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A positive response of rice rhizosphere to alternate moderate wetting and drying irrigation at grain filling stage

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ABSTRACT

Paddy fields are drained and irrigated several times during the whole rice growth period. Although studies have acknowledged the sensitivity of flooding and drainage in rice rhizosphere, current knowledge regarding how moderate drying at grain filling stage affects ecological characteristics of rice rhizosphere is limited. A field experiment with two irrigation regimes [alternate moderate wetting and drying irrigation (AMWD) and continuous irrigation (CI)] was conducted to investigate the changes in soil physical and chemical properties and microbial communities. Results from this investigation demonstrated that soil pH under AMWD was decreased, while Eh was increased. Moreover, soil electrical conductivity increased and decreased with a decline in soil water potential, interestingly all studied variables quickly recovered after re-watering.

The terminal restriction fragment length polymorphism (T-RFLP) analysis revealed that the diversity indices of bacterial communities were higher in drying phase as compared to the initial treatment of AMWD regime, but the evenness index decreased. Remarkably, AMWD process increased the proportion of aerobic bacteria, such as *Azotobacter*, nitrifying bacteria, phosphate and potassium solubilizing bacteria (which participate in the nutrient cycling). In addition, the increase of enzyme activity under AMWD regime promoted the release of nutrients, thereby enhancing the amounts of NO_3^--N, available phosphorus (P) and potassium (K) in soils, which met rice nutrient demands at late grain filling stage. This led to a promotion in plant physiological activities and grain filling, and hence increased grain yield. From these results we infer that there was a positive response of rice rhizosphere to AMWD irrigation at grain filling stage, which laid the groundwork to set up a sound irrigation system in rice fields without reducing its yield.

1. Introduction

Rice (*Oryza sativa* L.) is an important food crop for a large proportion of the world's population (Fageria, 2007). Worldwide, around 93 million ha of irrigated lowland rice provide 75% of the world's rice production (Lampayan et al., 2015a). However, irrigation water resource has shrunk in many areas due to global population growth, increasing urban and industrial demand (Bouman, 2007; Watanabe et al., 2013). To meet the major challenge of incremented rice production under increasing scarcity of water resources, alternate wetting and drying irrigation (AWD) has been widely adopted in many Southeast Asian countries and China as a water-saving technique (Chu et al., 2014; Lampayan et al., 2015b).

The most appealing feature of AWD to reduce irrigation water use is mainly attributed to rationally controlling the water supply amount and timing. Liu et al. (2013) indicated that water application from transplanting to maturity was 412–435 mm in AWD regime, which was 78.1–79.5% of that (527.5–547 mm) applied to the standard irrigation practice (continuous irrigation, CI). From these results it is obviously that AWD can significantly save an amount of irrigation water. Research demonstrates that in comparison with the CI regime, the alternate moderate wetting and soil drying (AMWD) regime has significantly progressed. Nevertheless, the alternate severe wetting and soil drying (ASWD) regime significantly decreased root oxidation activity, phytohormonal signaling, leaf photosynthetic rate, dry matter accumulation, and consequently affected the grain filling rate and grain yield (Zhang

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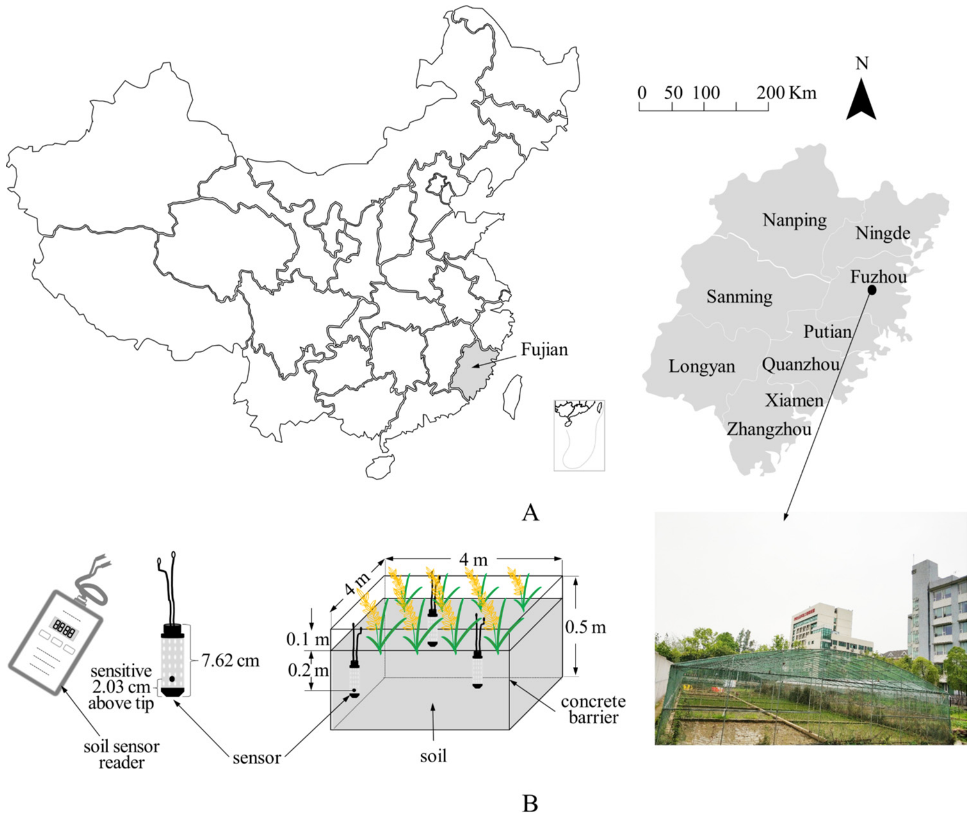

Fig. 1. Location of experimental station in Fuzhou (A) and schematic diagram of the set up of the experiment (B).

et al., 2009a; Liu et al., 2013; Dodd et al., 2015; Pascual and Wang, 2017). This implied that soil moisture content is a very important factor affecting grain yield. A moderate degree of soil hydropenia in the soil drying phase of AWD would not seriously affect plant water status and be a limitation factor for the rice plants growth (Zhang et al., 2010; Miao et al., 2015). However, the physiological mechanisms underpinning these responses are not fully understood, especially the effects of AMWD on belowground processes remains to be elucidated.

As an integral part of plant organs, roots are in direct contact with the surrounding environment of soil and involved in acquisition of nutrients and water (Yang et al., 2004). Soil moderate drying and rewatering can greatly promote the extension and initiation of root particularly secondary roots (Liang et al., 1996). The work of Yang et al. (2012) has shown that, when compared with the continuous flooding, AMWD regime significantly increased the number of mitochondria, Golgi bodies, and amyloplasts in root tip cells at the panicle initiation stage, and the ASWD regime exhibited an opposite effect. Numerous reports indicated that an increase in root biomass, root length density, root oxidation activity and root-sourced hormones promoted shoot system growth and development of shoot system, leading to higher grain yield (Yang et al., 2007; Dong et al., 2012; Zhou et al., 2017). Thus, indicating that the stronger physiological activities of roots may be the major reason for the high yield under water-saving irrigation. Nonetheless, the real situations of root growth in the field is not easily recognized by visual inspection and *in situ* sampling, and the assessments of the AMWD effects on rice root fitness are still hardly proceeded and inconclusive.

It is generally believed that about 30–60% of the net fixed carbon is transferred to the roots in annual plants, and a considerable proportion of that carbon (between 40 and 90%) can be released into the rhizosphere (Lynch and Whipps, 1990; Neumann and Römheld, 2000). The rhizosphere is a narrow region of soil that is strongly affected by plant root activities and metabolism (Bell et al., 2015). Under varying moisture conditions, several changes occurred in the rhizospheric environment. Previous literature indicated that when paddy field was subjected to drying processes, the gaseous exchange between the atmosphere and soil was strengthened, and adequate oxygen was consequently added to the rhizosphere (Miao et al., 2015). This can greatly improve soil redox and promote the action of microorganisms and avoid the accumulation of poisonous substances in the rhizosphere (Mao, 2002). Contrarily, flooding can lower the soil redox potential (Eh) and increase the hydrous oxides of Fe, Mn and Al, and this can increase metal adsorption (Li et al., 2015). It is noteworthy that soil Eh has been implicated not only as a ratio of oxidized to reduced forms that adopted to indirect changes of soil oxygen concentration, but an important role in regulating root growth, flowering development of floral organs, leaf sectoring, and photoperiodism (Xing et al., 2006; Rosso et al., 2009; Husson, 2013; Vo and Kang, 2013). All these suggest that rhizosphere environmental disturbances are one of the important factors affecting rice growth and its grain filling.

Therefore, we hypothesized that different irrigation regimes can produce severe modification in morphology and physiology traits of roots with significant impact on the above-ground plant growth and development. Since a comprehensive assessment of the influence on rhizosphere ecosystem functioning was lacking, we investigated the potential relation between rhizosphere ecological environment and the physiological status of rice plant under an alternate moderate wetting and soil drying regime (AMWD) at grain filling stage. The rhizosphere eco-factors were mainly focused on soil pH, redox potential (Eh), electrical conductivity (EC), available nutrient, enzymatic activities and bacterial communities structure. The purpose of this study was to find out the changing pattern of rhizosphere eco-factors and then provide a theoretical basis for high-yielding cultivation and water management of rice.