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Review

Effects of water deficit stress on agronomic and physiological responses of rice and greenhouse gas emission from rice soil under elevated atmospheric CO_2

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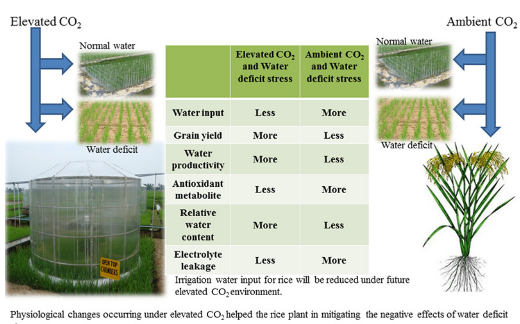
HIGHLIGHTS

- Agronomic management options are promising for mitigating water deficit stress.
- Rice crop behavior under elevated CO_2 condition was discussed.
- Opportunities under elevated CO_2 are reviewed to explore the future research needs.

GRAPHICAL ABSTRACT



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ABSTRACT

Rice is the foremost staple food in the world, safeguarding the global food and nutritional security. Rise in atmospheric carbon dioxide (CO_2) and water deficits are threatening global rice productivity and sustainability. Under real field conditions these climatic factors often interact with each other resulting in impacts that are remarkably different compared to individual factor exposure. Rice soils exposed to drought and elevated CO_2 (eCO_2) alters the biomass, diversity and activity of soil microorganisms affecting greenhouse gas (GHG) emission dynamics. In this review we have discussed the impacts of eCO_2 and water deficit on agronomic, biochemical and physiological responses of rice and GHGs emissions from rice soils. Drought usually results in oxidative stress due to stomatal closure, dry weight reduction, formation of reactive oxygen species, decrease in relative water content and increase in electrolyte leakage at almost all growth and developmental phases of rice. Elevated atmospheric CO_2 concentration reduces the negative effects of drought by improving plant water relations, reducing stomatal opening, decreasing transpiration, increasing canopy photosynthesis, shortening crop growth period and increasing the antioxidant metabolite activities in rice. Increased scientific understanding of the effects of drought and eCO_2 on rice agronomy, physiology and GHG emission dynamics of rice soil is essential for devising adaptation options. Integration of novel agronomic practices viz., crop establishment methods and alternate cropping systems with improved water and nutrient management are important steps to help rice farmers cope with drought and eCO_2. The review summarizes future research needs for ensuring sustained global food security under future warmer, drier and high CO_2 conditions.

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1. Introduction

Over the past few decades, water scarcity has emerged as one of the biggest challenges for sustaining rice production. Development of novel water saving technologies is an important step to help rice farmers cope with water scarcity (Liu et al., 2015). Rice crop is known to have high water requirement. Approximately 80% of the total irrigated fresh water resources in Asia is used by the rice crop (Bouman and Tuong, 2001). Farmers generally keep the field continuously flooded from transplanting to physiological maturity of rice crop. However, it is known that continuous flooding is not necessary for rice to achieve high yields. After seedling establishment phase, even in the absence of standing water in field, rice plant can extract soil water from the below surface soil around root zone (Lampayan et al., 2015). Therefore, rice may be one of the most opportune crops where large volume of water saving may be possible.

Rice is the second most important staple food crop in the world, grown on 160 million ha with an annual production of 740 million tons (Pathak et al., 2018). It is also a foremost staple food in Asia, where about 92% of the global rice is produced and consumed and source for about 35–80% of total calorie intake of Asian population. In India, rice is grown on 43 million ha, with a production of 165 million tons (Pathak et al., 2018). These accounts for 27% of the world rice area and, 22% of rice grain production. Worldwide, rice demand is increasing at the rate of 6% due to change in the dietary habit of the majority of the population of western and central Africa (Carriger and Vallee, 2007). Almost 75% of the global rice supply comes from 79 million ha of irrigated land in Asia. Thus, global as well as Asian food security in present and future will depend largely on the irrigated rice production system.

Some of the water saving technologies in rice farming developed by scientists worldwide are alternate wetting and drying (AWD), continuous soil saturation, irrigation at fixed soil moisture tensions varying from 0 to −40 kPa, or irrigation at an interval of 1–5 days after disappearance of standing water (Wang et al., 2017; Peng et al., 2011; Ghosh and Singh, 2010; Qin et al., 2010; Sharma et al., 2002; Singh et al., 2002; Bouman and Tuong, 2001; Borell et al., 1997; Chaudhary, 1997). Such water management systems are called partial aerobic rice systems (PARSs). Findings of these studies suggest that water saving technologies could increase crop water productivity without severe reductions in crop yield. Contrary to this, true aerobic rice system is a new production system in which rice is grown under nonpuddled, nonflooded, and nonsaturated soil conditions (Bouman et al., 2006; Tuong and Bouman, 2003).

The rice varieties cultivated under aerobic rice system (ARS) should be nutrient-responsive and adapted to aerobic soils having a yield potential of 70–80% of high-input flooded rice (Lafitte and Bennet, 2002). The irrigation practice in aerobic rice is by surface irrigation, which aims at keeping the soil wet, but not flooded or saturated. In practice, irrigation is applied to bring the soil water content up to field capacity, once a lower threshold has been reached. The water requirement of aerobic rice is potentially much less than that of flooded rice because of: (1) absence of puddling (2) reduced seepage and percolation losses (3) absence of evaporation losses from the ponded water layer (Bouman et al., 2005). Water requirement in aerobic rice systems were 30–50% less than in flooded systems; however, yields were also 20–30% lower (Bouman et al., 2006; Yang et al., 2005). For most of the upland crops, the threshold limit of irrigation is usually the soil water content halfway between field capacity and wilting point (Doorenbos and Pruitt, 1984). But for aerobic rice, the optimum threshold for re-irrigation still needs to be determined for different soil, varieties and agro-climatic conditions.

The timing and amount of irrigation are two critical factors for improving the water use efficiency (WUE) under limited water supply conditions. Due to lack of fixed criteria for re-watering the plots under different soil and climatic conditions, AWD often results in over-irrigation or under irrigation. It is difficult to decide when the best time to rewater the rice crop is? The number of days that the soil is left dry varies from 6 to 8 days for heavy soils and 4–5 days for lighter soils depending on the soil texture, crop stage, variety and weather (Bouman et al., 2007a). Yang et al. (2007) used tensiometers for measuring soil water potential (SWP) and concluded that SWP can be used as an irrigation index under different types of soil and climatic conditions. Additionally, several advantages for using SWP measured by tensiometer as a robust descriptor of the soil water regime were described in previous studies (Freire et al., 2018; Gutiérrez-Gómez et al., 2018; Mota et al., 2018; Kumar et al., 2017a; Dasgupta et al., 2015). Efficacious and beneficial use of AWD technologies requires improved understanding of crop response at varying levels of SWP and developing viable water-yield relationships for optimal crop productivity.

Water deficit stress (WDS) caused by varying levels of SWP is one of the main factors limiting rice production globally, as rice is more susceptible to WDS than other cereals (Norton et al., 2017; Haefele et al., 2016; Kato et al., 2004). It is imperative to increase rice productivity under limited water situation to alleviate food insecurity and poverty. One of the options could be the identification of WDS resistant rice cultivars through drought tolerance degree (Zu et al., 2017). It is a simple and accurate method to evaluate rice drought tolerance. Stress response by rice crop is a complex phenomenon including biochemical and osmotic adjustments (Chaves et al., 2009). WDS decreases plant growth by reducing cell division and cell elongation caused by turgor loss (Lawlor