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Influence of temperature and solar radiation on grain yield and quality in irrigated rice system

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ABSTRACT

An insight into optimal temperature and radiation (T&R) in different rice phenological stages will contribute to rice cultivation management and crop modeling. This study was aimed to unravel the responses of various rice cultivars to different T&R conditions and to identify the optimal T&R for both yield and quality in the Yangtze River Valley in China. For this purpose, two Indica and three Japonica cultivars were grown under irrigation conditions, respectively, on three sowing dates (April 30, May 10 and May 30) in 2012 and 2013 to acquire different combinations of T&R conditions. Various morphological, yield- and quality-related traits were investigated. This study demonstrated that temperature in this region is a limiting factor compared with radiation. Besides, there was a smaller variation of the average T&R in reproductive stage than in vegetative and grain filling stages. Therefore, T&R in various phenological stages were classified into three major combinations, namely, HL, LH, MM mainly based on temperature in vegetative and grain filling stages. MM combination had similar average daily temperature in both vegetative and grain filling stages compared with the average temperature of rice growth season. HL combination was of higher (at least 1 °C) average daily temperature in vegetative stage and lower (at least 1 °C) in grain filling stage compared with MM. Opposite to HL, LH combination was of lower average daily temperature in vegetative stage and higher in grain filling stage compared with MM. Most of the cultivars harvested the highest grain yield with highest T&R use efficiency in HL combination compared to the other two combinations. When the average temperature in vegetative stage was estimated to be 26–28 °C and 22–27 °C in grain filling stage, higher grain yield can be gained. Moreover, highly significant correlation was found between temperature and LAI (leaf area index), CGR (crop growth rate), and TDW (total above ground biomass) in vegetative stage. HI (harvest index) and all grain-processing and appearance-quality-related traits was highly significantly correlated with temperature in grain filling stage. In conclusion, HL combination with average daily temperature ranges of 26–28 °C in vegetative stage, and 22–27 °C in grain filling stage are recommended to achieve high grain yield and quality for irrigated rice in the Yangtze River Valley in China by adjusting sowing date and crop establishment.

1. Introduction

The impacts of climate changes on crop growth and yield have become increasingly concerned in recent decades (Peng et al., 2004; Lobell et al., 2011, 2012; Tao et al., 2012; Xiao and Tao, 2014; Zhang et al., 2014). The average global surface temperature was estimated by a linear trend to have raised by 0.74 °C ± 0.18 °C over the last 100 years (IPCC, 2007). In addition, accompanied with global warming, heat waves are likely to become more frequent (Tebaldi et al., 2006). Moreover, a distinct decreasing trend of solar radiation has also

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been found in some regions with the increase in aerosol concentration and other atmospheric pollutants (Stanhill and Cohen, 2001; Liepert, 2002; Shuai et al., 2013). China also suffers frequently from climate change. From 1960 to 2009, heat stress caused by global warming was reported repeatedly in the major rice planting areas in China (Tian et al., 2009; Tao et al., 2012; Tao and Zhang, 2013; Zhang et al., 2014). Moreover, with rapid economic development and serious pollution, the increasing concentration of aerosols has already caused a significant solar dimming at least since 1960 in some provinces in China (Che et al., 2005; Zhuang et al., 2011; Tao et al., 2012; Shuai et al., 2013).

China accounts for more than 30% of the global rice production. In China, 34.6% of total production of grains derives from rice (FAOSTAT, 2013), while more than 60% of rice is produced in the Yangtze River Valley (NBSC, 2012). Thus rice cultivation in the Yangtze River Valley influences China's food production and food security for the millions of people in this region. The Yangtze River Valley is a typical East Asian monsoon region that is sensitive and vulnerable to climate changes (Changjiang Water Resource Commission (CWRC), 2001; Fang et al., 2010). Annual temperature of the Yangtze River Valley had increased by 0.33 °C during the 1990 s and sharply increased by 0.71 °C from 2001 to 2005 relative to the 1961–1990 mean (Xu and Ma, 2009). Then tendency rate of monthly minimum value of daily maximum (minimum) temperature, monthly maximum value of daily maximum (minimum) and diurnal temperature range in this place is 0.33 (0.47), 0.16 (0.19), and −0.07 °C decade^{-1}, respectively (Wang et al., 2013). The hot spots of heat stress were also found in single rice growth areas in the Yangtze River Valley (Zhang et al., 2014). In addition, a general decline trend in solar radiation in the middle and lower reaches of the Yangtze River from 1981 to 2009 was discovered (Tao et al., 2013). Because of limited farmland resources in this valley, it is important to know the optimal temperature and radiation characteristics for rice growth in this vulnerable region. This study will support global climate research and modeling and provide the guidance for the management of rice growth in terms of the adaption to climate change.

Like most cereals, whole rice growth season is composed of two distinct sequential phenological stages, i.e., vegetative and reproductive. However, considering the importance of grain filling stage, it is divided into three phenological stages, i.e., vegetative, reproductive and grain filling (Yoshida, 1981). Each rice phenological stage has its own growth characteristics and requires dissimilar temperature and radiation (T&R) to develop well. Numerous researches have described the importance of T&R threshold in different phenological stages. Sipaseuth Basnayake et al. (2007) stated that temperature higher than 12 °C for 30 days after sowing is essential to rice seedling growth. Shimono et al. (2007, 2008) reported that temperature below 20 °C before rice panicle initiation would lead to the rising spikelet sterility. Tashiro and Wardlaw (1991) reported that a temperature ranging from 21.7 to 26.7 °C in grain filling stage is optimal for grain filling, while higher than 27 °C would lead to a reduction of grain yield due to a decrease in grain weight. Besides, Matsui et al. (2001); Matsui and Omasa (2002) observed that high temperature (>35 °C) during flowering would cause sterility in rice spikelets, decrease florets fertility and negatively affect rice reproductive growth. Recently, Sanchez et al. (2014) studied 140 scientific articles, determined the key temperature thresholds and the effect of extreme temperature on rice growth, and found that the optimal temperature in tillering was 28.4 °C, which was highest than that in other stages. While grain filling stage had the lowest optimal temperature (24.2 °C), and they all showed that temperature was of great importance to various stages of rice growth.

On the other hand, many evidences available showed the importance and the positive effect of solar radiation on rice grain yield (Yoshida et al., 1976; Islam and Morison, 1992; Peng et al., 2004). A globally average solar radiation reduction of 0.51 ± 0.05 W m^{-2} per year was reported (Stanhill and Cohen, 2011). The significant reductions will be great threat to rice production. In addition, Tao et al., 2013 found that the solar radiation declined by 0.5 MJ m^{-2} d-1decade-1 in single rice growth duration in the Yangtze River Valley during 1981–2009, which was closely related to yield reduction. Apart from rice, the studies on T&R have also been reported in other corps as well, such as corn, wheat and sorghum, etc. (Gesch and Archer, 2005; Akhtar et al., 2012; Maulana and Tesso, 2013).

However, the limitation of most previous researches lie in that only one or two phenological stages was separately examined, while few studies on the comprehensive effects of T&R throughout three phenological stages during whole rice growth season were conducted, particularly under field conditions. Hence, further studies are needed to determine the effects of T&R in different rice phenological stages. Therefore, this study will focus on (1) investigating the characteristics of T&R in different phenological stages aimed at enhancing grain yield; (2) determining optimal T&R range for achieving high grain yield and quality in the Yangtze River Valley in China; (3) identifying the relationship between T&R in different phenological stages and relevant rice agronomic traits, grain yield and quality.

2. Materials and methods

2.1. Site description and experimental design

Field experiments were conducted in 2012 and repeated in 2013, in the same farmer's field at Lanjie Village, Huaqiao Township, Wuxue County, Hubei Province, China (30°06′N–115°45′E). Hubei province, which located at the center of the Yangtze River Valley, has a humid subtropical climate, one of the most representative climates of the Yangtze River Valley. T&R in this place have a similar change tendency in rice growth season, namely, it increases from April to June, reaches a peak in July and August, and declines thereafter from September to November, although the variation of the average daily solar radiation was more significant than that of the average daily temperature there in the past 15 years (Annex 1). In addition, the average temperature and simulated radiation in the experiment years mostly fall into the variation range of those in the past 15 years.

The properties of soil determined from upper 20 cm layer were: pH 5.81, 20.6 g kg^{-1} organic matter, 0.19 g kg^{-1} total N, 5.28 mg kg^{-1} available Olsen-P, and 46.4 mg kg^{-1} exchangeable K. The treatments were arranged in a split plot design with sowing dates as main plots and cultivars as subplots. Three different sowing dates, April 20 (SD1), May 10 (SD2), and May 30 (SD3) were set as main-plot treatments. Five regional commercial rice cultivars with different temperature sensitivities were designated as the subplots, including two Indica cultivars namely Huanghuazhan, Chengnongshuijing, and three Japonica cultivars namely Liangeng7, Yanggeng4227, and Zhendao11, were allotted to subplots in a size of 6.4 m × 6.4 m with four replications.

The seedlings were transplanted 26–31 days after sowing at a hill spacing of 13.3 cm × 26.6 cm. The total N, P and K fertilizers were applied at the amount of 195, 33, and 125 kg ha^{-1}, in forms of urea, calcium superphosphate, and potassium chloride, respectively. Fertilizer-N was applied in four splits: 36% as basal, 23% at tillering, 23% at panicle initiation and 18% one week after panicle initiation. Fertilizer-P was fully applied as basal, while fertilizer-K was applied in three splits of 30% before sowing, 40% at tillering, and 40% one week after panicle initiation. Field management practices were carried out according to the standards recommended for the region. Insects, diseases, and weeds were intensively controlled by chemicals to avoid biomass and grain yield losses.