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On-farm Participatory Assessment of Short and Medium Duration Rice Genotypes in South-western Punjab

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ABSTRACT

The study reports the performance of short and medium duration rice genotypes (viz. PR-126, PR-122 and PR-124) via front line demonstrations (FLDs) on low fertility soils irrigated with poor quality underground water in south-western Punjab, India. A total of 550 FLDs were conducted during two consecutive years (*kharif* 2018 and 2019) at farmers' fields in different villages. The average rice grain yield of PR-122 was significantly higher by ~11.1 and 14.5 per cent, compared with PR-126 and PR-124, respectively. The mean net returns (MNRs) were significantly higher for PR-122 by Rs.12,778/- ha^{-1} and Rs. 16,818/- ha^{-1}, compared with PR-126 and PR-124, respectively. PR-122 had significantly higher B:C, compared with the other two genotypes in the south-western Punjab. The yield gap assessed from average yield potential was higher for PR-124 and the lowest for PR-126, while for PR-122 in between. However, the production efficiency of 54.5 kg ha^{-1} day^{-1} was higher for PR-126, compared with PR-124 (50.0 kg ha^{-1} day^{-1}) and PR-122 (50.6 kg ha^{-1} day^{-1}). The economic efficiency of PR-124 was lower by ~ Rs. 111.9 ha^{-1} day^{-1} and Rs. 43.6 ha^{-1} day^{-1} than the PR-126 and PR-122, respectively. The water use efficiency was higher for PR-126, compared with other two genotypes. The extension gap varied between -0.59 and -1.21 Mg ha^{-1} for three genotypes; with highest gap for PR-126 and the lowest for PR-124. The technology index varied between 5.6 and 14.8 per cent, and was the highest for PR-124 and the lowest for PR-122.

Keywords: Economic analysis, Production efficiency, Short duration rice varieties, Technology index, Water use efficiency, Yield gaps

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the major cereal crops for approximately half of the global population (Godfray *et al.,* 2010). Rice is cultivated after wheat in an annual rice-wheat cropping system occupying ~10 million ha (Mha) in Indian Indo-Gangetic Plains (IGPs) (Saharawat *et al*., 2012) that has been a lifeline for millions of food producers and consumers, contributing ~85 per cent towards country's cereal production (Timsina and Connor, 2001). Rice is highly energy intensive crop (Singh *et al*., 2019) under rice-wheat system that has been considered responsible for serious environmental and sustainability implications due to rapid groundwater depletion (Hira *et al.,* 2004), soil health degradation, reduced C sustainability due to open field rice residue burning and emission of greenhouse gases (Singh *et al*., 2020). Notwithstanding these sustainability issues, rice production has been expected to increase by ~40 per cent by the end of 2030 to meet the rising demand from the ever-increasing population (FAO, 2009).

Among different sustainability issues, the problem of rapidly declining ground water table has been the most

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debatable issues (Hira *et al*., 2004). Several water saving technologies have been developed and advocated for rice cultivation in north-western India including matric potential based irrigation scheduling, direct seeding of rice, cultivation on beds, laser land leveling, intermittent irrigation etc. Another approach is to use short duration rice varieties (Campbell *et al*., 2016). The researchers develop varieties which mature in less time and are insensitive to day length, making possible more crops each year in the same land (Bagchi *et al*., 2012). The traditional rice varieties matures in 160-200 days (De Datta, 1981), and are therefore are highly susceptible to climatic events. According to Hasan (2014) cultivation of short duration rice varieties is important for water saving while mitigating greenhouse gases emissions. Rice varieties with crop duration of 95-105 days can escape drought in rainfed ecosystems (Ohno *et al*., 2018) and allow more intense cultivation by taking advantage of the residual moisture in soil after the rice harvest (Haefele *et al*., 2016). The short duration varieties also had advantage of less risk of lodging and pest damage varieties over longer growth duration (Xu *et al.,* 2018). In irrigated rice ecosystems, many farmers prefer short duration varieties as they often face serious water shortages late in the dry season. Previously researchers remained focused on the development of medium duration varieties (Peng and Khush, 2003) due to their higher yield potential than that of short duration varieties under optimal conditions (Tirol-Padre *et al.,* 1996). The higher grain yield of medium duration varieties has been related to higher crop biomass and the associated ability to capture resources such as solar radiation, nutrients, water that increases growth duration (Kropff *et al*., 1994). In the south-western Punjab, the soils are salt affected and had poor quality underground waters. The cultivation of long duration rice varieties with high water requirement in this are with water shortage and poor quality underground water is not a viable option. Therefore, we investigated the yield potential, yield gaps, economics and efficiency indices (water use efficiency and nitrogen use efficiency) of short and medium duration rice genotypes viz. PR-126, PR-122 and PR-124 in the south-western Punjab, India to identify the economically and sustainably viable rice genotype for the region.

METHODOLOGY

The study area (south-western alluvial plain agro-eco-sub region; longitudes of 29º 59´ and latitude of 75º 23´) in Mansa district falls in a south-western Punjab, India and is characterized by hot, typic arid with hot and dry summers and cold winters, with mean annual temperature ranges between 24ºC and 27º C, mean annual precipitation ranges between 300-450 mm, covering 15-24 per cent of potential evapo-transpiration (Kumar *et al.,* 2006). Soils are generally coarse loamy to fine loamy, and are classified as *Ustic Haplocambids*, *Ustic Torripsamments,* and *Ustic Haplocambids*. A total of 550 FLDs on three rice varieties (short and medium duration) were conducted during two years (*kharif* 2018 and 2019) at farmer's field under irrigated conditions on sandy loam to loamy sand soils (Table 1). The crop was established through seedling transplanting in puddle (wet tillage) fields. About 25-30 days old rice seedlings were manually transplanted in the field. Weeds in rice crops were mainly controlled by the application of herbicides. Nitrogen is applied through urea (46% N). Phosphorus is mainly applied through diammonium phosphate (DAP; 18% N, 46% P_2O_5) and potassium is applied as muriate of potash (60% K_2O). Zinc is applied as zinc sulphate heptahydrate (21% Zn). For plant protection measures, chemical insecticides were used by the farmers. The canal and the under-groundwater used for irrigation to crops is extracted using electric motors. The harvesting of rice was done mechanically with combine harvesters. The information regarding quantity of fertilizers applied, number of irrigation applied, chemicals used for weed and insect-pest control etc. were recorded from the farmers in the structured interview schedule. Besides, the information regarding human labor and diesel fuel consumption for different farm operations was recorded for the estimation of economic indices for rice cultivation.

Economic indices of rice cultivation

The economics of short and medium duration rice varieties cultivated in south-western Punjab, India was assessed through mean total cost of cash inputs in rice cultivation (MCC), mean gross returns (MGRs), mean net returns (MNRs) and the benefit-cost ratio (B-C ratio) based on the data collected at farmers' fields during personal interviews. The data were recorded in structured interview schedule. The MCC for rice cultivation were estimated as sum of cost incurred for the purchase of various inputs and the deployment of human labor. The MGRs were calculated as a product of rice grain yield and the minimum support price (MSP) decided by the Government of India (GOI) during the study period (Eq. 1). The MNRs were calculated by subtracting the MCC from MGR (Eq. 2). The B-C was calculated as a ratio of MGR and MCC (Eq. 3).

$$\text{MGRs (Rs. ha}^{-1}\text{) = Rice grain yield x MSP} \quad \ldots (1)$$

$$\text{MNRs (Rs. ha}^{-1}\text{) = MGRs-MCC} \quad \ldots (2)$$

$$\text{B:C = MGR / MCC} \quad \ldots (3)$$

Production and economic efficiency

The production efficiency was estimated as a ratio of rice grain yield (kg ha^{-1}) and the average crop duration (in days). The average crop duration of 123, 130 and 147 days were considered for estimating the production efficiency of PR-126, PR-124 and PR-122, respectively using Eq. 4.

$$\text{Production efficiency (kg ha}^{-1}\text{ day}^{-1}\text{)} = \frac{\text{Rice grain yield (kg ha}^{-1}\text{)}}{\text{Avg. crop duration (day}^{-1}\text{)}} \quad \ldots(4)$$

The economic efficiency of rice cultivation was estimated as a ratio of MGRs and average crop duration (days) (Eq. 5).

$$\text{Economic efficiency (Rs. ha}^{-1}\text{ day}^{-1}\text{)} = \frac{\text{MGR (Rs. ha}^{-1}\text{)}}{\text{Avg. crop duration (day}^{-1}\text{)}} \quad \ldots (5)$$

Water use and nitrogen use efficiency

The water use efficiency for three different short and medium duration rice genotypes was estimated based on number of irrigations applied by the farmers. The average grain yield was divided by the total cm of water applied and expressed as kg ha^{-1} cm^{-1}. The fertilizer-N use efficiency (kg kg^{-1}) was estimated as a ratio of grain yield (kg ha^{-1}) and the amount of fertilizer-N applied (kg ha^{-1}).

Assessment of yield gaps and technology index

The crop yield gaps for rice cultivation were assessed using Eq. 6-9 (Samui *et al*., 2000; Singh *et al.,* 2018). Yield gap was assessed from average yield potential (Eq. 6), national average (Eq. 7), state average (Eq. 8) and district average (Eq. 9). The technology gap was estimated as a difference between average potential yield and the demonstration yield (Eq. 11). The extension gap was calculated as a difference between average yield and the lowest yield obtained in the demonstration plots (Eq. 11). The technology index (Eq. 12) was estimated as a ratio of difference between average yield potential and farmers' yield to that of average potential yield, according to the following equation.

$$\text{Yield gap}_{\text{(Av. yield potential)}} = \text{Average yield potential – Farmers' yield} \quad \ldots(6)$$

$$\text{Yield gap}_{\text{(National average)}} = \text{National average yield – Farmers' yield} \quad \ldots(7)$$

$$\text{Yield gap}_{\text{(State average)}} = \text{State average yield – Farmers' yield} \quad \ldots(8)$$

$$\text{Yield gap}_{\text{(District average)}} = \text{District average yield-Farmers' yield} \quad \ldots(9)$$

$$\text{Technology gap = Avg. potential yield – Demonstration yield} \quad \ldots (10)$$

$$\text{Extension gap = Average demo. yield – lowest demo. yield} \quad \ldots(11)$$

$$\text{Technology gap index (\%)} = \frac{\text{Av. yield potential-farmers' yield}}{\text{Av. yield potential}} \text{ X 100} \quad \ldots(12)$$

Statistical analysis

The statistical analysis of seed cotton yield was carried out by analysis of variance in randomized block design, RBD (Cochran and Cox, 1950). Mean separation for different treatments was performed using least significant difference (LSD) test at $p<0.05$. Statistical analysis was performed with SPSS for Windows 16.0 (SPSS Inc., Chicago, USA).

RESULTS AND DISCUSSION

Mean grain yield of PR-126 varied between 5.50 and 7.60 Mg ha^{-1} with mean yield of 6.70±0.22 Mg ha^{-1} at farmers' field in south-western Punjab (Table 1). The grain yield of PR-122 varied between 6.85 and 7.62 Mg ha^{-1}, with a mean value of 7.44±0.20 Mg ha^{-1}. However, the grain yield of PR-124 showed large variation (5.50-8.00 Mg ha^{-1}) at different study sites. The average rice grain yield of PR-122 was significantly higher by ~11.1 and 14.5%, compared with PR-126 and PR-124, respectively. The mean rice grain yield of PR-126 and PR-124 did not differ significantly in south-western Punjab. Earlier, Singh *et al.*, (2018) reported lower yield of medium duration rice varieties, compared with long

Table 1: Rice grain yield in demonstration at farmers' fields

Variety	Cropping system/ irrigation source/ soil type	Rice grain yield (Mg ha^{-1})			
		Max.	Min.	Mean	S.E.
PR-126	Rice-wheat/irrigated/canal and	7.60	5.50	6.70^{a}	0.22
PR-122	under-ground water/Sandy loam	7.62	6.85	7.44^{b}	0.20
PR-124	to loamy sand	8.00	5.50	6.50^{a}	0.31
Mean		7.74	5.95	6.88	0.24

Mean values followed by different letters at significantly different by least significant difference (LSD) test at $p<0.05$.

duration rice varieties. These results revealed that MCC for three rice genotypes did not differ significantly (Table 2). However, the MGRs were significantly lower for PR-126 and PR-124 genotypes, compared with PR-122. The MNRs were significantly higher for PR-122 by Rs.12,778/- ha^{-1} and Rs. 16,818/- ha^{-1}, compared with PR-126 and PR-124, respectively. These results revealed that PR-122 had significantly higher B:C, compared with the other two genotypes in the south-western Punjab.

The average yield potential of three rice cultivars viz. PR-126, PR-122 and PR-124 was 7.50, 7.88 and 7.63 Mg ha^{-1}, respectively (Table 3). The yield gap assessed from average yield potential was higher for PR-124 and the lowest for PR-126, while for PR-122 in between. The yield gap for PR-126 and PR-124 was due to poor plant population, early sowing, delayed application of fertilizer-N and transplanting of matured nursery seedlings (> 30 days old). The average yield of these genotypes was however higher by ~4.10, 4.90 and 3.91 Mg ha^{-1}, respectively when compared with the national average. However, compared with the state average, the average grain yield of PR-126, PR-122 and PR-126 was higher by 0.60, 1.30 and 0.40 Mg ha^{-1}, respectively. These results showed that yield gap for these three rice genotypes varied between 0.30 and 0.50 Mg ha^{-1} for PR-126 and PR-124.

Table 2: Mean cost of cultivation, mean gross returns, mean net returns and benefit: cost (B: C) of rice

Economic indicators	PR-126	PR-122	PR-124
MCC (Rs. ha^{-1})	$36,900^{a}$	$37,200^{a}$	$37,400^{a}$
MGR (Rs. ha^{-1})	$1,18,590^{a}$	$1,31,668^{b}$	$1,15,050^{a}$
MNR (Rs. ha^{-1})	$81,690^{a}$	$94,468^{b}$	$77,650^{a}$
B:C	3.2^{a}	3.5^{b}	3.1^{a}

Mean values followed by different letters at significantly different by least significant difference (LSD) test at $p<0.05$.

The production efficiency of 54.5 kg ha^{-1} day^{-1} was higher for PR-126, compared with PR-124 (50.0 kg ha^{-1} day^{-1}) and PR-122 (50.6 kg ha^{-1} day^{-1}) (Figure 1). The higher production efficiency of PR-126 was due to its short duration of only 123 days, while for PR-122 was due to its higher productivity under poor quality irrigation water conditions. Similarly, the economic efficiency was higher for PR-126 than the other two compared genotypes. The economic efficiency of PR-124 was lower by Rs. 111.9 ha^{-1} day^{-1} and Rs. 43.6 ha^{-1} day^{-1} than the PR-126 and PR-122, respectively. These results showed that water use efficiency was higher for PR-126 and the lowest for PR-124, while PR-122 in-between (Table 4). The higher water use efficiency of PR-126 was due to its short duration and therefore, less number of irrigations is required. Basha and Sarma (2016) reported significantly higher water use efficiency of aerobic rice (81.3 kg ha^{-1}

Table 3: Yield gap analysis

Grain yield (Mg ha^{-1})		PR-126	PR-122	PR-124
Actual yield*		6.70	7.44	6.50
Average yield potential		7.50	7.88	7.63
National average yield	2.57	—	—	—
State average yield	6.12	—	—	—
District average yield	7.00	—	—	—
Yield gap (Mg ha^{-1}) from				
Average yield potential		-0.80	-0.44	-1.13
National average		+4.10	+4.90	+3.91
State average		+0.60	+1.30	+0.40
District average		-0.30	+0.44	-0.50

*Values indicate average grain yield

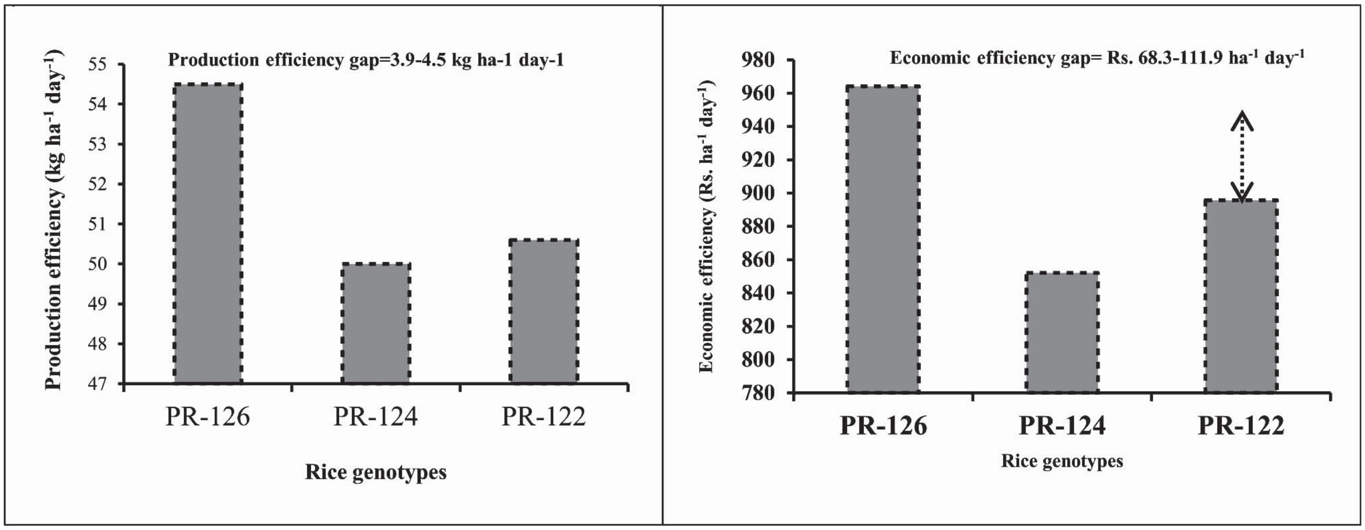

Figure 1 and 2: The production and economic efficiency of different rice genotypes in south-western Punjab, India

Table 4: Water use efficiency, fertilizer use efficiency and the technology and extension gaps of short and medium duration rice genotypes in south western, Punjab, India

Parameter	PR-126	PR-124	PR-122
Water use efficiency (kg ha^{-1} cm^{-1})	49.1	32.5	46.4
Nitrogen use efficiency (kg kg^{-1})	44.7	43.3	49.6
Technology gap (Mg ha^{-1})	-0.81	-1.13	-0.44
Extension gap (Mg ha^{-1})	-1.21	-0.59	-1.01
Technology index (%)	10.7	14.8	5.6

cm^{-1}) as compared to transplanted rice (36.1 kg ha^{-1} cm^{-1}) due to higher water requirement of transplanted rice. The amount of rice grains produced per kg of fertilizer-N applied (nitrogen use efficiency) varied between 43.3 and 49.6 kg kg^{-1} and was higher for PR-122 than the other two compared genotypes. Thompson *et al.* (2005) compared the two irrigation layouts by water management treatments of most interest (water maintained in the furrows; fully ponded flat) and reported that water use efficiency ranged from 7.1 to 8.1 kg ha^{-1} mm^{-1} of water used by the crop. Sarkar *et al*. (2017) reported a water use efficiency of 36 kg ha^{-1} cm^{-1} for rice under continuously flooded field conditions, compared with 226 kg ha^{-1} cm^{-1} under alternate wetting and drying regimes.

The extension gap varied between -0.59 and -1.21 Mg ha^{-1} for three genotypes; with highest gap for PR-126 and the lowest for PR-124 (Table 4). Extension gap of 1.3-1.8 Mg ha^{-1} in rice production has been reported in West Bengal (Sagar and Chandra, 2012). Singh *et al.* (2018) reported that extension gap suggests advantage of technology demonstration and need for motivation of farmers for adoption of scientific technology. The technology gaps for rice cultivation varied between -0.44 and -1.13 Mg ha^{-1}; with the highest gap for PR-124 and the lowest for PR-122. The technology index varied between 5.6 and 14.8 per cent, and was the highest for PR-124 and the lowest for PR-122. Sagar and Chandra (2003) reported that technology index range of 2-10 per cent and reported that this index indicates that technology is feasible for the reason.

CONCLUSION

Rice genotype PR-122 had significantly higher grain yield compared with other two genotypes (PR-126 and PR-124). Mean grain yield of PR-124 and PR-126 did not differ significantly. Although the MNRs and B-C ration were higher for PR-122, yet production efficiency of PR-126 and PR-124 was higher than the PR-122. This indicates that farmers may enhance area under PR-122 under poor quality irrigation underground water conditions. The economic efficiency and water use efficiency were higher for PR-126, compared with other two genotypes. It showed that this variety is suitable for saving irrigation water due to its short duration These results suggested that more intensified extension efforts are required to create awareness among the farmers in the south-western Punjab for the wide spread adoption of short duration PR-126 genotype to conserve underground irrigation water. The farmers should be aware about recommended crop production and management practices for PR-126 cultivation to reduce the extension gap and yield maximization for increased economic returns.

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