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Temperature and drought impacts on rice production: An agronomic perspective regarding short- and long-term adaptation measures

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ABSTRACT

This review addresses short- and long-term adaptation strategies in rain fed and irrigated rice production systems under two climate change scenarios, specifically temperature increases and drought incidence. Each scenario is discussed based on rice plant physiological responses to abiotic stress and, where applicable, consequent yield losses. Possible short- and long-term adaptation measures, mainly focused on crop management strategies and germplasm development, are suggested to overcome production losses. Increased temperature, for example, can adversely affect rice yields either as a result of spikelet sterility or reduced accumulation of assimilates. Most agronomic operations to minimize the impact of increased temperatures involve early sowing or the use of early maturing rice cultivars to avoid high temperatures at grain filling. These measures might be feasible, but inadequate, as periods of increased temperature become more frequent and severe particularly in regions where temperatures are already above optimum for rice growth. On the other hand, rice germplasm from exceedingly warm environments can be used for selecting traits which are appropriate for the development of high temperature stress-tolerant rice cultivars. Drought incidence causes stomata closure, which reduces the leaf CO_2/O_2 ratio, resulting in photosynthesis inhibition and subsequent reductions in biomass production and the life cycle of the plant. These are manifested in significant yield losses. Drought is a common phenomenon in many rice growing environments, and research on developing cultivars capable of escaping, avoiding and/or tolerating drought merits further attention. Crop management, including water management techniques, to mitigate drought stress has also advanced. The implementation of a water-saving technology called alternate-wetting and drying, for example, enables optimum use of irrigation water and reduces methane emissions by 48% compared to continuous flooding of rice fields. Therefore, the suggested adaptation measures are also aligned and discussed based on their potential to decrease methane emissions from rice fields. This paper highlights the importance of germplasm development and improved agronomic practices as the center piece of climate change adaptation in rice farming systems.

1. Introduction

Rice is one of the most important food crops, being a staple food for about half of the world's population (Fageria, 2003). Rice production must be increased about 60% to meet dietary needs by the year 2025 to match the explosive increase in world

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population (Fageria, 2007). However, the increasing environmental stress, continuing deterioration and shrinkage of arable land, and scarcity of irrigation water pose serious threats to global rice production (Garg et al., 2002). Given the sensitivity of rice to climate changes particularly those related to temperature increases (Schlenker and Roberts, 2009) and extended drought periods (Yoshida et al., 2015), coping with the future global demand for rice seems a difficult task. Additionally, changes in the length of the growing period due to temperature increases will affect not only rice yield but also will shift farming systems away from rice towards more suitable crops with adequate temperature optima (Korres et al., 2016). Most of the rice is currently cultivated in regions where temperatures are already above the optimal for growth (28/22 °C); therefore, any further increase in mean temperature or incidents of high temperatures period during sensitive stages of the crop may adversely affect the performance of the crop (Krishnan et al., 2011).

India and Bangladesh, for example, were already producing around a third of global rice production by 2012 but they may no longer be suitable for rice production in the future.

Drought stress is a major constraint to rice production, particularly in water-limited environments (Bernier et al., 2008; Mishra et al., 2014) such as those for upland rice cultivation. Large areas of lowland and upland rainfed rice occupy 31% and 11% of the global rice-growing area, respectively (Murty, 2001; Kamoshita et al., 2008). Evenson et al. (1996) reported an average annual global reduction of rice production due to drought of 18 Mt. The aim of this review is to highlight the physiological and yield response of rice to temperature and drought period increases and to suggest short- and long-term adaptation measures that are not merely feasible but optimal in terms of rice yield maintenance but also methane emissions.

2. Response of rice yield and physiology to climate change

2.1. Background information

The increasing release of greenhouse gases due to various anthropogenic activities is very likely going to accelerate climatic change (Glover et al., 2008). Plausible climate change scenarios include higher atmospheric CO_2 concentrations, higher temperatures, and changes in precipitation (Timsina and Humphreys, 2003; Trenberth et al., 2007). The effects of temperature and drought on rice physiology and yield will be discussed briefly in the following sections. The reader is advised to consult the informative reviews of Wassmann et al. (2009) and Krishnan et al. (2011) for an in depth analysis of temperature and drought stress on rice phenophysiological responses and yield production.

2.2. Effects of temperature increases on rice yield and physiology

2.2.1. Effects of temperature increases on quantitative and qualitative attributes of rice yield

Predictive models, based on low and high greenhouse gas emission scenarios, indicate that global surface temperature is likely to increase by 1.1–2.9 °C or by 2.4–6.4 °C by 2050 for the low and high emissions scenarios, respectively (Meehl et al., 2007). Increases in temperature can cause irreversible damage to plant growth and development (Wahid et al., 2007). Baker et al. (1992) and Matthews et al. (1997) reported a rice yield reduction of 7–8% for each 1 °C increase in daytime temperature from 28 °C to 34 °C. Many other scenarios have predicted higher yield reductions due to temperature increase. The yield of current varieties in southern Japan, for example, would be reduced by up to 40% (Horie et al., 1996). The sub-Saharan area has already seen declines in per capita agricultural output in recent decades, especially for staple foods including rice production (Adesina, 2010; Liu et al., 2008). Fig. 1 depicts the effects of temperature on rice yield and yield components based on which it becomes obvious that the optimum rice temperature for maximum yield and yield components lies between 22 and 30 °C.

Temperature greater than these depicted in Fig. 1 could cause irreversible yield losses mainly through spikelet sterility (Matsui et al., 1997). High temperature prevents swelling of pollen grains resulting in poor thecae dehiscence (Matsui et al., 2001), which eventually results in reduced panicle dry weight (Oh-e et al., 2007). In addition high temperature stress could also reduce panicle number per plant (Fig. 1).

Peng et al. (2004) and Mohammed and Tarpley (2009) found a negative correlation between increased night temperatures and rice yield. Since the majority of global rice is grown in tropical and semitropical regions, it is likely that higher temperatures would negatively affect rice production in these areas due to an increase in floret sterility that would subsequently decrease yields (Prasad et al., 2006a). Rice yield losses due to occasional extreme high night temperatures are already encountered in the US. This problem could get worse if temperature continue to increase (Peng et al., 2004).

Increased temperatures will also affect the grain quality of the rice mainly through increased chalk content (Wassmann and Dobermann, 2007). Lisle et al., (2000) reported a higher number of chalky grains in rice grown in a glasshouse at 38/21 °C compared to rice grown at 26/15 °C day/night temperature. Krishnan et al. (2011) presented that high-temperature stress causes loose packing of amyloplasts, resulting in the formation of chalky grains. Kobayashi et al. (2007) reported detrimental effects of increased temperatures on the grain quality of some *Oryza japonica* varieties under field conditions. Additionally, Morita et al. (2002) observed increases in damaged rice grains either at high day- or night-time temperatures. Likewise, high-temperature stress during ripening results in starch with a higher gelatinization temperature (Krishnan et al., 2011).