Drought responses of rice (*Oryza sativa*) under various drought severity levels and durations in biotron and field

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Introductory essay at the Faculty of Landscape Architecture, Horticulture and Crop Production Science 2015:1

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Photo: well watered (left) and drought stressed (right) rice plants

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Summary

Rice is an important staple food in human nutrition. Due to its semi-aquatic phylogenetic origin, rice is mainly produced in water intensive system. However, because of climate change, competition for water with other crops and modernization, rice production is becoming threatened by water shortage. Since drought is predicted to increase in the future, efforts have been made to develop drought adapted rice varieties. However genetic improvement has been slowed by the complex nature of drought and its strong interaction with the environment. Understanding the stress physiology will be a vital asset for the mitigation of climate change impacts in specific environments. This research project proposes to study physiological and grain quality responses of rice to various drought severity levels and durations in field and biotron environments.

Taxonomy, origin and cultivation of rice

Rice is the most widely consumed staple food in the world, particularly in Asia. Rice provides 20% of the world's dietary energy supply. It is also a good source of thiamine, riboflavin, niacin and dietary fibre (FAO 2004).

Rice belongs to the genus *Oryza* within the Poaceae family. Only two species (*O. sativa* and *O. glaberrima*) are cultivated among about 20 *Oryza* species. *O. sativa* (Asian rice) comprises the *indica* and *japonica* types. The wild progenitors of Asian rice are *Oryza rufipogon sensu stricto* and *Oryza nivara*, which are thought to be native to South and Southeastern Asia, extending northwards into Southern China (Fuller 2011), while *O. glaberrima* (African rice) originated from the inland delta of the Niger river (Wopereis 2009).

Rice is a semiaquatic plant and its production is water intensive (Wassmann *et al*. 2009, Bouman *et al.* 2007). Around 50% of the land used for rice production is irrigated, 34% of total rice cropped area is rainfed lowlands, 9% is rainfed uplands, and 7% flooded systems. Irrigated rice alone contributes 75% of the global rice production (IRRI 2007).

Drought and drought responses in rice

Drought is one of the major abiotic stresses that constrain rice production and yield stability (Lanceras *et al.* 2004). Drought adaptation mechanisms have been shown to be complex phenomena governed by different physio-biochemical processes at cell and organism level (Tripathy *et al*. 2000).

Rice responses to drought expressed by roots, shoots and leaves depend on the timing of this stress during plant growth (early, vegetative, intermittent or terminal drought), crop growth stage (seedling, vegetative or reproductive), drought severity level (mild or severe), edaphic properties and the target environment (Fukai and Cooper 1995). Terminal drought is the most detrimental to grain yield (Xangsayasane *et al.* 2014) whereas plants may recover from early and vegetative drought later in the growing season.

Drought avoidance (Fukai and Cooper 1995) through development of a deep root system capable to extract water from deeper soil layers (Price *et al*. 2002, Yue *et al*. 2006, Gouda *et al.* 2012), may be a rice plant response under water scarcity. Drought escape is achieved by short growth duration genotypes that avoid the reproductive or terminal drought (Price *et al*. 2002, Bing *et al.* 2006). Physiological mechanisms as osmotic adjustment (Kato *et al.* 2011**;** Gowda *et al.* 2012, Wei *et al.* 2014), or stomatal conductance (Comstock 2002; Price *et al.* 2002), along with biomass production or partitioning of grain and drought response index (DRI) are important traits for adaptation of rice to drought-prone sites (Guan *et al.* 2010, Xangsayasane *et al.* 2014). Furthermore, rice lines with enhanced adaptation to drought express high levels of chlorophyll, soluble sugars and proline, while their malondialdehyde content is lower than in susceptible plants (Wei *et al.* 2014). Under water deficit conditions, grains from a transgenic rice variety (developed by inserting AtCYP78A7 encoding a cytochrome P450 protein) which showed adaptation to drought, expressed higher content of cysteine, palmitoleic acid, oleic acid, arachidic acid, behemic acid and magnesium than the wild type which had higher levels of glycine, tyrosine, linoleic acid, linolenic acid, lignoceric acid and calcium. All compounds mentioned above were present at lower levels in both genotypes under well-watered conditions. In addition, the levels of copper and potassium were lower, or the same, under drought compared to well-watered conditions for the wild type, while they increased in transgenic rice under drought conditions (Nam *et al.* 2014).

Rice breeding for enhanced drought adaptation

Selection criteria

Kamoshita *et al*. (2008) differentiated plant characters enhancing adaptation to drought in rice into primary, secondary, integrative, phenology related, or plant type traits. Primary constitutive traits refer to root size, their branching arrangement and distribution pattern.

These root architectural traits determine hardpan penetration and osmotic adjustment potential. On one side, primary traits influence leaf drought adaptation through secondary traits like leaf water potential (LWP), canopy temperature and drought sensitivity scores which in turn affect integrative traits (yield components) and grain yield. On the other side, plant type characters such as number of tillers and plant height, as well as phenology traits (flowering time) may induce transpirational changes which in turn affect secondary and integrative traits' expression (Kamoshita *et al*. 2004).

Grain yield response under drought stress seems to result from a cumulative effect of several of the traits mentioned above, but may be influenced also by other factors. Variation in yield components under water stress may be related to variation in dry matter production (Boonjung and Fukai, 1996) and/or dry matter partitioning from other parts of the plant to the grains as a result of the capacity of roots, shoots and leaf system to translocate water and nutrients to different parts of the plant and effectively maintain evapotranspiration and photosynthesis (Guan *et al*. 2010). Moreover, the yield response behavior seems to be influenced by the moisture retention capacity of roots, shoots and leaves during the grain filling stage (Jain *et al.* 2013). Ouk *et al*. (2006) reported that grain yield of genotypes with higher drought response index (DRI) was less affected by drought. Plant water potential, leaf drought sensitivity score and grain yield components like spikelet infertility (Jearakongman 2005) seem more likely correlated to grain yield under managed stress (Babu *et al*. 2003; Atlin *et al*. 2004; Yue *et al*. 2006). Depth and thickness of root as well as conservative water use, playing a role in avoiding drought (Blum 2011), may influence the yielding performance under drought more than drought adaptation mechanisms (Kamoshita *et al*. 2008). For increased grain yield under drought, Serraj *et al*. (2009) proposed an optimization of physiological processes involved in plant response to drought, an efficient water use, dehydration- avoidance mechanisms as well as using genotypes well adapted to the target environment.

Problem description

Climate change scenarios (Wassmann *et al*. 2009) indicate water scarcity and drought to be much more frequent and intense in the near future (Turral *et al*. 2011). To face the drought increment in the future, an alternative sustainable measure is the use of cultivars with enhanced drought adaptation in combination with an efficient management of available water (Serraj *et al.* 2011). Hence, an increasing awareness of future water shortage has generated efforts to breed rice cultivars with enhanced adaptation to drought. The development of such cultivars has been hampered by the complex nature of drought adaptation, genotype × environment interactions and the difficulty of having an effective drought screening method (Verulkar *et al.* 2010).

Early research proposed indirect selection based on secondary traits related to tissue water content and water potential for improved yield (Jongdee *et al*. 2002, Pantuwan *et al*. 2002; Price and Courtois 1999, Fukai *et al*. 1995). This approach was however unsuccessful for improving grain yield under drought. Recent research shows the advantage of selecting high yielding cultivars (Kumar *et al*. 2008; Verulkar *et al*. 2010) by adopting grain yield as selection criterion and evaluating lines under both stress and irrigation (Verulkar *et al*. 2010). Nevertheless, phenotyping methodology that allows a clear distinction between drought tolerant and drought susceptible genotypes is yet to be developed (Kumar 2011).

Most research has been focused on a particular variable of drought without considering the combined effect of drought severity, its duration and pattern, and the developmental stage of the plant.

In the perspective of contributing to a better understanding of rice responses to drought, we will in this research project study the effect of drought duration and intensity on phenology and grain yield, and the heritability of traits providing enhanced adaptation to drought in rice germplasm grown by farmers in Rwanda, as well as advanced breeding materials provided by AfricaRice.

Objectives

General objective

This study aims at evaluating the combined effect of drought duration, drought severity and plant phenology on rice genotypes grown in Rwanda, under both field and controlled conditions in the biotron.

Specific objectives

1. Evaluate the effect of drought duration and drought intensity on growth, phenology and grain yield of rice
2. Determine the physiological and grain quality responses of rice to drought

3. Study the genotype × environment interaction and estimate heritability of drought adaptation traits influenced by drought intensity, duration and plant phenology.

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