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Short-term water management at early filling stage improves early-season rice performance under high temperature stress in South China

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ABSTRACT

Asymmetric warming and frequent temperature extremes are the consequences of climate change that are affecting crop growth and productivity over the globe while heat stress at early filling stage is of serious concern for the early-season rice in double cropping rice system of South China. In present study we assessed different short-term water management strategies to cope with the high temperature at early filling stage in rice. Water was applied as flood irrigation at two various depths i.e., 4–5 cm (I1) and 5–10 cm (I2) during 9:00–18:00 and then drained off at 18:00 as well as applied over-head during different time spans i.e., over-head sprinkle irrigation during 11:00–12:00, 13:00–14:00 and 14:00–15:00 at 60–80% relative humidity (RH) at early filling stage and regarded as S1, S2 and S3, respectively. A control was maintained with the maintenance of 1 cm water layer as normal farmer practice of this region. A fragrant rice cultivar, 'Yuxiangyouzhan' in early March (regarded as early season rice) in both 2014–15 and the effectiveness of different water management strategies were measured by estimating physio-biochemical responses, photosynthesis, yield and quality of rice exposed to high temperature stress at early filling stage. Our results showed that water treatments lowered lipid peroxidation (in terms of reduced malondialdehyde (MDA) contents) whilst proline and protein contents were affected differently. The water treatments also regulated the activities of superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), nevertheless, improved plant photosynthesis and gas exchange, rice yield and quality attributes considerably by lowering severity of canopy temperatures than control (CK). On average, both flood and sprinkler water application were proved effective against high temperature stress, nonetheless, flood irrigated treatments were remained more effective than sprinkler which provided 26.58 and 43.63% higher grain yields in 2014–15, respectively than CK. On average, 5.58 and 11.92% higher grain yields were recorded in flood irrigation than sprinkler irrigation whereas among individual water application treatments, I1 was noted as the most effective regarding grain yield of rice (26.76 and 49.35% higher yield than CK) in both years which suggests that maintenance of 4–5 cm water layer might be helpful for the rice to withstand against high temperature stress at post heading and/or early filling stage in early-season rice production in South China.

1. Introduction

Rice is ranked among the main cereals and recognized as main staple food that contributes to 35–75% of caloric intake for more than three billion peoples over the globe. A projection of world population by 2050 would likely to be 10 billion that signifies that the demand for rice will be higher in the upcoming years (Krishnan et al., 2011). Geographically, rice is widely cultivated over the globe i.e., from 50° N in Central Czechoslovakia and Manchuria-China, on the equator, to 35° S in Uruguay and New South Wales-Australia (Grist, 1986). It is widely grown from the regions received 50–3000 mm rainfall during its growing seasons. China is the largest producer of rice which contributes about 28% of the total rice production worldwide and more than 65% of its population solely relies on it (Liu et al., 2015). Further, during rice growing season, rice grain yields decline by 10% for every degree rise in minimum temperature (Peng et al., 2004). Along with yield, high temperature, particularly at reproductive stage affects gain quality characteristics as well (Cooper et al., 2008).

Global climate change and its impacts on crop production and agro-ecosystems are of serious concern in the recent era especially in a

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country like China where a rigorous increase in industrialization and urbanization make it more vulnerable to environmental extremities (Lin et al., 2007). Recently, concerns about climate change impacts on crop growth and productivity have markedly increased (Krishnan et al., 2007). Climate models estimated an average increase in global surface air temperature by 0.74 ± 0.18 °C from the last century and predicted an increase of 4–5.8 °C in near future (IPCC, 2007). Frequent and repeated heat waves due to global warming during 1960–2009 in major rice growing regions in China was previously reported by various researchers (Zhang et al., 2014).

Like many other cereal crops, rice also have two distinct phases i.e., vegetative and reproductive stages and sometimes can be divided into three phases i.e., vegetative, reproductive and grain filling stage (Yoshida, 1981). Each growth stage has its own temperature requirements for normal growth and development. For example, a report published by FAO (2005) indicated minimum and maximum critical temperature ranges at different rice growth stages i.e., at germination (16–45 °C), seedling emergence (12–35 °C), rooting (16–35 °C), tillering (9–33 °C), panicle heading (15–30 °C), anthesis (22–35 °C) and ripening (12–30 °C). However, Sipaseuth et al. (2007) reported that temperature higher than 12 °C is essential for normal rice seedling growth while temperature below 20 °C at panicle initiation may cause panicle sterility (Shimono et al., 2007). Moreover, a temperature range of 21–26 °C is an optimal range at grain filling stage while temperature ≥27 °C may cause loss in grain weight (Tashiro and Wardlaw, 1991a), however, temperature higher than 35 °C at flowering stage induce spikelet sterility and affects rice reproductive growth severely (Matsui et al., 2001). In a recent report, Sanchez et al. (2014) declared ≈28 °C is the optimal temperature for rice at tillering and ≈24 °C is optimal at grain filling stage, which are highest and lowest optimal temperatures, respectively than other growth stages. Photosynthesis is among those physiological processes that are most sensitive to high temperatures or heat stress whilst reduced photosynthetic rates effects assimilate partitioning, growth and yield of rice (Prasad et al., 2006). High temperature resulted in oxidative stress by producing reactive oxygen species (ROS) (Kreslavski et al., 2007) which in turn scavenged by the activities of anti-oxidants (Ashraf et al., 2015).

In South China, rice is grown twice a year, normally, in March (early season) and in July (late season) (Li et al., 2016; Pan et al., 2017). Moreover, the optimal temperature ranges to get optimum paddy yields during early-seasoned rice in Guangdong province (South China) are as follows: whole growth period is 23–24 °C, whereas from germination to tillering (18–21 °C), tillering to booting (21–25 °C), booting to heading (24–28 °C), and heading to physiological maturity is 27–30 °C (Wang et al., 2012). It has been reported that rice should be sown a bit earlier in Guangdong province for early-season rice in double cropping systems of South China than their normal sowing time (most probably March) in the fields due to the fluctuating rainfall pattern and temperature oscillation caused by a special climatic character of this regions called "*Dragon Boat Water*" (Huang et al., 2011). Recently, Shi et al. (2015) reported a significant increase in post-heading heat stress from 1981 to 2010 in double season early rice regions in China. They further argued that yields of double-season early rice are more vulnerable to heat stress at post-heading stages (such as grain filling) than single-season rice, and emphasized to develop some management strategies to stabilize rice production of this region under high temperature stress. Moreover, recent concerns of Mo et al. (2017) regarding effects of local climatic conditions and/or temperature fluctuations on yield and productivity of rice in Guangzhou, South China should also be addressed by developing some strategies for crop improvement. Keeping in view the potential increase in temperature at reproductive stages in South China, some mitigation and adaptive strategies are need of the day to maintain and/or even improve the rice productivity under high temperature in this region. To date, very few studies have been conducted to improve the rice performance by managing high temperature at early filling stage under field conditions in South China. Hence, this study was conducted in Guangdong province (major rice producing province in South China) with the hypothesis that rice yields can be stabilized and/or even improved by managing high temperature stress with short-term water management at early filling stage.

2. Materials and methods

Two year field experiment between March to July in 2014 and 2015 was conducted at Experimental Research Farm, College of Agriculture, South China Agricultural University, Guangzhou, (23°09′N, 113°22′E and 11 m from mean sea level) China. Rice grown in this season is regarded as 'early rice' in double rice cropping system of South China.

2.1. Plant material and growth conditions

Seeds of an aromatic rice cultivar 'Yuxiangyouzhan', a well-known and widely grown fragrant rice cultivar in South China, were collected from College of Agriculture, South China Agricultural University, Guangzhou China. Before sowing, seeds were soaked in water for 12 h at room temperature and then put it into the constant temperature incubator in 38 °C in dark for 12 h, shade dried and the germinated seeds were sown in PVC trays for nursery raising. PVC trays were placed in puddled field and covered with a plastic sheet to avoid any environmental extremities. Nursery was sown between 10–12th of March and transplanted in the puddled field between 10–12th of April in both years. The experimental field was under paddy cultivation from many years and the soil was sandy loam consisting 25.10 g/kg organic matter, 1.43 g/kg total nitrogen, 83.75 mg/kg available nitrogen, 0.96 g/kg total phosphorus, 22.38 mg/kg available phosphorus, 18.15 mg/kg total potassium, 150.20 mg/kg available potassium and 6.48 soil pH. This region has subtropical-monsoonal type of climate with mean annual air temperatures of 21.9 °C, mean annual maximum and minimum air temperatures of 31 °C in June and 15 °C in January, respectively (Li et al., 2016; Mo et al., 2016). At early filling stage during treatment application, the temperature range was 22–37 °C with 23–97% relative humidity in 2014 while in 2015 the temperature range was 24–36 °C with 37–100% relative humidity (Fig. 1a and b). After years of rice planting and based on our personal observations that rice grown in this region faced a heat wave which often lead to high temperature stress on the start of early filling stage (average temperature throughout the day reaches above 33 °C) which often caused panicle sterility and severe damage to grain filling.

2.2. Treatment description

Plants were grown under normal growing conditions till early filling stage and special water supply treatments were imposed between 12 and 17 June in 2014 and 14–19 June in 2015 (at early filling stage). The treatment description is as below:

CK: Maintenance of 1 cm water layer at soil surface throughout day and night (normal practice, soil water potential soil water potential (Ψsoil) = 0 kPa, measured by soil moisture meter (5M/HT4-TEN-30, Chinese Academy of Soil Sciences, Nanjing, China)).

I1: Maintenance of 4–5 cm water layer at soil surface between 9:00–18:00 and then drained off at 18:00.

I2: Maintenance of 8–10 cm water layer at soil surface between 9:00–18:00 and then drained off at 18:00.

S1: Overhead sprinkle irrigation to rice at 11:00–12:00 with 60%–80% relative humidity (RH).

S2: Overhead sprinkle irrigation to rice at 13:00–14:00 with 60%–80% relative humidity (RH).

S3: Overhead sprinkle irrigation to rice at 15:00–16:00 with 60%–80% relative humidity (RH).

The treatments were arranged in randomized complete block design (RCBD) in triplicate in each year with net plot size of 32 m^2. In the summer of South China, the temperature is reducing after 18:00 near