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Effect of zeolite application on phenology, grain yield and grain quality in rice under water stress

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ABSTRACT

Plant growth and grain yield of various upland crops in response to zeolite application have been extensively studied, but little information is available on the impact of zeolite application on rice grown in the lowlands under water stress. A two-year experiment was conducted using lysimeters in the field to evaluate the influence of zeolite application (15 t ha^{-1}) on phenology, grain yield and grain quality in a local rice cultivar (Shennong 9765) under three irrigation regimes (CF, continuous flooding irrigation; IAWD, improved alternate wetting and drying irrigation; and AWD, alternate wetting and drying irrigation). Regardless of water supply, zeolite application significantly increased leaf area index (LAI) at all the measured stages except for tillering, SPAD values at the jointing–booting and heading–flowering stages, photosynthetic rate (Pn) at heading–flowering stage, and grain yield and water use efficiency (WUE). Moreover, zeolite addition significantly increased the head rice rate and decreased the chalk rice rate and chalkiness. The IAWD and CF treatments had similar SPAD values and Pn at the heading–flowering stage, and grain yield, while the AWD treatment significantly reduced those values, relative to the CF treatment. The IAWD and AWD treatments significantly increased WUE, milled rice rate, head rice rate, peak viscosity, and breakdown, but decreased water use, LAI, chalky rice rate, chalkiness, cool viscosity, and setback. These results suggest that the adoption of IAWD with 15 t ha^{-1} of zeolite application could reduce irrigation water use, increase grain yield and improve grain quality in rice.

1. Introduction

Rice is the most important staple food worldwide providing about 20% of the daily calorie intake for half of the world's population (Khush, 2013). Rice is a water-intensive crop that often requires 2–3 times more water than other cereal crops such as maize and wheat (Bouman et al., 2007). The sustainability of rice production is being threatened by the increasing water scarcity (Rijsberman, 2006). In addition, rice production needs to increase substantially to feed the growing population in the coming decades (van Ittersum et al., 2013). Therefore, it is crucial to develop water-efficient irrigation strategies to reduce water use, while maintaining or improving grain yield (Carrijo et al., 2017).

In recent years, many irrigation water-saving strategies have been pioneered and promoted, including aerobic rice (Bouman et al., 2007), non-flooded mulching cultivation (Zhang et al., 2008a), intensification system (Zhao et al., 2009), and alternate wetting and drying irrigation (AWD, Ye et al., 2013; Lampayan et al., 2015; Carrijo et al., 2017). The most commonly practiced water-saving technique is AWD irrigation (Feng et al., 2007), which can reduce irrigation water by 15–30% (Cabangon et al., 2004; Yang et al., 2004; Belder et al., 2005), relative to continuous flooding irrigation (CF), but its effect on rice grain yield is an issue. Whether AWD leads to yield loss or not mainly depends on the degree and frequency of soil drying between irrigation intervals, and at what crop growth stage water stress occurs (Lampayan et al., 2015). Chi et al. (2003) developed the improved alternate wetting and drying irrigation (IAWD) that not only reduces irrigation water but increases grain yield. In general, the threshold of soil water potential (SWP) in AWD irrigation is fixed but can vary with growth stage under IAWD irrigation, depending on the sensitivity of rice to water stress at specific growth stages.

Soil amendments are an effective method for mitigating the adverse

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impact of water stress on plants by improving soil physical properties (Polat et al., 2004). Natural zeolite, as an inorganic soil conditioner, has been widely used to improve the growth and yield of upland crops due to its high cation exchange capacity and intensive affinity for nutrients and water (Malekian et al., 2011; Aghaalikhani et al., 2012; Hazrati et al., 2017). Several studies have reported that zeolite mixed with urea increased rice grain yields in flooded paddy fields (Kavoosi, 2007; Gevrek et al., 2009; Sepaskhah and Barzegar, 2010). Zeolite application at 5–15 t ha^{-1} on silty loam soil increased rice grain yield by 14.9% compared with the non-zeolite amendment (Chen et al., 2017). Colombani et al. (2014) showed that soil amended with zeolite reduced water and nitrogen losses relative to the unamended soil. Zeolite can hold water up to 60% of its weight due to its porous crystal structure (Polat et al., 2004) and lose and gain water reversibly without changing structure (Sangeetha and Baskar, 2016). Zeolite application can alleviate the adverse effects of water stress on plant growth due to its ability to absorb and control the release of water and, in turn, increase water availability to plants under drought conditions (Gholizadeh et al., 2010; Najafinezhad et al., 2015). Zeolite, as a soil amendment for crop production, improved water availability and increased water use efficiency (WUE) in strawberry (Abdi et al., 2006). While the positive effect of zeolite application in various upland crops during drying conditions has been extensively reported, little information is available on the response of lowland rice under AWD irrigation to zeolite application. Whether zeolite can alleviate the adverse effects of periodic drying conditions under AWD on rice growth and benefit yield performance need to be addressed.

Next to grain yield, grain quality in rice is another important factor for determining economic returns for rice growers. Moreover, consumers progressively prefer the high quality of rice with the improvement of economic level and enhanced purchasing power of many people in China (Zhang et al., 2008b). Rice quality is determined both genetically and environmentally (Krishnan and Surya Rao, 2005). Soil water status has a remarkable impact on rice grain quality, particularly during grain filling (Dingkuhn and Le Gal, 1996). Changing production practices from conventional flooded management to AWD irrigation often improves the milled rice rate, head rice rate, gel consistency and protein content (Yang et al., 2007; Huang et al., 2008; Zhang et al., 2008b). The application of zeolite to soil increases water availability and nutrient retention (Polat et al., 2004), which may impact rice grain quality by changing the soil water and nitrogen status during grain filling. Therefore, it is essential to elucidate the response of rice grain quality traits to zeolite application under AWD to better understand the underlying effects of zeolite in lowland rice production.

In this study, we hypothesized that the addition of zeolite to lowland rice fields would improve morphological and physiological traits, grain yield and grain quality in rice. The objectives of this study were to evaluate the effects of zeolite application on rice growth, grain yield and quality under various irrigation regimes.

2. Material and methods

2.1. Site description and materials

The experiment was carried out in non-weighing lysimeters at the Center Irrigation Experiment Station of Liaoning Province, China (42°08′57″ N, 120°30′45″ E, 47 m altitude), during two rice-growing seasons (May to October 2014 and 2015). The study area has a temperate continental monsoon climate with 7.5 °C average annual air temperature. Average annual rainfall is 672.9 mm, with the main rainy season from June to September. The soil was a clay loam with 22.3 g kg^{-1} organic matter, 75.4 mg kg^{-1} alkali hydrolysable N, 0.78 g kg^{-1} total N, 18.4 mg kg^{-1} Olsen-P, 81.3 mg kg^{-1} exchangeable K, a pH of 7.40, and bulk density of 1.50 g cm^{-3}.

This study used a local, mid–late season rice (*Oryza sativa* L.) cultivar, Shennong 9765, bred by the Rice Research Institute of Shenyang Agricultural University and characterized by high yield, good quality, and strong disease resistance (Shen, 2012). The chemical fertilizers used were urea (46% N), superphosphate (12% P_2O_5), and potassium sulfate (50% K_2O). Zeolite, with particle sizes from 0.18–0.38 mm, was obtained from a quarry in Faku County, Liaoning Province, China. The chemical content of zeolite is given in Table 1.

Table 1
Chemical content of zeolite.

Chemical content	Percentage (%)	Chemical content	Percentage (%)
SiO_2	65.6	Na_2O	0.39
Al_2O_3	10.6	K_2O	2.87
Fe_2O_3	0.63	TiO_2	0.069
FeO	0.09	P_2O_5	0.001
MgO	0.82	MnO	0.010
CaO	2.59	Loss on ignition	16.6
H_2O	8.16		

2.2. Experimental design

A split-plot design with three irrigation regimes, two zeolite application rates and three replications (lysimeters) was used in both years. The main plots were three irrigation regimes: CF, IAWD (Chi et al., 2003), and AWD. The sub-plots were zeolite application at two levels (Z_0: 0 and Z_{15}: 15 t ha^{-1}), as recommended by Chen et al. (2017). The lysimeters (2.5 m long × 2 m wide × 1.8 m deep) were constructed from concrete blocks and sealed with waterproof paint to prevent seepage between plots. There were 18 lysimeters (3 irrigations × 2 zeolite rates × 3 replicates) used for the experiment. A mobile rainout shelter was equipped above the plots to rigorously control the soil water content in the plots. The plots were irrigated using a pipe installed with a water meter. As the lysimeters had closed bottoms, 2 mm day^{-1} of water was drained into the gallery by opening the drainage outlet installed 1.8 m below the soil surface to simulate field conditions.

Zeolite was applied to the puddled plots and mixed into the soil to a depth of 5 cm with a rake. To determine the effect of zeolite application in the following growing season, zeolite was only applied in the first year. The 2015 experimental plots were the same as those in 2014 except there was no addition of zeolite. Details of the irrigation regimes are described in Table 2.

The soil water potential (SWP) at 15 cm depth was monitored daily at 8:00 and 14:00 using soil moisture tensiometers (made by the Institute of Soil Science of Chinese Academy of Sciences, Nanjing, China) installed in the IAWD and AWD plots. When the SWP dropped between the lowest and highest thresholds in the IAWD plots or to the thresholds in the AWD plots, or the water depth in the CF plots dropped to the lowest water depth, the plot was irrigated to the highest water depths shown in Table 2. The amount of irrigation water was estimated using volumetric water meters. In addition, when pesticides and fertilizers were applied, the plots must maintain standing water for a few days. Daily meteorological data, including air temperature and rainfall, were recorded by an automatic weather station located ~500 m from the experimental site (Fig. 1).

Seedlings were raised in the seedbed, with sowing dates of 25 April 2014 and 30 April 2015, and transplanted on 20 May 2014 and 24 May 2015 with a hill spacing of 30 cm × 15 cm with four seedlings per hill. For mid–late season rice in this area, farmers generally apply 210 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5, and 75 kg ha^{-1} K_2O annually. N as urea was applied in three parts: 43% as basal, 43% at tillering, and 14% at panicle initiation. Potassium was applied in two parts: 50% as basal and 50% at tillering. Phosphorus was applied as a basal dressing of 60 kg ha^{-1}. Insects and diseases were intensively controlled throughout the season with chemicals. Weeds were controlled manually. No noticeable crop damage was observed in either year.