ARTICLE IN PRESS

Saudi Journal of Biological Sciences xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Effects of different water management on absorption and accumulation of selenium in rice

Xinbin Zhou [a,1], Yingying Li [a,1], Fan Lai [b,*]

[a] College of Resources and Environment, Southwest University, Chongqing 400715, People's Republic of China
[b] College of Computer and Information Science, Southwest University, Chongqing 400715, People's Republic of China

ARTICLE INFO

Article history:
Received 27 July 2017
Revised 8 October 2017
Accepted 10 October 2017
Available online xxxx

Keywords:
Water management
Se
Rice

ABSTRACT

Rice is the staple food for more than half of the world's population, but selenium (Se) is low in many rice growing countries. Water management model affects rice soil pH and Eh, and then affects the bioavailability of Se in soil. A pot experiment was conducted to investigate the effects of water management on soil Se species, dynamics and selenium uptake by rice plants. Sodium selenite was added to the soil so that the soil selenium content reached 0.5 mg kg^{-1} to study the effects of 3 different water management modes on soil selenium uptake by rice plants. These three modes are flood irrigation (F), aerobic irrigation (A) and alternate flood and aerobic irrigation (AFA). The results showed that flooded irrigation treatment increased the soil soluble selenium concentration, and the selenium in soil solution mainly existed in the form of selenite and selenomethionine selenium oxide. The content of selenium in grain was 2.44 and 1.84 times that of flooded irrigation treatment under A and AFA respectively. The content of selenium in straw was 1.32 and 1.58 times that of flooded treatment under A and AFA respectively. After rice grain enzyme hydrolysis, HPLC-ICP-MS analysis showed that Selenomethionine was the main selenium speciation in rice grains. This study showed that aerobic flooded treatment is one of the most effective ways to increase selenium content in rice field.

1. Introduction

Selenium (Se) is an essential micronutrient in human body, and a component of glutathione peroxidase (GSH-Px) system, whose antioxidant capacity is more than 200 times that of vitamin E, which can reduce excessive oxidative damage and immune damage to the human body by free radicals (Taneja, 2016; Halim et al., 2017). Selenium plays a very important role in maintaining the immune system of human health and reducing the risk of cancer (Wallace et al., 2009).

Soil selenium content varies greatly in China. The content of selenium in soil of Enshi in Hubei is the highest, which can reach 45.5 mg kg^{-1}. According to the *Soil Selenium Environmental Quality Standard of China*, more than 72% of the areas in China are low selenium areas, but the content of available selenium in soil is very low, accounting for about 1.7%–5.5% of the total selenium content. The plant availability of selenium in soil is very low (Li et al., 2016). It is the most ideal strategy to increase selenium in human beings and the fundamental way to control selenium nutrition from the source if it is possible to control the bioavailability of selenium in soil and increase the content of selenium in rice plants by reasonable agronomic measures (Navarro-Alarcon and Cabrera-Vique, 2008).

Irrigation is one of the main measures for rice production. With the shortage of available water resources, the water management in rice cultivation has become the focus of agricultural research. In recent years, to reduce the rice irrigation water, various water management modes (such as alternate wetting drying irrigation and soil wetting irrigation) have been developed and promoted, which can not only reduce irrigation water consumption, but also become an important measure for high yield and high efficiency agriculture of rice (Mostafazadeh-Fard et al., 2011). Based on increasing rice yield and rice quality, these water management modes reduce irrigation water use and reduce fertilizer use, and

* Corresponding author.
E-mail address: zxbissas@163.com (F. Lai).
[1] contributed equally to this work and should be co-first author.

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2017.10.017
1319-562X/© 2017 Production and hosting by Elsevier B.V. on behalf of King Saud University.

have good environmental, ecological and economic benefits (Hamad et al., 2017).

Water management has great influence on the redox potential (Eh) and pH of rice fields, which may eventually control the selenium species and bioavailability in rice fields. The chemical forms of soil selenium are mainly selenate (+6 valence), selenite (+4 valence), elemental selenium (0 valence), selenide (−2 valence) and organic selenium. The Eh and pH play a major role in the chemical transformation of soil selenium forms (Masscheleyn et al., 1990). Therefore, scientists are trying to find an economical and effective way to increase selenium content in rice grains. Some available data show that in low selenium soil, compared with aerobic dry farming, the whole growth period flooding cultivation can significantly increase the Se content in rice stem and grain (Li et al., 2010), which may be because the iron oxide/hydroxide reduction dissolution in the flooded soil can release the adsorbed metal/nonmetal ions into the soil liquid phase (Grybos malgorzata et al., 2007). So, how water management affects soil selenium bioavailability, and then affects selenium content in rice grain, and the specific mechanism is still unknown. Therefore, 3 kinds of water management mode are set in this study: flood irrigation (Control), aerobic irrigation and alternate flooding and aerobic irrigation to analyze the change of soil redox potential and the variety and concentration of selenium in soil solution under different water management modes. How does the water management mode affect the allocation and accumulation of selenium in different organs of rice plants in low selenium soil? It is expected to select effective water management measures to promote the transfer of Se in soil to rice (Noor and Ashraf. 2017).

2. Materials and methods

2.1. Experimental soil

The neutral purple soil with the largest distribution in Sichuan Pot and the low phosphorus soil of 20–40 cm in the experimental field of Southwest University, Beibei District, Chongqing city was collected. The soil was dried to remove organic matter, debris and debris, and sieved over 2 mm after grinding for use. The tested purple paddy soil, pH 5.12, had organic matter 21.3 g/kg, total nitrogen 0.38 g kg^{-1}, total phosphorus 0.35 g kg^{-1}, alkali hydrolyzable nitrogen 83.65 mg kg^{-1}, available phosphorus 7.5 mg kg^{-1} and available potassium 97.8 mg kg^{-1}. To facilitate the study, the total soil selenium reached 0.50 mg/kg by adding sodium selenite. The tested rice variety was Yuxiang 203.

2.2. Experiment design

Rice seeds were sterilized with 15% sodium hypochlorite for 15 min, washed with deionized water and sown in selenium free sand cultures, cultured in greenhouse (with 28/14 h light and 20/10 h dark, illumination intensity 260–350 Mu mol m^{-2} s^{-1}, and relative humidity 60%–70%). Rice seedlings grew in quartz sand for 30 d. Rice seedlings were transplanted when they were about 15 cm. The soil was packed two weeks before transplanting 10 kg per pot. 0.29 g ammonium phosphate, 0.20 g urea, 0.22 g potassium carbonate as base fertilizer were applied per kg. Irrigation was made after base fertilizer and soil were mixed evenly. After transplanting rice plants, different water management measures were carried out: (1) Flooded treatment (F): During the whole growth period of rice plants, the water in the pot remains about 2.0 cm; (2) Aerobic treatment (A): Paddy topsoil remained free from water, and soil moisture content remained at around 35%; (3) Alternate flood and aerobic treatment (A-F-A): Irrigation kept the surface water layer at about 2 cm, and then fell naturally to the surface soil without aquifer. Now, the soil moisture content was about 35%, and irrigation was made again until the surface water layer was about 2 cm, and then cycled until the rice plants were mature. Each water management mode was set up 4 times, a total of 12 pots of rice were planted in a solar greenhouse in randomized blocks. Redox (Eh) and pH values of soil were measured at the 10th, 30th, 60th and 90th days respectively, and the soil solution was extracted at the 10th and 60th days, for determining the contents of selenium, iron, manganese and selenium in soil solution. Rice plants were harvested after ripening. The biomass and Se content of root, stem and leaf, rice husk and brown rice, as well as selenium form of brown rice were determined.

2.3. Analytical method

Soil Eh was measured using a pH meter (pHS-3C). The saturated calomel electrode and a platinum electrode were inserted into the soil surface at 2 cm, read after numerically stable. It was repeated 3 times to get the average.

A porous cup sampler was used to extract 20 ml soil solution, with 1 mL EDTA solution (0.1 mol L^{-1}) added in advance to prevent the transformation of Se with different valence states. After reaching 10 mL, the solution was filtered with a syringe-driven filter with the specification of 0.45 m, and kept at 0–4 °C for determination. The morphology of Se in soil solution was determined by high performance liquid chromatography inductively coupled plasma mass spectrometry (HPLC/ICP/MS) (Agilent 1200, Agilent, Technology, Agilent, 7500, USA) (Li et al., 2008; Tavakoli et al., 2016).

Determination of iron and manganese content in soil solution: 20 ml soil solution was extracted with a porous cup sampler. Each time the soil solution was extracted, it was immediately divided into two parts. 5 ml of soil solution was taken and diluted to 10 ml with 10% nitric acid for the determination of total selenium as well as iron and manganese content in soil solution. The remaining soil solutions were directly determined by atomic fluorescence spectrophotometer for selenium and pH (Li et al., 2016; Samad et al., 2017).

Methods for determination of Se content in various parts of rice followed the methods of Zhang et al., and selenium content in solution to be determined after digestion was determined by AF-610A atomic fluorescence spectrometry. Determination conditions: PMT voltage of 280 V; HCl full cathode current of 80 Ma; carrier gas flow rate of 800 mL min^{-1}; sample volume of 1 mL; atomizer height of 7 mm, room temperature; sampling pump of 100 r min^{-1}; sampling time of 18 s; pump stop time of 5 s. Soil samples (GBW07403) and blank samples were digested simultaneously, and selenium recovery was 90%–105% (Zhang et al., 2006).

2.4. Statistical analysis

Excel 2003 and SPSS 18 software were used for statistical analysis and drawing. Duncan statistical method was used for significance analysis.

3. Result analysis

3.1. Dynamic changes of soil Eh and pH under different water management

Compared with A, the soil redox potential was significantly reduced by F and AFA, but the soil pH increased (Fig. 1a and b). Soil Eh range was 325–385 mV, F had the lowest Eh, the value range was 53.3–130 mV. The AFA range was 125–370 mV, respectively, and about 300 mV for F and A. During the whole rice growth period, the pH of the soil solution was maintained at about 6.3, the pH