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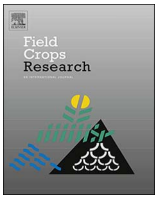

Agronomic performance of inbred and hybrid rice cultivars under simplified and reduced-input practices

Shen Yuan, Lixiao Nie, Fei Wang, Jianliang Huang, Shaobing Peng*

National Key Laboratory of Crop Genetic Improvement, MOA Key Laboratory of Crop Ecophysiology and Farming System in the Middle Reaches of the Yangtze River, College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, Hubei 430070, China

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ABSTRACT

Hybrid rice has higher yield potential than inbred rice under optimum growing conditions when large amount of resources are provided. However, little attention has been paid to the performance of inbred and hybrid rice cultivars under simplified and reduced-input practices (SRIP). Field experiments were conducted to evaluate the performance of widely grown inbred (Huanghuazhan, HHZ) and hybrid (Yangliangyou 6, YLY6) rice cultivars across farmers' practice (FP) and SRIP treatments in central China in 2014 and 2015. Compared with FP, reducing N input by 50.0% ($SRIP_N$) caused maximum yield reduction of 12.8%, while reducing planting density by 33.3% ($SRIP_D$) did not affect grain yield as much as $SRIP_N$. The large reduction in resource inputs did not cause substantial yield losses because of compensation among yield components. The average yield of YLY6 was 1.38 t ha^{-1} higher than that of HHZ. Higher yield of YLY6 was mainly resulted from longer total growth duration, and higher total dry weight, leaf area index, and 1000-grain weight than HHZ. More importantly, the yield advantage of YLY6 over HHZ was greater in SRIP than in FP, which implies that YLY6 was less sensitive to reduced inputs than HHZ. Overall, the yield stability of YLY6 was significantly higher than that of HHZ across the crop management treatments and years. These results suggest that hybrid rice is more suitable to simplified crop management practices with reduced inputs than inbred rice.

1. Introduction

China is the largest rice producer and consumer in the world (Cheng and Li, 2007). Rice yield in China has increased by more than two times over the last five decades (FAO, 2017), which has contributed significantly to the nation's food security. The increase in rice yield was primarily attributed to crop genetic improvement, increased agronomic input, and improved crop management practices (Cassman, 1999). In the past, the main focus of rice research in breeding and crop management was high yielding without much consideration of inputs of labor and other resources in China. Achieving super high yields was also advocated in rice production with ample supply of labor, water, and agro-chemicals. In recent three years, however, Chinese government has issued several key policy documents which emphasized on the increases of crop production efficiency with reduction in various inputs (MOA, 2015; Fang et al., 2016). As a consequence, rice production is in the unprecedented period of transition in China (Peng, 2014).

A serious labor shortage has occurred recently in the rural areas of China with the development of urbanization and the acceleration of industrialization (Fang, 2007). As result, rural labor cost has increased by 4.27 times from 2003 to 2013 (Zhong, 2016). In addition, the increase in the prices of agro-chemicals and seeds was substantial over the same period. Overall, the cost of rice production in China has increased from 10,829 CNY ha^{-1} in 2004 to 17,648 CNY ha^{-1} in 2014 (NDRC, 2015). This has resulted in a large decline in the profit of rice production and farmers' willingness to grow rice (Xu et al., 2010). More importantly, high agro-chemical inputs have put great burdens on the environment in recent years (Zhang et al., 2013). Clearly, it is vital to increase resource use efficiency with simplified and reduced-input practices (SRIP) in rice production.

Inputs of N fertilizer and seeds represent a major proportion of rice production costs, second to labor input. Rice crop in China uses about 36% of the total N fertilizer used for rice production in the world, although its planting area accounts only for 19% of the world total rice planting area (Peng et al., 2002). The average N application rate per unit area for rice production in China is 75% greater than in other countries (Peng et al., 2010). High N input leads to low N use efficiency (NUE) due to rapid N losses (Peng et al., 2006), which may further induce soil acidification (Guo et al., 2010), water pollution (Diaz and Rosenberg, 2008), and increased emissions of greenhouse gas (Cassman

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* Corresponding author.
E-mail address: speng@mail.hzau.edu.cn (S. Peng).

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et al., 2003). Acidified soil can lead to high heavy metal concentration in rice grains (Zhao et al., 2015). The over use of N fertilizer may decrease yield and economic benefit because rice planted in excessive N condition is more susceptible to lodging, pests, and diseases (Cu et al., 1996). Several studies have demonstrated that there is room to reduce total N input in rice production without sacrifice in yield (Peng et al., 2010; Fan et al., 2011).

Transplanting is a major establishment method in most rice producing areas in China. The labor shortage and high seed costs have caused the desirability of reducing planting density in recent years. Farmers transplant rice at a wide spacing to reduce seed and labor inputs. Such practice do not necessarily cause yield losses because the reduced hills m^{-2} are compensated by increased tillering and growth of individual plants (Li et al., 2013). In fact, high planting density could result in a yield loss due to excessive tiller number and leaf area, increased unproductive tiller percentage, and high spikelet sterility (Kabir et al., 2008). Furthermore, the dense canopy and less ventilation around the plants at high density can create favorable conditions for diseases and make plants more prone to lodging (Islam et al., 2008). Therefore, reduction in planting density can be a potential option for SRIP to reduce rice production costs without yield penalty.

Rice grain yield potential has been greatly improved due to the development of semi-dwarf cultivars in the 1950s, hybrid rice in 1970s, and super hybrid rice in 1996 (Peng et al., 2009; Zhang et al., 2009). It is well documented that hybrid rice has 15–20% higher yield potential than inbred cultivars (Yuan et al., 1994; Peng et al., 1999). Peng et al. (2008) reported that super hybrid rice has further improved rice yield potential over ordinary hybrid rice cultivars. The high yields of hybrid and super hybrid cultivars are often achieved under optimum growing conditions when large amount of resources are provided, which lead to a perception that hybrid and super hybrid rice performed better than inbred rice only under high-input conditions (Islam et al., 2007; Katsura et al., 2007; Zhang et al., 2009). There are limited information on the performance of inbred and hybrid rice cultivars under SRIP. In this study, we grew inbred and hybrid rice cultivars under reduced N rate and planting density. The objectives were to (1) determine the effects of SRIP on the yield and yield attributes of inbred and hybrid rice cultivars, and (2) compare the suitability of inbred and hybrid rice cultivars for simplified crop management practices with reduced inputs.

2. Materials and methods

2.1. Site description

Experiments were conducted in farmer's fields during the middle growing season from May to October in 2014 and 2015 at Dajin Township, Wuxue County, Hubei Province, China (29°51′N, 115°33′E, 23 m altitude). Wuxue County is located in central China in the basin of the Yangtze River and it represents a typical agricultural region of central China where agricultural production is highly intensive. Prior to the experiment, soil samples from upper 20 cm layer were collected for analysis of soil properties. Soil had a clay loam texture with pH of 5.29 and 5.27, organic matter of 23.02 and 19.93 g kg^{-1}, total N of 1.79 and 1.83 g kg^{-1}, available P of 12.01 and 49.66 mg kg^{-1}, and available K of 123.3 and 167.5 mg kg^{-1} in 2014 and 2015, respectively. In both years, climate data (daily minimum temperature, maximum temperature, and solar radiation) were collected during the growing season from a weather station located near the experimental site, and are shown in Fig. 1.

2.2. Experimental design

Experiments were laid out in a split-plot design with crop management treatments as main plot and cultivars as subplot and with four replications in both years. For crop management treatments, farmers' practice (FP) was compared with simplified and reduced-input practices (SRIP) including reduced N input ($SRIP_N$) and reduced planting density ($SRIP_D$). The detailed information of three treatments is shown in Table 1. Two widely grown rice cultivars in central China, Huanghuazhan (HHZ) and Yangliangyou 6 (YLY6), were used as the experimental materials. HHZ is an indica inbred cultivar developed in 2006 with Huangxinzhan as the female parent and Fenghuazhan as the male parent (CRDC, 2016). YLY6 is an indica hybrid cultivar developed by two-line system in 2001 with Guangzhan63–4 s as the female parent and Yangdao 6 as the male parent.

Pre-germinated seeds were sown in a seedbed with the sowing date of 10 May in 2014 and 11 May in 2015. Twenty five-day old seedlings were transplanted on 4 June 2014 and 5 June 2015. Seedlings were transplanted at a hill spacing of 13.3 × 30.0 cm in FP and $SRIP_N$, and of 20.0 × 30.0 cm in $SRIP_D$, with two seedlings per hill. Phosphorus (40 kg P ha^{-1}, calcium superphosphate) and zinc (5 kg Zn ha^{-1}, zinc sulfate heptahydrate) were manually broadcasted and incorporated in all plots 1 d before transplanting for basal application. Potassium (100 kg K ha^{-1}, potassium chloride) was split equally and applied at basal and panicle initiation. Nitrogen fertilizers for $SRIP_N$ (90 kg ha^{-1}, basal: panicle initiation = 6:4) and other treatments (180 kg ha^{-1}, basal: mid-tillering: panicle initiation = 4:3:3) were applied in the form of urea in both years. To minimize seepage between plots, all bunds were covered with plastic film and the plastic film was installed to a depth of 20 cm below soil surface. Water depth of 5–10 cm was maintained in the whole period except for the period when mid-season drainage was carried out. Mid-season drainage lasted for 10 days starting at 20 and 15 days after transplanting in 2014 and 2015, respectively. Weeds, pests, and diseases were intensively controlled by chemicals to avoid yield loss.

2.3. Sampling and measurements

Twelve hills were sampled from each subplot at mid-tillering, panicle initiation, heading, and maturity. Panicle and stem (main stems plus tillers) numbers were recorded at maturity and other stages, respectively. Plant samples were separated into leaf, stem (culm plus sheath), and panicle. The green leaf area was measured using a leaf area meter (LI-3100, LI-COR, Lincoln, NE, USA) and was expressed as leaf area index (LAI) at mid-tillering, panicle initiation, and heading. The maximum stems m^{-2} and maximum LAI was defined as the highest values across all stages. Dry weights of leaf, stem, and panicle were determined after oven-dried at 80 °C to constant weight. Panicles at maturity were hand-threshed and filled spikelets were separated from unfilled spikelets by submerging them in tap water. Empty spikelets were separated from partially filled spikelets by winnowing. Three subsamples with each of 30 g filled spikelets and 2 g empty spikelets were taken to determine the numbers of filled and empty spikelets, whereas the entire sample was counted to determine the number of partially filled spikelets. The numbers of filled, partially filled, and empty spikelets were added to determine total spikelets m^{-2}. Dry weights of rachis, filled, partially filled, and empty spikelets were determined after oven-dried at 80 °C to constant weight. Total dry weight was the summation of the dry weights of leaf, stem, rachis, filled, partially filled, and empty spikelets. Productive tiller percentage was defined as the percent of productive tillers (total panicles m^{-2}–main stems m^{-2}) to maximum tillers m^{-2}. Spikelets per panicle (spikelets m^{-2}/panicles m^{-2}), grain filling percentage (100 × filled spikelets m^{-2}/total spikelets m^{-2}), harvest index (100 × yield/total dry weight), and crop growth rate (total dry weight/growth duration in the main field) were calculated. Yield was determined from a 5-m^2 area at maturity in each subplot and adjusted to the standard moisture content of 0.14 g H_2O g^{-1} fresh weight. Grain moisture content was measured with a digital moisture tester (DMC-700, Seedburo, Chicago, IL, USA).

Plant N concentration was determined by an elemental analyzer (Elementar vario MAX CNS/CN, Elementar Trading Co., Ltd, Germany). Plant N accumulation was the summation of N content of each