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Productivity trade-off with different water regimes and genotypes of rice under non-puddled conditions in Eastern India

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ABSTRACT

Increasing farm labor scarcity and depletion of natural resources such as water are posing a major threat to the sustainability of traditional puddled transplanted rice (PTR) farming in Eastern India. Dry-seeded rice (DSR) or non-puddled transplanted rice (NPTR) could be used as an alternative to PTR. To understand the trade-off with different water management and rice genotypes under non-puddled conditions, a field experiment was conducted during 2014–2015 on a sandy clay loam soil of Bhubaneswar, Odisha. The treatments for water regimes were based on soil water tension (no stress, 10 kPa, and 40 kPa) at 15-cm soil depth and the cultivars used in the study were inbreds (Lalat and Sahbhagi Dhan) and hybrids (Arize® 6129, 6444, and US 323).

In both years, rice yields were higher in the dry season than in the wet season. However, both establishment methods performed similarly in all the seasons. With an increase in water stress, there was a significant decline in yield and yield attributes in the dry season. Irrigation input in the dry season was roughly more than double that in the wet season. Irrigation input was relatively higher in DSR than in NPTR in all the seasons, which might be because of an extra irrigation required for DSR crop establishment than for transplanting in non-puddled conditions where watering is done only for ease of transplanting. There was irrigation saving of 25% and 58% in 10 kPa and 40 kPa, respectively, compared to no stress in the dry season. A consistent trend of an increase in irrigation water productivity (WP_I) and input water productivity (WP_{I+R}) was observed with an increase in stress. Arize® 6444 produced the highest grain yield, irrigation and input water productivity, and its performance was also better in terms of tiller density, LAI, and biomass. Our findings highlight the potential of hybrids compared with inbreds and their performance under DSR was found to be superior. Even though the yield in no stress was slightly higher than in 10and kPa, the irrigation water savings in 10 kPa were distinctly significant.

1. Introduction

Rice is an important staple food in Asia, covering 85% of the total world rice area (FAI, 2009; IRRI, 2006). In Asia, rice is grown on 143 Mha, out of which 44 Mha are grown in India, contributing about 106.7 million tons of grain production, out of which dry-season (*rabi)* rice adds 15.2 million tons while the remaining 91.5 million tons come from wet-season (*kharif)* rice (GOI, 2016a). The stagnation in the productivity of rice and depletion of natural resources in Northwest India (Ladha et al., 2003; Pathak et al., 2003; Rodell et al., 2009) for the past decade have impelled the country to put extra efforts into increasing production and productivity in Eastern India. A major part of Eastern India receives about 1268 mm of rainfall (Kumar et al., 2010), therefore has favorable conditions for rice production. However, the present productivity of rice in Eastern India is low of ~2 t ha^{-1} (GOI, 2016b; Sudhir-Yadav et al., 2017) and uncertain because of its dependency on monsoon and poor management practices, which result in negative net returns, most often in years of natural calamities such as drought, flood, and cyclone (Barah and Pandey, 2005).

In Odisha State of Eastern India, manual puddled transplanting (PTR) and *beushening* are the most dominant rice establishment methods. *Beushening* is an age-old practice that consists of broadcasting a high seed rate (~100 kg ha^{-1}) prior to the onset of monsoon rain followed by cross ploughing (*beushening* operation) in the standing rice crop 4–6 weeks after rice emergence when about 10 cm of rainwater accumulates, along with *kellua* (redistribution of rice seedlings and removal of uprooted weeds). Seedling redistribution and manual weeding operations are predominantly handled by women farmers/laborers. These operations are rainfall dependent and, if they become delayed, risks of yield losses due to weed competition are much higher

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Table 1
Basic soil properties.

Depth (cm)	pH	EC (dS m^{-1})	OC (g/kg)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Texture	Sand (%)	Clay (%)	Silt (%)	BD (g cm^{-3})
0–10	6.4	0.18	4.8	143.8	38.5	117.0	loam	47.6	24.4	28.0	1.67
10–20	6.3	0.14	3.3	137.5	33.2	98.6	sandy clay loam	67.6	25.8	6.60	1.87
20–30	6.5	0.01	4.7	131.3	25.4	125.4	sandy loam	76.6	17.8	5.60	1.88
30–60	7.3	0.10	2.9	62.5	15.8	153.4	sandy loam	75.2	19.1	5.70	1.48

in *beushening*. Similarly, for PTR, farmers need to rely on rains or irrigation to accumulate 15–20 cm of standing water for churning of the soil. Both these methods are followed to control weeds and optimize plant stand. However, these methods consume large amounts of labor, energy (for intensive tillage), and water, which are becoming scarce; hence, these traditional crop establishment methods are becoming less attractive and economical. The reported amount of irrigation water required for puddling varies from 100 mm (Sudhir-Yadav et al., 2011) to 544 mm (Bhuiyan et al., 1995). Also, high labor demand at transplanting time and rising labor scarcity and wages are compelling farmers to shift to labor-efficient methods (Kumar and Ladha, 2011). Moreover, semi-dwarf and short-duration cultivars are considered not suitable for *beushening* since stem breakage may occur during cross-ploughing (Gautam et al., 2013). Hence traditional long duration and tall cultivars are used both in PTR and *beushening* which occupies the field for long time.

Dry drill-seeded rice (DSR) is a feasible option to *beushening* and PTR that brings an opportunity to reduce input cost and irrigation water (Dawe, 2005; Humphreys et al., 2005) by using pre-monsoon rainfall more efficiently for crop establishment and early crop growth. The labor requirement in direct seeding is about 34% that of transplanted rice (Ho Nai Kin and Romli, 2002). Balasubramanian and Hill (2000) reported that direct seeding offers a higher tolerance of water deficit and higher profit in areas with an assured water supply. A few other advantages are minimal disturbance of soil structure in DSR and reduction in methane emissions as compared to puddling. Another option to reduce water input is transplanting in non-puddled soil (Malik et al., 2011). Non puddled transplanted rice (NPTR) also helps in timely transplanting, saving energy and therefore input cost (Haque et al., 2015). Input water savings of 35–57% have been reported for dry direct-seeded rice sown into non-puddled soil compared with puddled soil (Sharma et al., 2002; Singh et al., 2002).

Rice, being a staple crop, is grown with utmost importance but with a misconception that it requires an enormous amount of water. High seepage and percolation losses are the main reasons for the much higher water use in flooded rice than in other crops. Improved non-puddled crop establishment has potential to save irrigation water, but water consumption will depend on irrigation scheduling. In clay-loam soil, Sudhir-Yadav et al. (2011) reported higher irrigation input in DSR than in PTR when irrigation was applied daily, whereas ~33% savings occurred when irrigation was applied at 20 kPa. The response to irrigation schedule and crop establishment method can vary with cultivars. In recent times, public organizations and the private sector have released a few very promising drought-tolerant rice varieties that can produce similar yield under normal conditions but can give higher yield under water stress conditions (Dar et al., 2014).

The performance of cultivars with different duration varies with water stress: some are susceptible during the vegetative stage and some at flowering and reproductive stage (Pantuwan et al., 2002). Lalat is a local variety of Odisha developed by Orissa University of Agriculture and Technology (OUAT). It has medium duration (125–130 days) and is commonly grown in most parts of Odisha. Sahbhagi Dhan is a drought-tolerant and short-duration cultivar (110–115 days) recommended for the eastern states of India developed by the Centre for Rainfed Upland Rice Research Station (CRURRS), Hazaribag, in collaboration with the International Rice Research Institute (IRRI), Philippines. Sahbhagi Dhan has shown a yield advantage of 0.8–1 t ha^{-1} over other varieties under drought conditions (Yamano et al., 2013). Some recently released hybrids (Arize® 6129, Arize® 6444, Arize® Tej, and Arize® Dhani) developed by Bayer are known to perform better in Northern India and parts of Eastern India. Arize® 6444 (135–140 days) and Arize® 6129 (115–120 days) are suitable for the direct-seeded system and for non-puddled mechanically transplanted rice (CSISA Annual Report, 2015), are resistant to bacterial leaf blight (BLB), and produce maximum productive tillers and hence give higher yield. US 323 developed by US Agriseeds is of 115–120 days' duration with better tillering ability and higher yield.

Therefore, this study was undertaken to evaluate crop growth and development, yield, and irrigation input and understand the trade-off for different cultivars, water regimes, and establishment methods.

2. Materials and methods

2.1. Experimental site

A replicated field experiment was conducted for two years (2014–2015) and four seasons at the research farm of Orissa University of Agriculture and Technology (OUAT), Bhubaneswar (20°15′N, 85°48′ E, 30.6 m ASL), during the dry season (January to May) and wet season (June to October). The region is characterized by a subtropical climate with average annual rainfall of 1451 mm (Odisha Agriculture Statistics, 2013–14), of which the maximum is received during June to October. The soil at the experimental site is sandy clay loam with uniform texture up to a depth of 100 cm with the exception of the top 10 cm (loam). Selected soil properties at the time of sowing the first crop are shown in Table 1. The last five years' cropping history was rice in the wet season followed by an oilseed crop such as mustard/groundnut in the dry season.

2.2. Experimental design

The experimental design was a three-factorial experiment with two crop establishment methods, dry-seeded rice (DSR) and non-puddled transplanted rice (NPTR), three water regimes based on soil water tension (no stress, 10 kPa, and 40 kPa) at 15-cm soil depth, and five cultivars (Lalat, Sahbhagi Dhan, Arize® 6129, Arize® 6444, and US 323), replicated thrice. Thus, there were a total of 30 treatment combinations. The establishment methods (EM) were allotted to the main plot, water regimes (W) to subplots, and cultivars (V) to sub-subplots in a split–split plot design. Each sub-subplot was of 7 m × 4 m size.

2.3. Field preparation

The experimental field was cultivated and laser leveled about 2 weeks before the establishment of the experiment followed by the layout of the experiment. Since the water regime treatments were allotted to subplots, each subplot block was bounded by earthen bunds with a plastic lining to a depth of 40 cm to minimize lateral movement of water into and through the bunds. There were 1-m-wide buffers also between all subplots.