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Responses of candidate green super rice and super hybrid rice varieties to simplified and reduced input practice

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ABSTRACT

Producing higher grain yield with less environmental impact is a challenge for the future of agriculture. Breeding green super rice (GSR) varieties is one of the promising ways to meet this challenge. Green super rice is supposed to have better performance than super hybrid rice (SHR) under reduced input condition. In the present study, seven elite candidate GSR varieties and five representative SHR varieties were planted under the farmers' practice (FP) and the simplified and reduced input practice (SRIP) in 2015 and 2016. The objectives were to compare the grain yield and NUE of the candidate GSR and SHR under FP and SRIP, and investigate the agronomic and physiological traits of GSR. Averaged across all varieties, the reduction in grain yield at SRIP compared to FP was 1.04 t ha^{-1} in 2015 (10.37%) and 0.50 t ha^{-1} in 2016 (5.55%). The average grain yield of GSR varieties was similar to that of SHR in 2015, but SHR had significantly greater (7.42%) average grain yield than GSR in 2016. In comparison to FP, yield reduction at SRIP for the candidate GSR and SHR varieties was 9.27% and 11.48% respectively in 2015, and 4.74% and 5.85% respectively in 2016. Grain yield of FP was significantly correlated with that of SRIP (R^2 = 0.73). Averaged across varieties, total aboveground nitrogen uptake and nitrogen use efficiency for grain production between GSR and SHR were comparable. Among the GSR varieties, 9Y6H exhibited relative high yield stability and NUEg across treatments and planting years; however, SHR varieties showed consistently better yield stability than most of the GSR varieties. Overall, candidate GSR varieties had similar response to SRIP with the SHR varieties. In addition to breeding GSR varieties, future studies should also focus on the green traits of the SHR varieties.

1. Introduction

In the last two decades, increasing studies have focused on sustainable intensification of agriculture due to two great challenges that the future of agriculture faces: 1) meet substantial increases in food demand and 2) decrease agriculture's global environmental impacts (Cassman, 1999; Cassman et al., 2003; Ju et al., 2009; Godfray et al., 2010; Foley et al., 2011; Tilman et al., 2011; Mueller et al., 2012; Seufert et al., 2012; Chen et al., 2014; Cui et al., 2014). Organic farming – a system aimed at producing food with minimal harm to ecosystems, animals or humans – is often proposed as a solution, however, there is a yield penalty of organic farming ranging from 20 to 25% compared to conventional farming (Seufert et al., 2012; de Ponti et al., 2012). Closing yield gaps and increasing resource use efficiency are necessary strategies towards meeting the above two challenges through optimization of nitrogen (N) and water management and adoption of advanced crop varieties (Godfray et al., 2010; Foley et al., 2011; Mueller et al., 2012).

Rice is the main staple food for over 50% populations of the world (Tao et al., 2014). As one of the largest rice producers and consumers in the world, China occupied 18.8% of global rice growing area and contributed 28.1% of production in 2014 (FAO, 2016). Since the 1980s, rice yield has increased significantly due to crop genetic improvement, improved crop management practices, and increased agronomic inputs, especially N fertilizer input (Yu et al., 2012; Song et al., 2015). Rice breeding for high yield potential indirectly selected higher lodging resistance and tolerance to N fertilizer, which resulted in farmers applying large amounts of N fertilizer in order to maximize grain yield (Peng et al., 2002; Ju et al., 2015). The overuse of N fertilizer leads to low N use efficiency (NUE, Peng et al., 2002) and a variety of environmental consequences such as soil acidification (Guo et al., 2010). Studies showed that the amount of N fertilizer input could be

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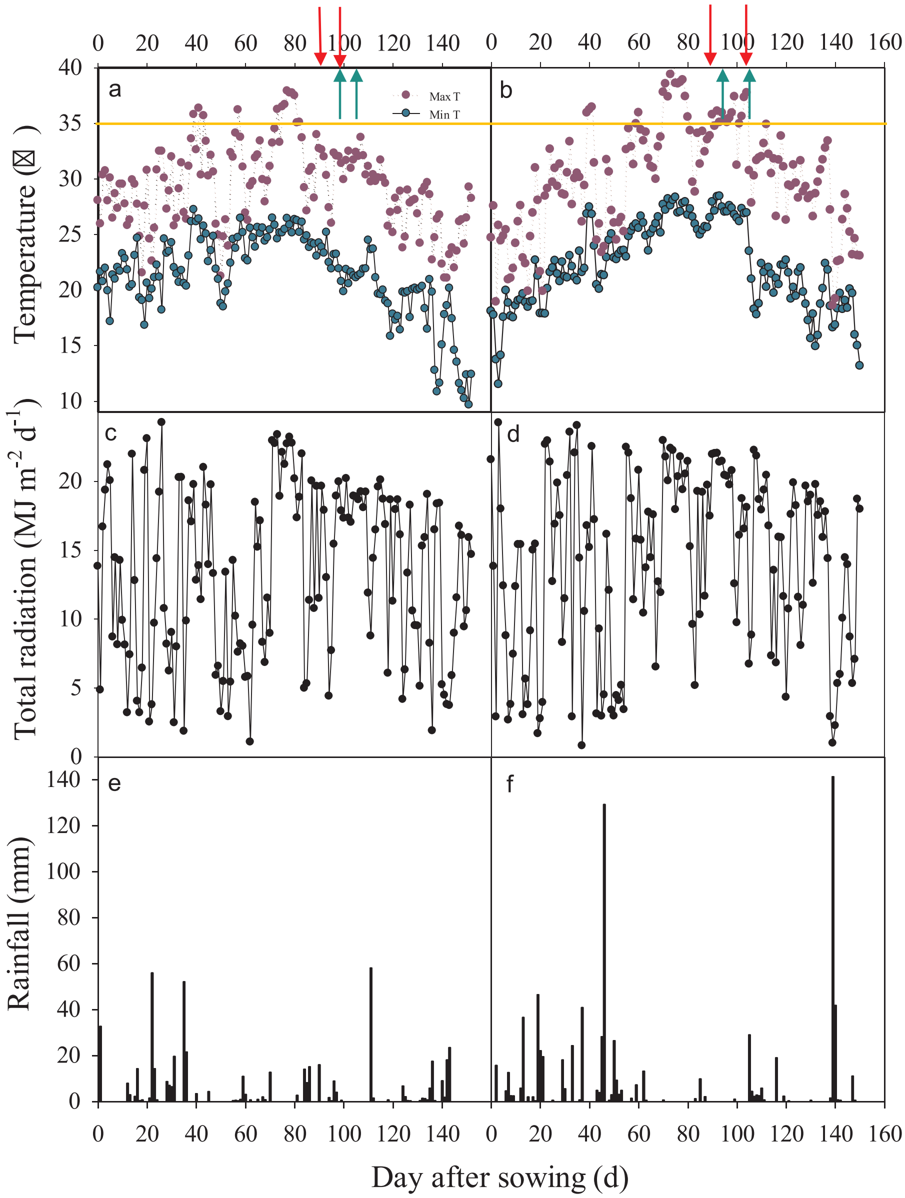

Fig. 1. Daily minimum and maximum temperature (a, b), solar radiation (c, d), and rainfall (e, f) throughout the growing season at Wuxue County, Hubei Province, China in 2015 (a, c, and e) and 2016 (b, d, and f). The distance between two arrows in Fig. 1a and b represents the duration of heading stage for all varieties in 2015 and 2016, respectively. The red arrows show heading stage at FP (90–99 d in 2015 and 90–103 d in 2016), and green arrows show heading stage at SRIP (99–105 d in 2015 and 95–104 d in 2016). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

substantially reduced without affecting yield from studies both at the regional and global scales (Mueller et al., 2012) and field experiments (Cui et al., 2014). To reduce N fertilizer application and increase the NUE in rice production, scientists developed a range of optimized crop management practices such as Site-Specific N Management (SSNM, Dobermann et al., 2002), Real-Time N Management (RTNM, Peng et al., 2006), the San- Ding Cultivation Method (SDCM, Zou et al., 2006), and "Three Controls" Nutrient Management Technology (TCNM, Zhong et al., 2007). Moreover, a set of integrated soil–crop system management practices based on a modern understanding of crop ecophysiology and soil biogeochemistry increased average yields for rice from 7.2 t ha^{-1} to 8.5 t ha^{-1} without any increase in N fertilizer (Chen et al., 2014).

Rice is traditionally grown in flooded condition and consumes approximately 80% of the total irrigated fresh water resources in Asia (Bouman and Tuong, 2001). However, water availability for agriculture production is decreasing as water consumption by industry and cities increases rapidly (Bouman et al., 2007), which threatens the productivity and sustainability of the irrigated rice (Ashouri, 2014). Therefore, many water-saving regimes have been introduced to save water and improve water use efficiency (WUE), such as alternate wetting and drying (AWD) irrigation (Zhang et al., 2008; Ye et al., 2013). However, rainfed-irrigation or rainfed condition are promising ways to reduce water use in rice production in the middle and lower reaches of Yangtze River, where annual rainfall is 800–1400 mm, and there is still an increasing tendency in rainfall (Yang et al., 2010; Li et al., 2011). Compared with flood and AWD irrigation, rainfed condition resulted in a 10% reduction in rice yield, but increased WUE by 52%–96% in Hubei Province, China (Li et al., 2006). Moreover, comparable yield was produced at flooded and rainfed condition in our previous study in Wuxue County, Hubei Province, China (data not shown). In addition to optimization of N and water management, interaction of planting density and N on grain yield has also been investigated. Recently, Tian et al. (2017) demonstrated that adjusting the transplanting density could be an efficient method to reduce the amount of N fertilizer and increase the N fertilizer use efficiency.

Although extensive crop management practices had been investigated and put into practice to reduce input and increase resource use efficiency, progress of genetic improvement in resource use efficiency was slow. Actually, as early as a decade ago, Zhang (2007) proposed strategies to develop Green Super Rice (GSR) varieties to meet the challenges for sustainable rice production. In a narrow sense, the