Field Crops Research 205 (2017) 157–169

Contents lists available at ScienceDirect

Field Crops Research

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

Seasonal differences in the rice grain yield and nitrogen use efficiency response to seedling establishment methods in the Middle and Lower reaches of the Yangtze River in China

Song Chen[a], Qinying Ge[b], Guang Chu[a], Chunmei Xu[a], Jinxiang Yan[a], Xiufu Zhang[a], Dangying Wang[a,*]

[a] China National Rice Research Institute, Chinese Academy of Agricultural Sciences, Hangzhou 310006, Zhejiang, China
[b] Longyang Agricultural Technology Extension Institute, Baoshan 678000, Yunnan, China

ARTICLE INFO

Article history:
Received 25 November 2016
Received in revised form
27 December 2016
Accepted 28 December 2016
Available online 11 January 2017

Keyword:
Rice (*Oryza sativa* L.)
Seedling establishment method
Crop growth season
Nitrogen rate

ABSTRACT

The seedling establishment phase is important for the productivity and profitability of rice (*Oryza sativa* L.) production. To evaluate the role of climatic and physiological factors in different growth seasons in determining the rice grain yield, field experiments were conducted with four seedling establishment methods: manual transplanting (TP), seedling throwing (ST), machine transplanting (MT), and direct seeding (DS). Three nitrogen application rates were also tested (zero, medium, and high N rate) under single, early, and late seasons in the Middle and Lower reaches of the Yangtze River in 2013 and 2014. The results showed that the average grain yields of MT, ST and TP did not differ significantly under the N rate of 127.5–142.5 kg N/ha. Under the high N rate (187.5–202.5 kg/ha), the average grain yields in TP were 6.5%, 10.6%, and 36.7% greater than those in MT, ST, and DS, respectively, suggesting that TP rice had greater yield potential than the others, irrespective of rice seasons. In the single season condition, the grain yield advantage of TP over MT and SC might be attributable to the higher panicle-bearing tiller rate and greater sink size in TP with high N rates. It is less clear why the yield was not significantly higher in the double season. On the other hand, the average grain yields were −3.5%–8.8%, 6.4%–15.0%, and 29.4%–37.1% lower under DS than under the other treatments in the single, early, and late seasons, respectively, suggesting that DS might be a promising choice with less input and stable yield output in the single season. The dramatic yield loss in DS in the late season might be attributed to the reduced grain setting rate (a 20.3%–33.3% decrease under DS compared with the other treatments in the late season), indicating that the current varieties used for TP in the late season were not suitable for DS cultivation. The correlation between the grain yield and climate factors suggests that the light and temperature accumulation in the double season might be a barrier to narrowing the yield gaps between DS and TP rice in early and late rice, but was not the yield-limiting factor in the single season.

1. Introduction

Rice seedling establishment is a key phase in rice production and determines the productivity and profitability of the rice planting system (Yamauchi and Biswas, 1997). Seedling establishment refers to the period between the sowing of the rice seeds in the nursery bed and formation of the root system and canopy structure in the paddy field and is closely associated with the nutrient, water, and light use of plants (Sasaki, 2004; Hara, 2013). To adapt to different ecological and socioeconomic landscapes, several seedling establishment methods have been developed (Zhang et al., 2012; Horgan et al., 2014) based on whether the seed is directly sown in the field (direct seeding rice) or transplanted (transplanted rice). Transplanted rice seedlings can be produced on wet/dry bed nurseries or specialized seed trays and transplanted at different seedling ages using manual, machine, and throwing transplanting methods (Saito et al., 1995; Guo et al., 2010; Badshah et al., 2013; Chauhan et al., 2014; Miao et al., 2016). In China, the dominant method for rice seedling establishment is manual transplanting, which accounts for more than 50% of the rice planting area in China (Zhang et al., 2012). However, this method requires a large amount of energy and labor (Bhushan et al., 2007) and

* Corresponding author.
E-mail address: Wangdanying@caas.cn (D. Wang).

http://dx.doi.org/10.1016/j.fcr.2016.12.026
0378-4290/

involves working in a stooped posture and moving through muddy fields (Thomas, 2002). Given the scarcity of peasant labor due to the growing number of young farmers migrating from rural to urban areas for jobs (Levine et al., 2008), alternative rice establishment methods requiring less labor have been developed in recent decades in China. Throwing transplanting, direct seeding, and machine transplanting accounted for 25.1%, 27.5% and 8.7% of the national rice planting area, respectively, in 2015 (China-National-Rice-Research-Institute, 2016).

Rice is the main staple food crop for more than 3 billion people (Fageria, 2007), and paddy rice accounts for more than 12% of the global crop planting area (FAOSTAT, 2010). Much research has focused on the advantages and disadvantages of each seeding method. For example, direct seeding has considerably lower labor costs than transplanting but faces challenges of weed control, crop lodging, impaired kernel quality, and stagnant yields (Farooq et al., 2011). Transplanting enables better control of weeds, but the plants are prone to transplanting shock, a physiological injury caused by uprooting and replanting (Salam et al., 2001) that affects the process of seedling recovery, slows rice development, and reduces grain yield to varying degrees (Salam et al., 2001; Kotera et al., 2004; Li et al., 2016). In general, adopting different seedling establishment methods leads to different agronomic practices in terms of primary tillage, seedbed preparation, planting density, seeding/planting date, weeding, and water management (Yamauchi and Biswas, 1997; Ehara et al., 1998; Salam et al., 2001; Badshah et al., 2013; Zhao and Liu, 2015; Li et al., 2016). These practices directly affect the seedling/tillering characteristics in the vegetative stage (Chen et al., 2008) and growth period (Guo et al., 2010; Chauhan et al., 2014), as well as biomass accumulation and nitrogen uptake (Ehara et al., 1998; Ali et al., 2015). Ultimately, different seeding methods have an effect on grain yield as well as the efficiency of utilization of resources such as fertilizer, water and/or solar energy (Chen et al., 2008; Ai et al., 2014; Chauhan et al., 2014; Horgan et al., 2014).

The Middle and Lower reaches of the Yangtze River comprise the largest and most important agricultural region of China. They cover an area of 20 million ha (Mha), of which 20.8% is agricultural land. The annual average precipitation is approximately 1000–1500 mm per year, and the effective degree temperature is over 4500–5000 °C days (Chen et al., 2013). The major cropping systems in the Middle and Lower reaches of the Yangtze River are single rice-winter crops and double season rice-winter crops. Direct seeding, throwing transplanting and machine transplanting account for 17.7%, 13.9%, and 12.0%, respectively, in double season rice, and 9.5%, 43.5%, and 2.0%, respectively, in single season rice (Zhang et al., 2012). Numerous reports have compared the yields among different seedling establishment methods (Yamauchi and Biswas, 1997; Wu et al., 2013; Huang et al., 2015); however, limited information is currently available on the seasonal yield differences in seedling establishment methods under similar agronomic practices. Moreover, the physiological and climatic factors that determine agronomical traits and yield performance under single and double rice-cropping systems in farmers' fields in China remain unclear.

To fill this gap, field experiments were carried out under single and double rice-cropping systems in the Middle and Lower reaches of the Yangtze River in China. This study aimed to (1) compare the grain yield and agronomic nitrogen use efficiency of different seedling establishment methods, (2) determine the seasonal variation in grain yield due to the adoption of different seedling establishment methods, and (3) identify the climatic and physiological factors that are critical to yield performance under single and double rice-cropping systems in the Middle and Lower reaches of the Yangtze River in China.

2. Materials and method

2.1. Site description

Field experiments were carried out during three different rice seasons in 2013 and 2014, including the early and late rice season as well as a single rice season. In 2013, the double season experiments (early and late seasons) were performed in the Hua-feng village in Jiangshan county, Zhejiang province (28°73′ N, 118°63′E, 152 m altitude) and in the Ding-shang village in Hanshou county, Hunan province (28°77′ N, 111°91′ E, 66 m altitude). The single rice season experiment was carried out at the experimental farm in Lujiang county, Anhui province (31°26′ N, 117°28′ E, 18 m altitude) and CNRRI's experimental farm in Fuyang county, Zhejiang province (30°05′ N, 119°90′ E, 21 m altitude). In 2014, the double season experiments took place in the Ding-shang village in Hanshou county (28°77′ N, 111°91′ E, 66 m altitude) and in the Heping village (28°25′ N, 113°08′ E, 73 m altitude) in Changsha county, Hunan province. The single season rice was planted at the experimental farm in Lujiang county, Anhui province (31°26′ N, 117°28′ E, 18 m altitude). Both the climate conditions during the growth period and the soil fertility traits of the experimental sites are presented in Tables 1 and 7. Soil sampling and properties were determined according to the Laboratory Manual for Agriculture and Soil Analysis (Pao, 2005). The climate data for the sites were obtained from the National Meteorological Information Center (http://data.cma.cn/site/index.html).

2.2. Experimental design and plant cultivation

The rice varieties used were Chunyou84, Zhongzao39, and Xiangwanxian12 (or Huanghuazhan) for the single, early, and late season, respectively. The field experiment utilized a split-plot randomized complete block design in triplicate. The main plot treatments were four rice establishment methods: manual transplanting (TP), direct seeding (DS), seedling throwing (ST), and mechanical transplanting (MT). Split-plot treatments included three nitrogen levels: 0 kg N/ha, medium nitrogen (MN), and high nitrogen (HN) levels.

For TP, seeds were sown on the nursery bed in late-March, mid-May, and late-June for the early, single, and late rice season, respectively. Rice seedlings with 2–3 fully expanded leaves were transplanted into the puddle field approximately 20–30 days after sowing. For DS, rice seeds were manually broadcast on the plowed, wet paddy field. The sowing date was approximately 10 days later than that in TP to keep the dates of the heading stage similar. For ST, rice seeds were sown on the nursery plate (375 holes per plate) at the rate of 60 g of seeds per plate, and the density of rice seedlings was controlled by the number of plates. For MT, the seedling nursery was similar to that of SC, and the seedlings were transplanted by a rice transplanter (Yanji 2ZT-9356B, JLKA, China). The planting density in TP, ST, and MT followed the guidelines for high-yield rice practice (China-National-Rice-Research-Institute, 2016); the seedling density of DS was approximately 30–50% greater than that of TP according to comments from local experts, and the seeding rate was calculated based on the 1000-grain weight and the germination rate.

Three nitrogen levels were used: control (0 kg N ha^{-1}), medium nitrogen (142.5, 142.5, and 127.5 kg N ha^{-1} in the single rice, late rice, and early rice season, respectively), and high nitrogen (202.5, 202.5, and 187.5 kg N/ha in the single rice, late rice, and early rice season, respectively). Approximately 50% of the nitrogen fertilizer was incorporated as basal fertilizer one day before transplanting. The remaining N fertilizer was broadcast as urea at the tillering and booting stages of the rice, with 25% in each application. A total of 135 kg ha^{-1} of potassium was applied to each plot, with 50% as