Field Crops Research 154 (2013) 226–235

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Combination of site-specific nitrogen management and alternate wetting and drying irrigation increases grain yield and nitrogen and water use efficiency in super rice

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ARTICLE INFO

Article history:
Received 31 July 2013
Received in revised form 26 August 2013
Accepted 26 August 2013

Keywords:
Super rice (*Oryza sativa* L.)
Alternate wetting and drying irrigation (AWD)
Site-specific nitrogen management (SSNM)
Nitrogen use efficiency
Water use efficiency
Root oxidation activity

ABSTRACT

Site-specific nitrogen management (SSNM) and alternate wetting and drying (AWD) irrigation are two applied technologies developed in recent years in rice production. Little is known, however, how synergistic these two technologies can be in terms of grain yield, nitrogen and water use efficiencies. We investigated this issue using super rice under SSNM, AWD, or both. Two super rice varieties subjected to four N and irrigation treatments, i.e., continuously flooded (CF) and farmer's N practice (FNP) (CF-FNP), CF-SSNM, AWD-FNP, and AWD-SSNM, were field-grown in 2011 and 2012. SSNM or AWD significantly increased the percentage of productive tillers, leaf area duration, leaf photosynthetic rate, root oxidation activity and dry matter accumulation during grain filling compared with FNP or CF. Such increases were more evident when both AWD and SSNM were adopted together. The AWD-SSNM treatment increased not only the number of spikelets per panicle, but also the percentage of filled grains and grain weight. Root biomass at heading time and the harvest index were significantly higher under the AWD-SSNM treatment than those under any other treatments. When compared to those under the CF-FNP treatment, grain yield, N partial factor productivity (grain yield over the N rate) and WUE (grain yield over the amount of irrigation water and rainfall) under the SSNM-AWD treatment were increased by 12.4–14.5%, 26.5–30.7% and 22.8–26.7%, respectively, and also significantly higher than those under SSNM or AWD alone. The results suggest that synergistic interaction between SSNM and AWD occurs in the yield formation, and such an interaction could increase not only grain yield, but also resource-use efficiency in super rice.

1. Introduction

Site-specific nitrogen management (SSNM) and alternate wetting and drying (AWD) irrigation are two applied technologies developed in recent years in rice production (Li et al., 2012; Peng et al., 2010; Yao et al., 2012). In SSNM, the total amount of N application was based on attainable or target grain yield, yield without N fertilizer, and agronomic nitrogen use efficiency, and N rates applied during the rice growing season were adjusted according to the leaf N status measured with a chlorophyll meter (SPAD) or a leaf color chart (LCC) (Peng et al., 1996, 2006, 2010; Yang et al., 2008). On-farm demonstrations in six provinces in China during 2003–2007 showed that SSNM could reduce N fertilizer by 32% and increase rice grain yield by 5%, and therefore, could markedly increase N use efficiency (NUE) when compared with farmers' N practices (FNP) (Peng et al., 2010). In AWD, irrigation is applied a few days after water has disappeared from the surface so that periods of soil submergence alternate with periods of nonsubmergence during the whole growing season (Belder et al., 2004; Tuong et al., 2005; Yao et al., 2012). This technique is adopted in many Asian countries such as China, Bangladesh, India, and Vietnam, and could substantially reduce irrigation water and lead to an improvement in water use efficiency (WUE), relative to continuously flooded (CF) irrigation (Belder et al., 2004; Tuong et al., 2005; Yao et al., 2012; Zhang et al., 2008, 2009). However, little is know if

Abbreviations: AWD, alternate wetting and drying; CF, continuously flooded; DAH, days after heading; DAT, days after transplanting; FNP, farmers' N practice; IE_N, internal N use efficiency; LAD, leaf area duration; LAI, leaf area index; LCC, leaf color chart; NUE, nitrogen use efficiency; PFP_N, N partial factor productivity; ROA, root oxidation activity; SSNM, site-specific nitrogen management; WUE, water use efficiency.

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0378-4290/$ – see front matter
http://dx.doi.org/10.1016/j.fcr.2013.08.016

grain yield, NUE, and WUE could be further increased by adoption of both SSNM and AWD, and if both technologies could be used in newly bred super rice.

China has successfully bred super rice or super hybrid rice varieties in recent years by use of intersubspecific heterosis and improvement of plant type (Cheng et al., 2007; Katsura et al., 2007; Peng et al., 2008). Today, about 110 super rice varieties have been released (Deng, 2013, personal communication), and these varieties could increase grain yield potential by 8–15% compared with ordinary hybrids or inbred varieties (Peng et al., 2009; Yao et al., 2012). However, the high-yielding of super rice varieties was often achieved when nutrient and water were amply supplied (Yao et al., 2012; Zhang et al., 2009). Crop management strategies for the full expression of yield potential and, at the same time, for achieving high resource-use efficiency have not been developed for these varieties (Peng et al., 2009). It would be very useful to understand the agronomic and physiological performance of super rice varieties under SSNM, AWD, and both.

In current study, two super rice varieties were field-grown and four treatments of CF-FNP, CF-SSNM, AWD-FNP, and AWD-SSNM were conducted. The objective was to investigate grain yield, NUE, and WUE of super rice under the SSNM, AWD, and both, and to understand their agronomic and physiological basis by determining percentage of productive tillers, leaf area duration (LAD), leaf photosynthetic rate, dry matter accumulation, root biomass and root oxidation activity (ROA).

2. Materials and methods

2.1. Plant materials and growth conditions

The experiment was conducted at a research farm of Yangzhou University, Jiangsu Province, China (32°30′ N, 119°25′ E, 21 m altitude) during the rice growing season (May to October) of 2011, and repeated in 2012. The soil was a sandy loam [Typic fluvaquents, Etisols (U.S. taxonomy)] with 24.4 g kg^{-1} organic matter, 102 mg kg^{-1} alkali hydrolysable N, 34.7 mg kg^{-1} Olsen-P, and 67.5 mg kg^{-1} exchangeable K. The field capacity soil moisture content, measured after constant drainage rate and made gravimetrically, was 0.189 g g^{-1}, and bulk density of the soil was 1.33 g cm^{-3}. The average air temperature, precipitation, and sunshine hours during the rice growing season across the two study years measured at a weather station close to the experimental site are shown in Fig. 1.

Two 'super' rice (*Oryza sativa*. L) varieties currently used in local production, Yangjing 4038 (*japonica*) and II you 084 (an *indica* F_1 hybrid), were grown in the field. Seedlings were raised in the field with sowing date on 10 May and transplanted on 10 June at a hill spacing of 20 cm × 20 cm with two seedlings per hill. Both varieties (50% of plants) headed on 25–26 August, and were harvested on 15–16 October.

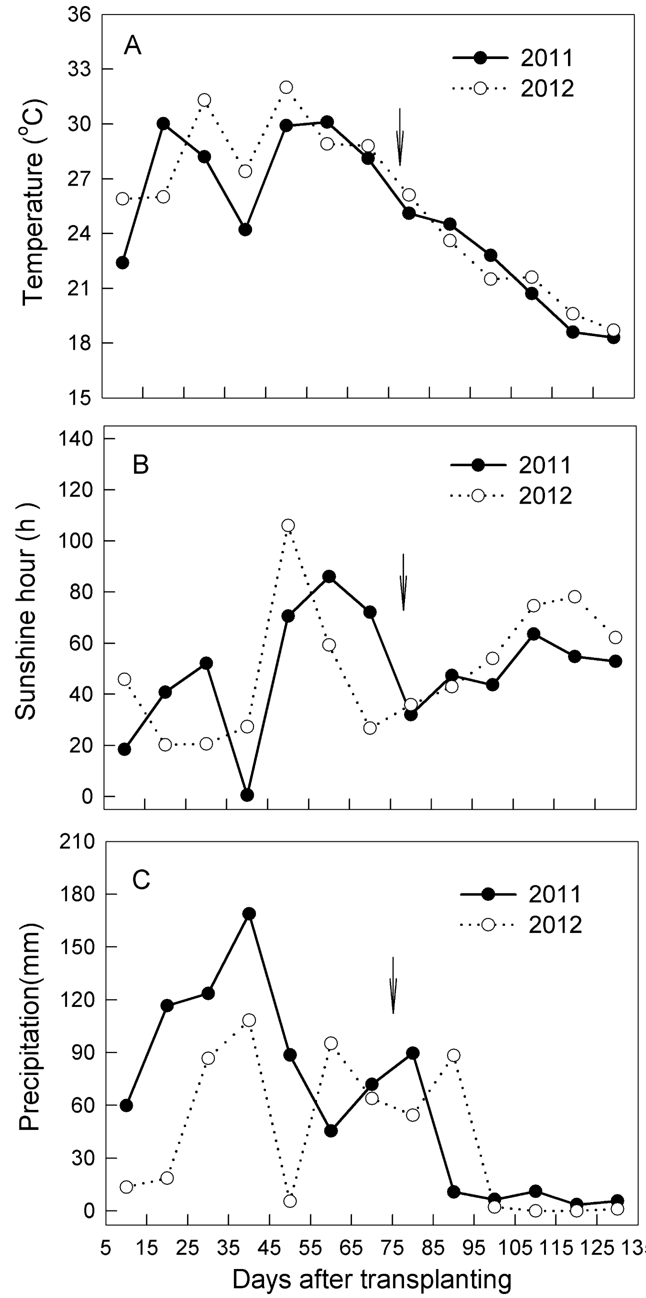

Fig. 1. The mean temperature (A), sunshine hours (B), and precipitation (C) during the growing season of rice in 2011 and 2012 at the experiment site of Yangzhou, Southeast China. Data are means of per 10 days from the transplanting of rice. Arrows indicate the heading time.

2.2. Treatments

The experiments were laid out in a complete randomized block design with three replicates. Plot dimensions were 6 m × 5 m and plots were separated by an alley 1 m wide with plastic film inserted into the soil to a depth of 0.50 m to form a barrier. Treatments consisted of four crop management treatments including CF-FNP, CF-SSNM, AWD-FNP, and AWD-SSNM.

2.2.1. CF-FNP

Application of fertilizer and irrigation were mainly based on local farmers' practice. In FNP, N as urea (162 kg ha^{-1} for Yangjing 4038 and 144 kg ha^{-1} for II you 084), phosphorus (60 kg ha^{-1} as single superphosphate) and potassium (75 kg ha^{-1} as KCl) were applied and incorporated before transplanting. N as urea was also applied at mid-tillering (40.5 kg ha^{-1} for Yangjing 4038 and 36 kg ha^{-1} for II you 084) and panicle branch differentiation (67.5 kg ha^{-1} for Yangjing 4038 and 60 kg ha^{-1} for II you 084) as top dressing. The total N application was 270 kg ha^{-1} for Yangjing 4038 and 240 kg ha^{-1} for II you 084. Except drainage at the mid-season, the field was continuously flooded with 2–3 cm water level until one week before harvest (CF).

2.2.2. CF-SSNM

Irrigation was based on local farmers' practice (CF) and N application was according to the method of SSNM. The total amount of N application was 240 kg ha^{-1} for Yangjing 4038 and 210 kg ha^{-1} for II you 084. The details of N management are shown in Table 1. The threshold of SPAD or LCC values for N application and the