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Screening of Rice Cultivars for Morpho-Physiological Responses to Early-Season Soil Moisture Stress

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Abstract: The majority of rice (*Oryza sativa* L.) produced in the southern USA is drill-seeded and grown under upland-like conditions because permanent flooding is established after the four-leaf stage. Therefore, rice during the seedling growth stage will be subjected to variable soil moisture content. A greenhouse experiment was conducted to evaluate the performance of 15 rice cultivars commonly grown in Mississippi of USA under early-season soil moisture stress. Twenty morpho-physiological parameters of rice seedlings subjected to three different levels (100%, 66% and 33% field capacity) of soil moisture, from 10 to 30 d after sowing, were measured. Significant moisture stress × treatment interaction ($P < 0.001$) was observed for most of the parameters. Further, the total drought response index (TDRI) was developed to score the cultivars for drought tolerance with the variation from 26.88 to 36.21. Accordingly, the cultivars were classified into different groups of tolerance. The cultivars CL152 and CL142-AR were classified as the least and the most tolerant to drought based on TDRI and standard deviation, respectively. Even though both total root ($R^2 = 0.98$) or shoot ($R^2 = 0.76$) drought responses indices were positively correlated with TDRI, root traits were important in deriving the indices. Therefore, TDRI could be used to select cultivars for drought tolerance in a given environment and develop rice varieties with early-season drought tolerance. However, further research is needed to identify and characterize tolerance at other stages to assist breeding programs in rice.

Key words: drought; field capacity; morpho-physiological parameter; *Oryza sativa*; root; shoot; soil moisture content; total drought response index

Rice (*Oryza sativa* L.) growth and development is sensitive to water-limited conditions due to the lower ability of taking up resources compared to other crops (Henry et al, 2016). Upland rice develops deep and thick roots during drought stress (Fukai and Cooper, 1995) to improve its root hydraulic properties (Lipiec et al, 2013) and extract water from deeper soil profiles (Asch et al, 2005). Deep and thick roots allow upland rice to yield higher than lowland rice under drought stress conditions (Fukai et al, 1999). The rice plant shows several morphological changes at different growth stages in response to drought stress. These involve reduced plant height, leaf rolling, leaf senescence, stomatal closure, decreased leaf elongation and lower dry matter production (Farooq et al, 2010; Kumar et al, 2015). Physiological changes, such as chlorophyll content, canopy-to-air temperature differences, transpiration and photosynthesis, have also been observed in response to water stress (Fukai and Cooper, 1995). Drought can delay many development processes like panicle initiation and anthesis in rice during the reproductive stage (Rahman et al, 2002) that can lead to spikelet sterility and reduced number of panicles per unit area (Boonjung and Fukai, 1996; Yue et al,

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2006). Thus, reduced biomass at the vegetative stage and lower number of filled grains at the reproductive stage under drought stress severely reduce the final yields in rice (Fukai et al, 1999). However, the impact of drought stress on various morpho-physiological changes significantly differ among rice cultivars (Yue et al, 2006; Kumar et al, 2015) which underscore the importance of screening rice germplasm for drought tolerance. Therefore, analyses of different root and shoot traits and their response to drought can be useful for improving the selection criteria in the breeding of drought-resistant cultivars and for identification of genetic donors for drought tolerance in rice (Fukai and Cooper, 1995).

Different methods have been used in previous studies to examine drought tolerance among rice cultivars at different growth stages (Fukai et al, 1999; Yue et al, 2006; Todaka et al, 2015). These studies have recognized the reproductive stage as more critical to drought stress in rice. Drought scoring was used as a primary criterion for screening rice genotypes for drought tolerance at later growth stages or under field conditions (IRRI, 2014). Several genetic approaches like identification of quantitative trait loci (QTLs) have been explored to study the stress tolerance in rice at the reproductive growth stage (Ye et al, 2012). Despite extensive research, little attention has been paid to the genetic aspects of root growth responses to soil moisture stress (Suralta et al, 2008; Fleury et al, 2010). Further, few studies have addressed rice susceptibility to moisture stress during the early growth stages (Islam et al, 2012; Singh et al, 2017). Aforementioned studies have mainly made use of osmotic media, like polyethylene glycol and NaCl, to determine seed germination response against drought stress under *in vitro* conditions. Greenhouse studies have successfully determined morphological and physiological growth and development of seedlings in response to drought stress by developing different levels of soil moisture content (Gajanayake et al, 2013). The rate at which the leaves initiate from the shoot apex determines the plant growth rate and is highly controlled by the environment. The four-leaf stage (V4 stage) in rice is synonymous with the end of the seedling stage. Therefore, developing and maintaining different soil moisture contents from emergence to the V4 stage could be an effective approach to study moisture stress response of rice seedlings under greenhouse conditions.

Dry direct seeding is a practice of sowing seeds in dry soils or soils having moisture levels below field capacity. Kumar and Ladha (2011) reported that 67% of rice is dry direct seeded in the United States of American. The erratic distribution of rainfall results in that only 28% of the annual rainfall occurs during April to September (Kebede et al, 2014), which often results in prevailing dry climatic conditions at the time of the rice growing season in Mid-South of USA. Studies on screening and selection of the rice cultivars suited to the dry direct seeding method in the rice-producing states of USA like Mississippi are scarce. Also, no drought tolerant cultivars have been identified that could be made available to rice farmers to combat the impact of dry soil conditions during early season growth. Rice farmers, therefore, can suffer serious economic loss resulting from poor stand establishment under dry direct seeding, which often gets worse with increased weed competition. However, under no rainfall condition, the rice farmers in Mississippi go for one or two flushing following planting to stimulate seedling establishment. The flushing involves standing water in the rice fields during seedling stage followed by drainage. However, flushing not only uses large quantities of water but also increases a lot the cost to run water into the fields. This in turn increases farmer's investment required to produce rice, thereby reducing the profitability of rice production. Moreover, the adoption of water saving strategies like direct drill seeding, dry bed planting and multiple inlet systems (Vories et al, 2005) to replenish water in the Mississippi alluvial aquifer may increase the risk of the rice cultivars being exposed to moisture stress during the early stages of growth and development. Thus, selection and development of drought tolerant cultivars is a more practical and sustainable solution to boost up and complement these water saving strategies. The overall objective of this study, therefore, was to identify tolerance to drought stress among rice cultivars based on different levels of soil moisture stress subjected during the early seedling growth stage. The specific objective was to classify the rice cultivars based on their degree of tolerance to the different levels of soil moisture stress.

MATERIALS AND METHODS

Seed materials

The 15 rice genotypes involved a diverse germplasm pool that includes both pure line cultivars and hybrids