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Genotypic performance under intermittent and terminal drought screening in rainfed lowland rice

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ABSTRACT

Drought is a major constraint to rice production in the rainfed lowlands of South East Asia. The timing and severity of water stress is highly variable from year to year and the current drought screening method for rainfed lowland rice utilizes a late planting to impose a prolonged terminal drought in the wet season. In this paper, an alternative drought screening method was investigated for areas where photoperiod insensitive genotypes are commonly grown with the aim of identifying promising genotypes exposed to short-duration intermittent drought, a condition that is more frequently experienced in the rainfed lowlands in the wet season. To assess the usefulness of intermittent drought screening the performance of genotypes was compared with that tested under traditional flooded and terminal drought treatments in wet and dry seasons for two years.

Mean yield reduction in intermittent and terminal drought was 13 and 35% respectively in the wet season and 34 and 59% respectively in the dry season, indicating that the proposed intermittent drought screening in the dry season and the current terminal drought screening in wet season would provide the magnitude of drought severity that would be appropriate for screening. Genotypes shown to be drought tolerant, based on their drought response index (DRI), were consistent in intermittent and terminal drought screening. There was no significant relationship between potential grain yield obtained under well watered treatments and DRI, indicating that some drought tolerant genotypes can achieve high yield, thus adaptation to a wide range of rainfed lowland conditions is expected. Due to genotypic variation in flowering in relation to rainfall or irrigation events in the terminal and intermittent drought treatments respectively, delay in flowering was not consistent across experiments and thus, is not expected to be a useful trait for selection particularly when using intermittent screening methods. It is therefore concluded that intermittent drought with appropriate level of drought stress could be used with DRI as a criterion for selection of well adapted genotypes suitable for the rainfed lowlands.

1. Introduction

Rice is mostly grown in rainfed lowlands in the Mekong Region where drought is a major constraint to production (Ouk et al., 2006; Fukai and Ouk, 2012). In Thailand, about 76% of the total 9.2 million hectares grown to rice are under rainfed conditions and yield losses due to drought are as high as 45% (Jongdee et al., 2006), while in Cambodia, drought can occur at any time during the wet season, and grain yield reduction due to drought ranged from 12 to 46% in a 3 year study at 8 locations (Ouk et al., 2006). In Laos, drought is also a major constraint for rainfed lowland rice production and water availability maps for this rice ecosystem have been produced for a main rice growing province of the country (Inthavong et al., 2012). There is a wide range of drought-stress environments, differing in timing and intensity of stress (Fukai and Cooper, 1995; Fukai et al., 1999a). While drought develops regularly after the wet season, planting of short-duration photoperiod insensitive genotypes and appropriate photoperiod sensitive genotypes has resulted in rice crops being commonly harvested at the onset of dry season, thus escaping from the terminal drought. On the other hand, the intermittent drought that develops with short dry period and disappears with rainfall events during crop growth is common in Laos and Cambodia (Tsubo et al., 2009; Inthavong et al., 2011). The occurrence of drought and other constraints has

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resulted in a large genotype-by-environment interaction in rainfed lowland rice multi-location trials conducted in Northeast Thailand and Laos (Rajataserееkul et al., 1997; Romyen et al., 1998; Fukai et al., 1999a; Inthapanya et al., 2000, 2001). This necessitates a large number of testing locations and years for selection of widely adapted genotypes (Cooper and Somrith, 1997; Cooper et al., 1999).

The development of appropriate genotypes with greater drought resistance, thus conferring yield stability, would contribute to improve productivity in the rainfed rice environment. However, progress in developing drought resistant genotypes for the wet season has been slow. This is largely due to the unpredictable timing and severity of rainfall and drought events resulting in large genotype by environment interaction. However, the growing environment may be manipulated to produce drought conditions for screening for drought tolerance. A controlled drought environment can be established more readily in the dry season (Lafitte et al., 2006), but the short-day environment will confound with photoperiod sensitivity. To reduce the chance of rainfall interfering with drought development in the wet season, trials are generally planted later and standing water may then be drained from the field so that the crop has a better chance of being exposed to drought; this is particularly so for terminal drought screening trials (Pantuwan et al., 2002b; Jongdee et al., 2006). Drainage techniques can create severe stress under lowland treatments and the timing of drainage can be adjusted to induce different types of drought (Pantuwan et al., 2002a; Ouk et al., 2006). However, this late planting method also causes bias against photoperiod sensitive genotypes because flowering takes place when the photoperiod sensitive plants are still small. Late planting may also not be readily achieved in some locations, as in southern India where pre-monsoon direct seeding is practiced (Kumar et al., 2008).

The breeding strategy for drought tolerance is to use drought tolerant donor as parents in crosses to high yield potential genotypes and then screen for high yield in multi-location trials (Fukai and Cooper, 1995; Cooper et al., 1999). However, selection based solely on grain yield may not be efficient in the development of widely adapted genotypes, because crop development and production processes interact strongly with timing and intensity of drought-stress, which vary across locations, seasons and years. Hence, much of the initial efforts to improve grain yield under drought focused on improvement of secondary traits such as root architecture, leaf water potential, panicle water potential, osmotic adjustment and relative water content (Fukai et al., 1999b; Price and Courtois, 1999; Jongdee et al., 2002; Pantuwan et al., 2002b; Toorchi et al., 2003). However, more recent studies (Atlin and Lafitte, 2002; Bernier et al., 2008) have shown that these traits are often not highly correlated with grain yield. Moreover, gains in yield by selecting for secondary traits have not yet been clearly demonstrated in rice.

Drought response index (DRI) is based on grain yield adjusted for variation in potential yield and flowering date, and has been used for selection of drought tolerance (Ouk et al., 2006). Selection for DRI under drought treatments allows breeders to identify donor lines with high drought tolerance and is an important component of breeding program aimed for development of adapted genotypes for the rainfed lowlands. Genotypes adapted to the rainfed lowlands need to be drought resistant, but they also need to have high yield potential to maximize yield in seasons without severe drought development (Kamoshita et al., 2008; Fukai and Ouk, 2012). If drought occurs regularly at a certain period during the growing season, genotypes that escape the drought period can be adopted. This has been a common practice with the use of photoperiod-sensitive genotypes that flower by the end of wet season. The genotypes that produce high yield in drought-prone environments are not necessarily drought resistant, and particularly under mild drought treatments, the variety's potential yield under well watered treatments commonly determines the actual yield. This has led to the adoption of a concept for improving drought tolerance in which, selection is first based on yield potential and then secondly selects for drought tolerance or escape depending on predictability of drought in the target environments (Fukai and Ouk, 2012). While selecting for yield potential may be achieved by conducting trials in fully irrigated conditions, strategies for selecting for drought tolerance may be improved by avoiding late planting for exposure to unnatural terminal drought in the drought screening trials. Associations between drought tolerant genotypes and high yield potential genotypes are also not clearly identified.

In Laos, most genotypes released are photoperiod insensitive and commonly planted early to avoid terminal drought, but they frequently experience intermittent drought during growth. This study aimed to develop an effective selection strategy, particularly the use of intermittent drought screening for improving drought tolerance in rainfed lowland rice.

2. Materials and methods

2.1. Location and experiment outline

The soil at the experimental site, the Agriculture Research Center, Vientiane, Central Laos (latitude 18°8′58 N and longitude 102°44′4 E) was characterized as clay texture, low soil pH, and low N and P availability (Table 1). In total 4 rice experiments were conducted in the dry (DS) and wet (WS) seasons of 2010 and 2011. Each experiment consisted of flooded, and intermittent and terminal drought treatments. In the flood treatment, standing water was maintained around 5–10 cm depth after transplanting until 15 days after flowering of the last variety. The intermittent drought treatment commenced 20 days after transplanting by draining standing water from the paddy. When the free water level in the paddy declined to 40 cm below the soil surface, the field was flooded for 5 h and then drained, and this cycle was repeated until mid-grain filling. The terminal drought treatment was imposed 40 days after transplanting when standing water was drained with no further irrigation being applied throughout the growth period.

Alpha lattice design with three replications was used for each experiment with 40 or more genotypes in 2010DS, 2010WS and 2011WS. A split–split plot design with three replications was applied in 2011DS with six genotypes allocated to sub-plots, but only the main effect of the three water treatments was reported here.

2.2. Plant materials

In 2010DS, a total of 227 fixed lines were tested under three water treatments; 141 genotypes selected from the Lao rice breeding program, of which 5 populations derived from crosses between drought tolerant donors (Chaogeng 1, Chaodeng 2, HomNangNuan, KNL and TDK21-B-24-19-1-B) and Lao popular genotypes, i.e. TDK1/Chaodeng1 (TDK10234), TDK7/Chaodeng 2 (TDK10239), TSN1/HomNangNuan//TSN1 (TDK10299), TSN1/KNL//TSN3 (TDK10301) and TDK5/TDK21-B-24-19-1-B (TDK10236), 13 high yielding rainfed lowland rice genotypes selected at Ubon Rice Research Center (URRC), Thailand, and 73 high yielding genotypes selected for irrigated conditions by the International Rice Research Institute (IRRI). In the 2010WS experiment, there were 70 genotypes selected from the three water treatments in 2010DS, of which 47 were from the Lao rice breeding program, 16 from IRRI and 7 from URRC. In 2011DS, there were 6 genotypes, two performed well in each water treatment selected from the experiment in 2010WS. In 2011WS, 40 genotypes were tested, of which 26 genotypes performed well in three water treatments in the 2010WS experiment; 10 genotypes developed for drought prone