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Grain yield, water productivity and nitrogen use efficiency of rice under different water management and fertilizer-N inputs in South China

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ABSTRACT

The increasing scarcity of irrigation water necessitates the development of water-saving technology in rice production. Our previous studies have shown that “safe” alternate wetting and drying irrigation (AWD15) can effectively save water, improve water productivity while maintain grain yield compared to continuous flooding (CF) and farmer’s water management practice (FP) under a single fertilizer-N input. The objectives of this study are (1) to investigate the superiority of this novel water management practice compared with FP; and (2) to examine whether there is an interaction between water and N input and whether fertilizer-N input needs to be adjusted under AWD15. Two field experiments were conducted during the late cropping seasons of 2014 and 2015. A hybrid rice variety Tianyou3618 was grown under two water management (AWD15 and FP) and four fertilizer-N rates (0, 90, 180, 270 kg N ha^{-1}). Grain yield, water productivity and nitrogen use efficiency were determined. Compared to that of FP, irrigation water input of AWD15 was reduced by 24.1% in 2014 and 71.4% in 2015. The number of irrigations decreased and water productivity increased significantly. No significant differences existed between AWD15 and FP in grain yield, biomass, leaf area index and nitrogen use efficiency. Nitrogen input level had significant effects on yield, biomass, harvest index and nitrogen use efficiency in both years. Grain yield increased with N rate and the optimal N rate was 180 kg N ha^{-1}. No significant interaction was found between water and nitrogen rate regarding biomass production and grain yield. Our results demonstrated that no change in N input is needed under AWD15 condition and AWD15 is advantageous over farmer’s water management practice under all N levels investigated in South China. This is the first report on the performance of AWD15 under different fertilizer-N levels in South China.

1. Introduction

Water and nitrogen are important inputs for rice production. The scarcity of fresh water resources now threatens rice production in China (Yao et al., 2014). South China is one of the major rice-producing regions in the country, with a total planting area of 5 Mha. More than 80% of cereal food produced comes from rice (National Bureau of Statistics of China, 2015). Two rice crops are grown annually under irrigation in this region. Although there is abundant rainfall in South China, water shortage is still a major problem for rice production because of the uneven distribution of the rainfall among seasons and regions (Liu et al., 2011). Moreover, climate change has brought an alarming situation to agricultural production, such as an increase in the occurrence of periods of water scarcity. Global warming is likely to result in a 24% greater demand for water in the double-cropping areas of rice in South China (Ye et al., 2015).

In rice production, farmers often apply more N fertilizers than the minimum required for maximum crop growth to maximize grain yield (Peng et al., 2002). Water scarcity, environmental

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pollution caused by excessive application of fertilizers, and the high costs of irrigation and fertilizers, demand for greater increase than ever in grain yield of rice with less water and less fertilizers (N fertilizer in particular) in China (Peng et al., 2002, 2006). Thus, there is an increasing need to develop water-saving and N-fertilizer efficient technologies for economical and environment-friendly production of rice.

For rice, water-saving technologies include alternate wetting and drying (AWD) irrigation, saturated soil culture, and aerobic rice, etc. (Bouman et al., 2007b). AWD has been used in many countries in Asia since being developed by IRRI since 1990s. The practice provides a chance of more rice production in water scarce areas. "Safe" AWD (AWD15), with a threshold of 15 cm in water depth below the soil surface, also has other potential benefits, such as (1) increase in farmers' income (Lampayan et al., 2015b), (2) reduction in lodging of rice plants because of better rooting system and better control of some pests and diseases such as golden apple snail (Bouman et al., 2007b), and (3) reduction of methane (a greenhouse gas) emissions (Yagi et al., 1996; Liang et al., 2016). Up to now, AWD15 has become one of the most commonly practiced water-saving irrigation technologies in Asia (Tuong et al., 2005; Lampayan et al., 2015b; Liang et al., 2016). However, this technology was introduced by us into South China only in recent years. More information is needed to validate its adaptability to this region and its superiority over local farmers' water management practice.

Water and nutrient may interact with each other to produce a coupling effect. Some studies (Wang et al., 2004; Sun et al., 2009, 2010) indicated that there was a significant interaction between nitrogen application and water management on nitrogen absorption and utilization and grain yield in rice. However, other studies have found no significant interaction between them (Yang et al., 2008; Yao et al., 2012). Under the growing conditions of lowland rice in South China, the interaction between water management practice (AWD15 and FP) and nitrogen input has not been documented yet and needs to be investigated. When AWD15 is practiced, continuous standing water will not be observed in the field except for the first 10 days after transplanting and during the flowering stage. The field will alternately experience flooding and drying conditions. We speculate that nutrient loss (nitrogen in particular) caused by water runoff from the field may be reduced considerately, resulting in an indirect improvement in nitrogen use efficiency under AWD15. In addition, non-point source pollutants (nitrogen in particular) may be reduced due to less water runoff (Xue et al., 2013). Furthermore, if an interaction exists between water management practice and nitrogen rate, then the N input will have to be changed under AWD15.

Water management with a midseason drainage is a common practice widely used nowadays by farmers to control the unproductive tillers in China. Continuous flooding (CF) was widely used by rice farmers until the 1980s but has been gradually replaced by the present midseason drainage (regarded as farmer's practice or FP in this paper) (Zou et al., 2009; Liang et al., 2016). A direct comparison between AWD15 and FP is more meaningful, but previous studies on AWD15 by other researchers were based on a comparison between AWD15 and CF. In our previous studies, we found that AWD15 was advantageous over both CF and FP in saving water (Liang et al., 2016). However, more evidences are needed to confirm the superiority of AWD15 to FP. In the current study, we grow rice under two water management (AWD15 and FP) and four fertilizer-N rates (0, 90, 180, 270 kg N ha^{-1}) to determine the effect of water and N input on grain yield, water productivity and nitrogen use efficiency. We hypothesize that rice yield, water productivity and nitrogen use efficiency will be higher under AWD15 and would be optimal at a certain N input level.

2. Material and methods

2.1. Experimental site description

The experiments were conducted at the Baiyun Experimental Farm of Guangdong Academy of Agricultural Sciences in Guangzhou (113°23′E, 23°17′N, altitude of 41.0 m), Guangdong, China, during 2014 and 2015 late seasons (August to November). The field had been continuously cropped with puddled rice twice a year and was surrounded by flooded rice fields during the two cropping seasons. The field soil had pH of 5.5 and contained 23.1 g kg^{-1} organic matter, 13.6 mg kg^{-1} available P, and 82.9 mg kg^{-1} available K. Mean rainfall (from 1992 to 2015) was 1106 mm in the early cropping season (April–July), and 577 mm in the late season (August–October). The area has a mean temperature of 21–23 °C, relative humidity of 75%, and solar radiation of 12.4 MJ m^{-2} day^{-1}.

2.2. Experimental treatments and design

The experiment was laid out in a split-plot design with water regime (W) as the main plot and nitrogen (N) treatment as the subplot. Two W and four N treatments were tested with three replicates and 24 subplots (4.2 m × 6.8 m) were established in the field. The W treatments were farmers' irrigation practice with midseason drainage (FP) and safe AWD at the −15 cm threshold level for irrigation (AWD15). The N treatments were 0, 90, 180, and 270 kg N ha^{-1}, respectively. All plots were separated each other with bunds and had a separate draining outlet to drain water into ditches. The bunds were covered with plastic film (0.15 mm) which was inserted to 40 cm depth below soil surface to minimize seepage between plots. In order to reduce or avoid the residual effect of precropping fertilizers, rice was grown and no fertilizers was applied in the same field in the previous season of both years. The field was irrigated with underground water which came from a depth of 126 m below ground surface and was pumped into a water storage tank. The water inflowed into each plot directly through PVC pipeline. The variety in this experiment was Tianyou3618, which is recognized as a super hybrid rice by the Ministry of Agriculture of China and has been widely planted in South China.

In both water treatments, the field was flooded to a water depth of 3–5 cm for the first 10 days after transplanting to promote seedling establishment and control weeds. Two water treatments were imposed afterwards. In the FP treatment, field water was kept at 2–5 cm until the tiller number reached 80% of the expected panicle number at harvest, a midseason drainage (about 25 DAT) was imposed to depress excessive growth of tillers until 10 days after the visible panicle initiation occurred. The field was re-flooded and the water was kept at 2–5 cm during the entire heading stage. After heading, shallow wetting irrigation was carried out. Whenever the water disappeared in the field, 2–3 cm of water was applied to re-flood the field. At 7 days before harvest, the field was allowed to dry. In the AWD15 treatment, timing of irrigation was based on the water depth in the field water tube installed in each plot (Lampayan et al., 2015a). Irrigation time and frequency thus varied slightly across replicates. The tubes were installed in the field to 15 cm depth below the soil surface. When the ponded water disappeared in the water tubes, then irrigation was applied to re-flood the field up to 5 cm above the surface. At initial flowering (when 10% of the panicles had fully emerged from the boot), AWD15 treatment was suspended and water depth was maintained at 2–5 cm depth to reduce the risk of spikelet sterility caused by water-deficit stress at this sensitive stage. After completion of the flowering stage, the AWD15 cycles were repeated until 7 days before harvest.

Nitrogen in the form of urea was applied four times: 30% as basal, 30% at 25–27 DAT, 30% at 40–45 DAT, and 10% at heading. Seeds were sown in the seedbed on 21 July in 2014 and 20 July in