 2005a). Soil pH was determined in a 2.5:1 water/soil suspension using a pH meter (LY/T 1239-1999). Soil available P was

determined by the extraction with HCl and NH₄F (LY/T 1233-1999). Soil available Fe was extracted using the diethylenetriamine penta-acetic acid (DTPA) method and analyzed with an atomic absorption spectrophotometer (AAS) (LY/T 1262-1999). The soil P digested solution were measured by inductively coupled plasma optical emission spectrometer (ICP-OES). The soil C was determined using X-ray fluorescence spectrometry. The soil As was determined by atomic fluorescence spectrometry (AFS) method. The inorganic As in grains was determined by liquid chromatography-atomic fluorescence spectrometry (LC-AFS). The seven-step sequential extraction of soil As used for this study is described as follows: water soluble fraction (Ws-As) (double deionised water); exchangeable fraction (Ex-As) (2.5 g soil extracted by 25 ml of 1 M MgCl₂, pH = 7.0, for 20 min); carbonate bound fraction (Car-As) (1 M NaOAc adjusted to pH = 5.0 with acetic acid, for 6 h); humic acids bound fraction (HF-As) (0.1 M Na₄P₂O₇, pH = 10.0, for 3 h); Fe–Mn oxides bound fraction (Fe–Mn–As) (0.04 M NH₂OH·HCl in 25% (v/v) HOAc at 96 °C, for 6 h); organic matter and sulfides bound fraction (OM-As) (5 ml of 30% H₂O₂ and 3 ml of 0.02 M HNO₃ for 2 h, a second 3 ml of 30% H₂O₂ for 3 h, at 85 °C); residual fraction (Res-As) (total digestion with a concentrated mixture of HCl/HNO₃/HF/HClO₄). Arsenic concentrations in all the prepared solutions were determined by hydride generation atomic fluorescence spectrometry (HG-AFS). The extraction method has been validated and recommended by CGS (2005b), mainly modified from the methods of Tessier et al. (1979) and Donisa et al. (2003).

2.3. Quality control

The sampling procedure and chemical analysis were performed according to the standard methods recommended by China Geological Survey (CGS, 2005b). The element measurements were validated by certified reference materials (CRM) GBW 10010 (Chinese rice flour) and GBW 07415 (Chinese paddy soil). The average CRM recovery was within 90–110%. The accuracy of the sequential extraction procedure was verified by comparison of the difference between the sum of the individual phase concentrations and the total digested concentration. The recovery ((species sum/total As) × 100) was 81–97%, showing a satisfactory quality control.

2.4. Statistical analysis

Data were statistically analyzed by Microsoft Office Excel 2007, Surfer 10 and SPSS 16.0. The location and sample map was produced using ArcGIS 9.2.

3. Results

3.1. Soil properties and As concentrations

The total soil As, TOC, pH, available P, total P and available Fe in 56 soil samples are shown in Fig. 2. The soils are slightly acid, with pH ranging from 3.83 to 8.03 (mean 5.41) and the TOC contents range from 8.50 to 44.60 g/kg with a mean value of 21.70 g/kg.

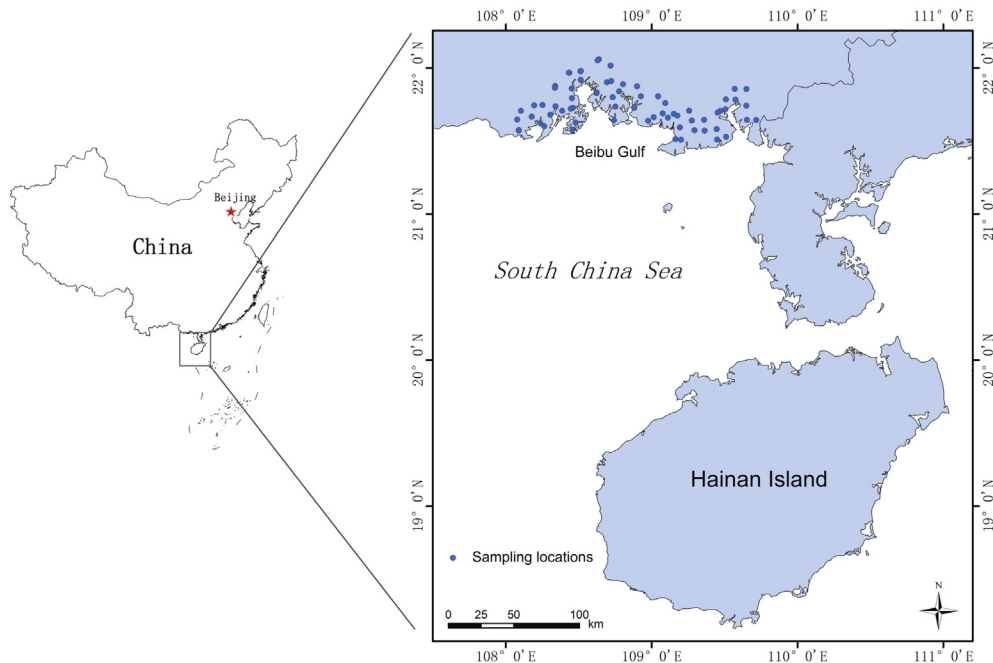


Fig. 1. Study area and sampling locations.

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