



On-farm assessment of a new early-maturing drought-tolerant rice cultivar for dry direct seeding in rainfed lowlands

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ABSTRACT

Dry direct seeding of rice (DDSR) is becoming a common practice in drought-prone lowland areas where there is insufficient labor for transplanting, but early-season drought often causes poor crop establishment, which allows subsequent weed infestation. Although early-maturing drought-tolerant cultivars have been released in tropical Asia in the last decade, almost all farmers in these areas still use cultivars selected for irrigated lowlands. The objective of our study was to compare a new drought-tolerant cultivar (Rc348) and a popular cultivar of farmers (Rc10) in DDSR under rainfed lowland conditions. On-farm experiments in three villages in northern Luzon, the Philippines, showed that the yield of Rc10, but not Rc348, was negatively associated with soil drying. Although their average yields were comparable (Rc348, 3.03 t ha⁻¹; Rc10, 3.00 t ha⁻¹), Rc348 yielded 34% more with moderate to severe weed infestation or soil dryness (3.12 vs. 2.33 t ha⁻¹). Weed infestation increased with increasing soil dryness, but the weed pressure was more severe for Rc10 than for Rc348. Rc348 had a higher seedling emergence percentage, number of seedlings m⁻², and ground cover at 30 days after sowing than Rc10 in drought-prone fields at upper (drier) positions in the toposequence. These results were validated by an on-station experiment with controlled drought stress at the International Rice Research Institute. We suggest that the adoption of newly released cultivars from the breeding programs for rainfed rice with reliable seedling emergence and early vigor in the presence of fluctuating soil moisture would stabilize the yield of DDSR in the target drought-prone areas.

1. Introduction

Rainfed lowland rice ecosystems, that lack an irrigation infrastructure, occupy 47 × 10⁶ ha in tropical Asia (GRiSP, 2013). Rice production is affected by erratic rainfall and erratic dry spells (Haefele et al., 2016). Water availability often depends on the position of the rice field in a toposequence, with lower-elevation fields receiving more water through seepage and percolation from higher-elevation fields (Boling et al., 2008; Homma et al., 2004). The intensity and frequency of both drought and flash floods in rainfed lowlands are likely to increase as a result of predicted future climate change (Wassmann et al., 2009). In addition, younger residents in impoverished rural areas are gradually migrating to urban areas in search of better jobs owing to the

low annual income from rainfed agriculture (Manzanilla et al., 2016). Thus, technologies to reduce the risks due to climate, improve productivity and overcome labor scarcity are important in stress-prone lowlands; direct seeding of rice may offer a means to address these concerns.

Dry direct seeding of rice (DDSR) has been proposed as a promising technology to reduce loss due to drought in rainfed environments (Fukai and Ouk, 2012; Haefele et al., 2016). This technique is based on sowing dry rice seeds onto unsaturated, unpuddled soils (Pandey and Velasco, 2002). DDSR is practiced in the upper Ganges river delta in India, the Mekong river floodplain in Cambodia, the Khorat plateau in Thailand, the inland dry zone in Myanmar and undulating coastal areas in Indonesia and the Philippines. Furthermore, transplanting of rice

Abbreviations: CEC, cation exchange capacity; DAS, days after sowing; DS, drought-stressed; DDSR, dry direct seeding of rice; IRRI, International Rice Research Institute; LSD, least-significant-difference; TPR, transplanting of rice; WW, well watered

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(TPR) has been increasingly replaced by DDSR in drought-prone environments to compensate for water and labor shortages (Haeefe et al., 2016; Lantican et al., 1999; Tomita et al., 2003). In TPR, planting is often delayed by the uneven distribution of rainfall in the early wet season. This forces farmers to either use old seedlings or to abandon these plants and start a new nursery bed (Saleh and Bhuiyan, 1995; Sharma et al., 2005), which risks serious yield reductions due to drought during the late wet season (Pantuwan et al., 2002). In contrast, DDSR can efficiently utilize early-season rainfall (Saleh and Bhuiyan, 1995), with less labor and water requirements for land preparation and crop establishment, than TPR (Haeefe et al., 2016). In addition, the early establishment and harvest in a DDSR system can allow farmers to plant a post-rice crop (Saleh and Bhuiyan, 1995; Pandey and Velasco, 2002). The use of early-maturing cultivars is another option to further increase the likelihood of escaping the late-season drought (Haeefe et al., 2016). Several early-maturing drought-tolerant rice cultivars have recently been released, with growth durations (from sowing to harvest) ranging from 95 to 100 days in South and Southeast Asia (Kumar et al., 2015; Manzanilla et al., 2016).

DDSR can achieve comparable yields to TPR in irrigated areas where water and weeds can be controlled (Sharma et al., 2005; Sudhir-Yadav et al., 2011). However, poor seedling establishment and subsequent weed infestation, exacerbated by reduced crop competition, remain major yield constraints for DDSR in drought-prone rainfed lowlands (Fukai and Ouk, 2012). The unlevelled soil surface in fields caused by the dry land preparation creates drier patches within a field in DDSR (Hayashi et al., 2009). Crop uniformity is adversely affected by the heterogeneous hydrological conditions, which favors weed growth (Tomita et al., 2003). Yield loss caused by weed infestations in DDSR was estimated at 20–50% in rainfed lowlands (Fukai and Ouk, 2012). While DDSR may reduce risk of drought at the end of the wet season as crop establishment in the main fields is advanced to the onset of the season, dry spells often restrict seedling emergence and early canopy expansion (Hayashi et al., 2009; Tuong et al., 2000). The final yield depends on the degree of early vigor and radiation interception in non-flooded DDSR fields (Kato and Katsura, 2014; Okami et al., 2011; Sandhu et al., 2015). Stable establishment despite hydrological fluctuations is required for the crop to develop sufficient cover to suppress weeds in rainfed rice (Namuco et al., 2009; Zhao et al., 2007).

Progress has been made in the genetic improvement of drought tolerance in DDSR during the last decade (Swain et al., 2017). Consequently, new drought-tolerant cultivars suitable for DDSR in rainfed lowlands have been released (Kumar et al., 2015). Previous greenhouse studies showed that a new drought-tolerant cultivar developed achieves quicker establishment and greater early vigor in DDSR under drought than cultivars developed for irrigated lowlands (Yamane et al., 2018). However, its agronomic performance under natural rainfed conditions in farmers' fields remains uncertain. To date, the majority of farmers in rainfed areas still use improved rice cultivars that had been developed for irrigated lowlands, which are, in turn, highly susceptible to drought (Kumar et al., 2015; Manzanilla et al., 2016). We hypothesized that the new drought-tolerant cultivar would show better seedling emergence and more stable yield in on-farm studies than the popular cultivars that have been used in DDSR under rainfed lowland conditions. Additional on-station studies focusing on the drought effect on the seedling establishment are likely to clarify the findings from on-farm studies.

The objective of this study was to compare the on-farm performance of a drought-tolerant cultivar and a locally popular cultivar in rainfed areas in the Philippines where DDSR has rapidly expanded. To validate the results from the on-farm experiments, we evaluated the seedling establishment and early vigor of the same cultivars in an on-station field experiment.

2. Materials and methods

2.1. On-farm trial

The on-farm experiments were conducted during the wet season of 2016 in three villages (Santa Rosa, Casilan, and Prado), Umingan municipality, Pangasinan Province, the Philippines (in western seaboard of Luzon; 15°54'N, 120°49'E). In the Philippines, the average grain yield of rainfed rice is 31% lower than that of irrigated rice (2.96 vs. 4.31 t ha⁻¹; PSA, 2016). Pangasinan Province has more than 80,000 ha of rainfed lowland rice, accounting for 31% of the total rice area (PSA, 2016). The villages are located in a typical drought-prone environment, where rice is grown under rainfed lowland conditions owing to a lack of irrigation facilities. The soil (0–10 cm) was a light clay (clay 21%, silt 70%, sand 9%) with pH 6.5 (H₂O) and a cation exchange capacity (CEC) of 16.0 meq per 100 g. Total soil N and C were 0.080 and 0.775 g kg⁻¹, respectively, and available P (Bray-2) was 28 mg kg⁻¹ (Yamane et al., 2018).

Thirty farmers (10 farmers in each village) who practice DDSR were selected for the study. Their average age was 46 years and average landholding was 3.27 in ha size. Each farmer's field was located within an area of diameter 8 km, with elevations ranging from 65.8 to 85.0 m above sea level, measured by a GPS receiver (eTrex 10, Garmin Ltd., Olathe, KS, USA). Certified seeds of Rc348 (IR81047-B-106-2-4, released in 2014), a new early-maturing drought-tolerant cultivar, and Rc10 (IR50404-57-2-2-3, released in 1992), a popular early-maturing irrigated rice cultivar, were provided to the farmers. Rc10 is the second-most-widely grown cultivar in rainfed lowlands of the Philippines (Philippine Rice Research Institute, 2017). Farmers planted the two cultivars in adjacent fields. However, 13 farmers who decided to postpone the sowing due to drought switched to wet direct seeding (i.e., pre-germinated seeds on puddled soils) soon after sudden rainstorms as the soil became saturated. Thus, we evaluated the 17 farmers' fields in this study who used DDSR (8 farmers in Santa Rosa, 7 in Casilan, and 2 in Prado). Field management followed farmers' practices such as weed, nutrient, and pest management. Total N input ranged from 67 to 270 kg ha⁻¹. After preparation of the dry land (i.e., one pass with a rotovator followed by one or two passes with a disc harrow) from late May, all the 17 farmers broadcast dry rice seeds onto the dry soil between 2 June and 24 June, and then covered the seeds with soil in one pass with a spike-tooth harrow (Supplementary Table S1). The air temperature and rainfall were recorded at the meteorological station of the Philippine Atmospheric Geophysical and Astronomical Services Administration nearest the study sites (around 30 km from the sites). The mean daily temperature during the experiment (May to October) were 28.8 °C and total rainfall was 2916 mm. Drought occurred during crop establishment and there was only 32 mm rainfall during a 19-day period in mid-June and only 11 mm over the same interval during the early growth stage in mid-July (Supplementary Fig. S1).

Soil hydrological conditions were recorded weekly as a score (which ranges from 0 to 3) based on the method of Haeefe et al. (2013): 0, flooded soil (standing water in the field); 1, saturated soil (no standing water but soggy); 2, moist soil (unsaturated but not dry); or 3, dry soil (based on soil color, and presence of cracks). Weeds infestation were visually scored (which ranges from 0 to 8) according to the method of Hayashi et al. (2009) at 30 days after sowing (DAS) and at maturity in eight 50 cm × 50 cm quadrats per plot (Table 1). The environmental stress score (which ranges from 0 to 100) was computed as follows:

$$\text{Environmental stress score} = \left(\frac{\text{weed score}}{8} + \frac{\text{soil hydrology score}}{3} \right) \times 100 \div 2$$

The number of seedlings that emerged per unit area (in four 50-cm × 50-cm quadrats per plot) was counted at 30 DAS. The percentage emergence was calculated by dividing the number of seedlings m⁻² by

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