Indian Journal of Agricultural Sciences **91** (9): 1296–1301, September 2021/Article
https://doi.org/10.56093/ijas.v91i9.116073

Performance of rice (*Oryza sativa*) cultivars as influenced by irrigation regimes and establishment methods

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Received: 21 June 2020; Accepted: 25 February 2021

ABSTRACT

The present study was carried out at Punjab Agricultural University, Ludhiana during *kharif* 2016 and 2017 to compare economics, energetics, crop and water productivity of rice (*Oryza sativa* L.) cultivars grown under variable irrigation regimes and crop establishment methods. Results revealed that the rice variety PR 126 produced 22.6 and 23.3% higher grain yield than PR 115 and PR 124, respectively. Scheduling irrigation at 2 days after infiltration of ponded water (DAIPW) in puddled transplanted rice (PTR) resulted in highest grain yield (7.07 t/ha), which was statistically similar to irrigation at 3 DAIPW in PTR (6.96 t/ha), but significantly higher than direct seeded rice (DSR) irrigated at 2, 4, 6 and 8 DAIPW. The interaction between cultivars and establishment-irrigation regimes showed that PR 126 performed statistically equal under PTR and DSR conditions at all irrigation regimes except 6 and 8 DAIPW. However, maximum net returns and B:C was obtained from PR 126 when puddled transplanted and irrigated at 2 DAIWP. PR 124 irrigated at 2 DAIPW in PTR consumed maximum amount of irrigation water (130.3 cm). Compared to that, PR 126 when direct seeded and irrigated at 4 DAIPW saved 42.8 cm of irrigation water and registered 43, 30.2, 6.6 and 6.3% higher apparent crop water productivity, total crop water productivity, energy use efficiency and energy productivity, respectively with statistically similar grain yield and B:C.

Keywords: Cultivars, Establishment methods, Irrigation regimes, Rice, Water productivity

Irrigated agriculture is the prime user of freshwater accounting for more than 70% of withdrawal from the surface and underground water resources (Johansson *et al*. 2016). Out of the total water used for irrigation, 50% is consumed in rice (*Oryza sativa* L.) cultivation (Bouman *et al.* 2007). India is the second-largest producer of rice in the world after China (Anon 2018). In Punjab, rice is being cultivated on 3.07 million ha during *kharif* with total paddy production of 19.97 million tonnes (Anon. 2019). Transplanting paddy seedlings into puddled soil is labour-intensive and deteriorates soil physical properties (Bhatt *et al.* 2016). Huge water requirement of paddy (140-160 cm) led to the depletion of groundwater resources of the state. Besides this, irrigation water is the highest energy consumption input in agriculture, which becomes more expensive due to replacement of centrifugal pumps with submersible pumps for groundwater extraction. Amid alarming water crisis, increasing energy and labour scarcity; researchers and policy makers are advocating water saving technologies. Shift from continuous ponding of water to alternate wetting and drying, short-duration cultivars, direct seeding and use of micro-irrigation methods are the promising technologies, which can save irrigation water in rice cultivation (Kato *et al.* 2009). Although, maintenance of adequate soil moisture through irrigation is important to harvest good crop but continuous ponding throughout the crop growth period is redundant. However, the level of soil moisture depletion that rice can endure without significant reduction in grain yield needs to be quantified and that value may vary depending on the choice of cultivars and establishment method. Brar *et al.* (2018) reported that scheduling irrigation at 1, 2 and 3 days after infiltration of pounded water resulted in 5.6, 13.1 and 19% saving of irrigation water; and 2.4, 5.5 and 7.9% higher energy use efficiency over continuous pounding without any significant reduction in grain yield of transplanted rice.

In view of this, the current investigation was conducted to study the effect of irrigation regimes on energetics, economics, crop and water productivity of rice cultivars grown under two different crop establishment methods in North-western India.

MATERIALS AND METHODS

The experiment was conducted at the Research Farm of Department of Agronomy, Punjab Agricultural University, Ludhiana, during *kharif* 2016 and 2017. The experimental site is located at 30º56' N latitude, 75º52' longitude and at an

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altitude of 247 m (amsl). Ludhiana is situated in the central plain zone of Punjab in trans-gangetic agro-climatic zone of India. The climate of this region is semi-arid, sub-tropical with dry and hot summers during April to June, humid and hot monsoon periods during July to September, mild early winters during October to November and cold winters during December to February. The average annual rainfall of the region is 755 mm, out of which about 70% is received during July to September due to the south-west monsoons and limited is received during winters (December to February) due to the north-east monsoons. The meteorological data of both the years obtained from the Meteorological Observatory, Punjab Agricultural University, Ludhiana, are presented in Fig 1 and 2. The mean weekly maximum and minimum air temperatures during 2016 ranged from 32.0–42.5°C and 16.1–29.2°C, whereas, during 2017, it ranged from 31.4–39.2°C and 16.2–28.5°C, respectively. The total amount of rainfall received during both the crop seasons were 514.2 and 428.0 mm, respectively. The mean weekly relative humidity ranged from 54.1–91.3% and 50–90.6% during 2016 and 2017, respectively. The soil of the experimental site was alluvial sandy loam (Typic

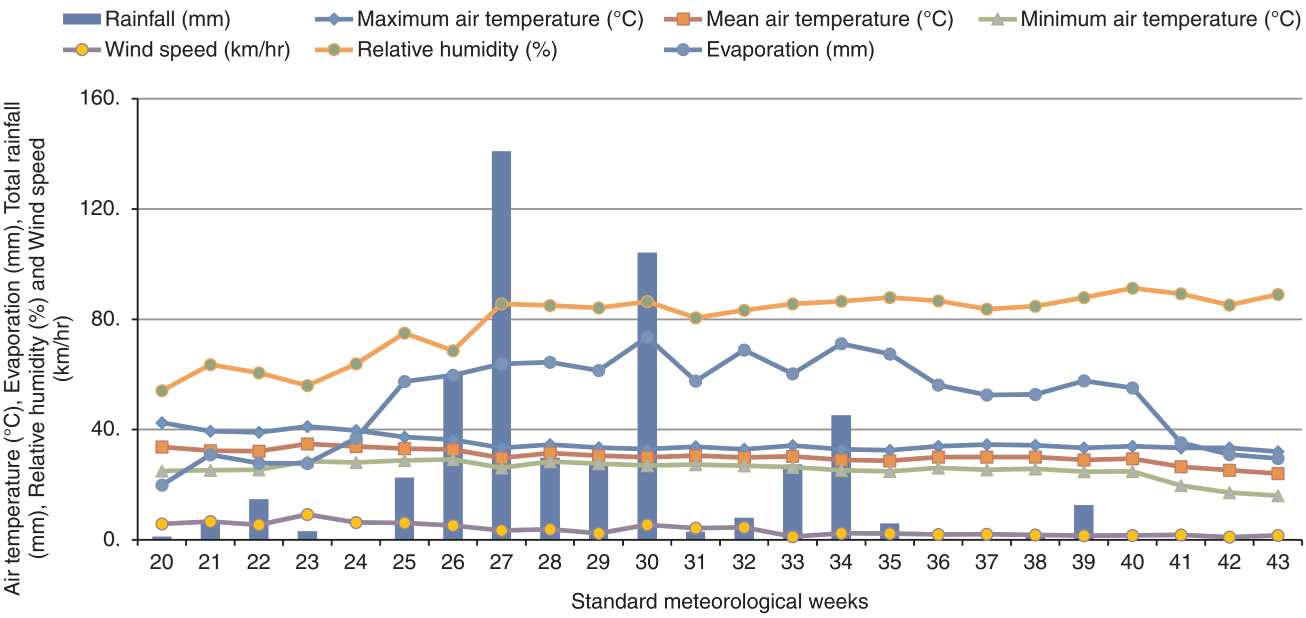

Fig 1 Weekly average air temperatures (ºC), wind speed (km/h), total weekly rainfall (mm), evaporation (mm) and relative humidity (%) recorded during crop growing season (*kharif* 2016).

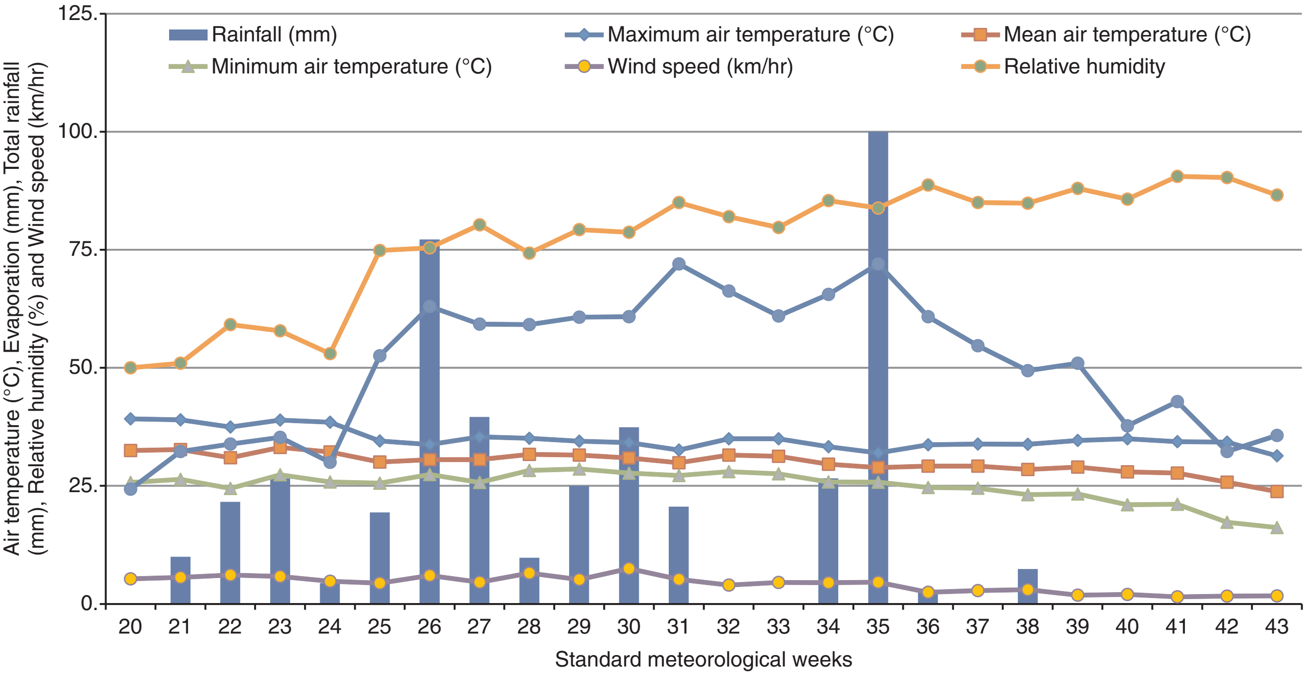

Fig 2 Weekly average air temperatures (ºC), wind speed (km/h), total weekly rainfall (mm), evaporation (mm) and relative humidity (%) recorded during crop growing season (*kharif* 2017).

Ustochrept), normal in reaction (7.1) and low in organic carbon (0.33%) and available N (182.4 kg/ha), medium in available P (13.2 kg/ha) and available K (166.7 kg/ha).

The research experiment was conducted in split-plot design keeping three rice cultivars (PR 115, PR 124 and PR 126) in main plots and six combinations of crop establishment methods (direct seeding and puddled transplanting) and irrigation schedules (irrigation at 2, 4, 6 and 8 days after infiltration of ponded water (DAIPW) for direct seeded rice (DSR) and irrigation at 2 and 3 DAIPW for PTR) in subplots with three replications. DSR was sown with seed drill at 2-3 cm deep with row to row spacing of 20 cm using 20 kg seed/ha. To keep check on weeds, stomp 30 EC (pendimethalin) at 2.5 l/ha was sprayed as pre-emergence within two days of sowing followed by post emergence application of Nominee Gold 10 SC (bispyribac sodium) at 250 ml/ha at 25 days after sowing (DAS). Nitrogen 150 kg/ha was applied in three equal splits at 4, 6 and 9 weeks after sowing. In PTR, seeds were sown in nursery on the same day when DSR was seeded. Thereafter transplanting was done at 20 cm × 15 cm spacing in the puddled field using 25 days old seedlings. Water was kept ponded for the first 15 days after sowing and subsequent irrigations were applied as per irrigation schedules. To control weeds, pretilachlor 50 EC at 1.5 L/ha was applied 2 days after transplanting and nitrogen was applied 125 kg/ha in three equal splits at 1, 3 and 6 weeks after transplanting. To work out the total amount of irrigation water applied in each treatment, a water meter was installed on the PVC pipe from which irrigation water has to pass through. Apparent and total crop water productivity (ACWP and TCWP) was calculated as defined in literature by Brar *et al.* (2018):

ACWP (kg/m^3) = Marketable grain yield (kg/ha)/ Irrigation water applied (m^3/ha)

TCWP (kg/m^3) = Marketable grain yield (kg/ha)/ Irrigation water applied+ Rainfall (m^3/ha)

Total energy used per ha was calculated by addition of partial energies of agricultural inputs, viz., seed, labour, fuel, irrigation, farm machinery, agrochemicals etc. By using energy equivalents, energy output from the economic product and by-product was calculated and is expressed in MJ/ha (Brar *et al*. 2015). Based on these equivalents, energy indices, viz. energy use efficiency (EUE), energy productivity (EP) and specific energy (SE) were calculated:

EUE (%) = Energy output (MJ/ha) ×100/Energy input (MJ/ha)

EP (kg/MJ) = Grain output (kg/ha)/Energy input (MJ/ha)

SE (MJ/kg) = Energy input (MJ/ha)/Grain output (kg/ha)

Analysis of variance (ANOVA) was performed using Proc GLM (SAS Software 9.3, SAS Institute Ltd, USA) for two years separately so as to study the effect of irrigation regimes on different rice cultivars under direct seeded and puddle transplanted conditions. Comparison of means were done with critical difference at 5% probability level. Since, similar trends were observed in results during both the years, pooled analysis was done considering years as main factor to enhance the precision of cultivars and irrigation schedules.

RESULTS AND DISCUSSION

Grain yield and yield attributes: Short duration paddy cultivar PR 126 recorded significantly higher grain yield than PR 115 and PR 124 when averaged over crop establishment methods and irrigation regimes (Table 1). PR 126 produced 22.6 and 23.3% higher grain yield than PR 115 and PR 124, respectively. This might be because of better translocation of photo-assimilates towards developing grains, which is apparent from significantly higher number of tillers per plant and grains per panicle (Table 1). Irrigation regimes at 2 days after infiltration of ponded water (DAIPW) in puddled transplanted rice (PTR) resulted in the highest grain yield (7.07 t/ha) which was statistically similar with 3 DAIPW in PTR (6.96 t/ha) but significantly higher than the grain yield of DSR irrigated at 2, 4, 6 and 8 DAIPW. Maximum yield of DSR was observed when irrigated at 2 DAIPW (6.09 t/ha) which was statistically at par with irrigation regime at 4 DAIPW (5.86 t/ha) but significantly higher than 6 and 8 DAIPW. This was because of corresponding increase in number of effective tillers, number of grains per panicle and 1000-seed weight (Table 1). Brar *et al.* (2015) also recorded statistically similar yield attributes and grain yield in puddled transplanted basmati rice with irrigation application at 2 and 3 DAIPW, but irrigation at 4 and 5 DAIPW caused significant reduction in grain yield.

The interaction between rice cultivars, establishment methods and irrigation schedules manifested that cultivars PR 124 (long duration) and PR 126 (short duration) recorded statistically similar grain yield in puddled transplanted conditions at both irrigation regimes, *i.e.* 2 and 3 DAIPW. Conversely, PR 124 produced significantly lower grain yield than PR 126 in direct seeding conditions regardless of irrigation regimes. In direct seeding conditions, short duration rice cultivar PR 115 when irrigated at 2 and 4 DAIPW, produced significantly higher grain yield than long duration cultivar PR 124 irrigated at respective regimes. However, reverse was true in puddled transplanted conditions, where PR 124 performed better than PR 115. This was the reason that both the cultivars recorded almost same grain yield when averaged over crop establishment and irrigation regimes. Low grain yield realized by PR 124, a long duration cultivar resulted from inappropriate partitioning of photo-assimilates to developing vegetative parts and grains, which is clear from significantly lesser tillers per plant and grains per panicles (Table 1). Significantly lesser grain yield and yield attributes were observed in direct seeded PR 124 than PR 115 and PR 126 because of higher incidence of brown leaf spot disease in PR 124. Significant variation in grain yield of PR 115 and PR 124 was recorded with change in establishment methods, but PR 126 performed statistically identical under both puddled transplanted and direct seeding conditions at all the irrigation regimes except 6 and 8 DAIPW.

Table 1 Yield and yield attributes of rice cultivars as influenced by establishment methods and irrigation regimes (pooled over 2016 and 2017)

Cultivar	DSR				PTR		Mean
	2 DAIPW*	4 DAIPW	6 DAIPW	8 DAIPW	2 DAIPW	3 DAIPW	
Grain yield (t/ha)							
PR 115	5.86	5.67	3.50	2.17	6.43	6.32	4.99
PR 124	5.20	4.86	3.14	2.10	7.29	7.16	4.96
PR 126	7.21	7.04	4.79	2.79	7.49	7.41	6.12
Mean	6.09	5.86	3.81	2.35	7.07	6.96	
CD (P=0.05)	Cultivar: 0.28, EIR**: 3.0, Cultivars × EIR: 5.2						
Effective tillers/m²							
PR 115	377.5	357.1	266.7	208.4	308.5	298.9	302.9
PR 124	345.0	303.0	241.7	194.8	298.6	286.9	278.3
PR 126	380.0	368.6	278.7	217.1	323.0	309.4	312.8
Mean	367.5	342.9	262.4	206.8	310.0	298.4	
CD (P=0.05)	Cultivar = 10.8; EIR = 18.9; Cultivars × EIR = NS						
Grains per panicle							
PR 115	110.7	106.7	95.5	92.4	114.9	112.5	105.5
PR 124	112.7	109.9	99.8	90.6	119.0	117.1	108.2
PR 126	126.3	122.6	113.9	94.5	126.7	123.8	118.0
Mean	116.6	113.1	103.1	92.5	120.2	117.8	
CD (P=0.05)	Cultivar = 5.0; EIR = 4.6; Cultivars × EIR = NS						
1000 grain weight (g)							
PR 115	21.0	20.6	19.7	17.4	21.3	20.9	20.2
PR 124	23.2	22.8	20.1	18.3	23.8	23.5	22.0
PR 126	20.7	20.4	18.7	17.4	20.8	20.7	19.8
Mean	21.6	21.3	19.5	17.7	22.0	21.7	
CD (P=0.05)	Cultivar = 0.3; EIR = 0.5; Cultivars × EIR = 0.9						
Irrigation water applied (mm)							
PR 115	1078.5	874.5	663.5	512.5	1220.5	1004.5	892.3
PR 124	1168.5	969.0	728.0	582.0	1302.5	1095.5	974.3
PR 126	1078.5	874.5	663.5	512.5	1220.5	1004.5	892.3
Mean	1108.5	906.0	685.0	535.7	1247.8	1034.8	
Apparent crop water productivity (kg/m³)							
PR 115	0.547	0.648	0.522	0.419	0.528	0.628	0.549
PR 124	0.455	0.503	0.426	0.360	0.561	0.653	0.493
PR 126	0.671	0.802	0.722	0.539	0.615	0.736	0.681
Mean	0.558	0.651	0.557	0.439	0.568	0.672	
CD (P=0.05)	Cultivar =0.031; EIR =0.033; Cultivars × EIR = 0.058						
Total crop water productivity (kg/m³)							
PR 115	0.604	0.679	0.394	0.258	0.620	0.704	0.543
PR 124	0.456	0.489	0.316	0.261	0.658	0.740	0.487
PR 126	0.753	0.857	0.631	0.318	0.720	0.820	0.683
Mean	0.604	0.675	0.447	0.279	0.666	0.755	
CD (P=0.05)	Cultivar =0.034; EIR =0.043; Cultivars × EIR = 0.074						

*Days after infiltration of ponded water, **Establishment-irrigation regimes. Rainfall was 49.4 cm during cropping season 2016 and 37.0 cm during 2017.

Water productivity functions: Mean irrigation water applied was 9.2% higher for PR 124 as compared to PR 115 and PR 126 because of 10-12 days longer crop duration (Table 1). In DSR, irrigation at 2 DAIPW resulted in 22.3, 61.7 and 106.9% higher amount of irrigation water applied than irrigation at 4, 6, 8 DAIPW, respectively. Direct seeded rice required 12.6% less irrigation water than the puddled transplanted rice at same irrigation regime of 2 DAIPW. The amount of irrigation water applied in PTR was higher due to obligatory requirements of puddling and continuous ponding of water for first 15 days. Though, increase in interval of subsequent irrigations from 2 DAIPW to 3 DAIPW saved 21.3 cm of irrigation water applied in PTR.

The mean ACWP and TCWP were significantly higher for PR 126 to the tune of 38.1 and 40.2%, respectively than PR 124. This was because of significant higher grain

Table 2 Energetics and economic analysis of rice cultivars as influenced by establishment methods and irrigation regimes (pooled over 2016 and 2017)

Cultivar	DSR				PTR		Mean
	2 DAIPW*	4 DAIPW	6 DAIPW	8 DAIPW	2 DAIPW	3 DAIPW	
Energy input (×10^3 MJ/ha)							
PR 115	27.2	25.9	24.6	23.6	28.1	26.7	26.0
PR 124	27.8	26.5	25.0	24.1	28.6	27.3	26.6
PR 126	27.2	25.9	24.6	23.6	28.1	26.7	26.0
Mean	27.4	26.1	24.7	23.8	28.3	26.9	
Energy output (x 10^3 MJ/ha)							
PR 115	86.1	83.3	51.5	31.9	94.5	92.9	73.4
PR 124	76.4	71.4	46.2	30.9	107.2	105.3	72.9
PR 126	106.0	103.5	70.4	41.0	110.1	108.9	90.0
Mean	89.5	86.1	56.0	34.6	103.9	102.4	
Energy use efficiency (%)							
PR 115	316.5	321.4	209.1	134.9	336.3	347.3	277.6
PR 124	275.1	269.3	184.6	128.2	374.3	385.2	269.5
PR 126	389.4	399.1	286.2	173.4	391.7	407.2	341.2
Mean	326.7	329.5	226.4	145.4	367.5	380.0	
Energy productivity (kg/MJ)							
PR 115	0.215	0.219	0.142	0.092	0.229	0.236	0.189
PR 124	0.187	0.183	0.126	0.087	0.255	0.262	0.183
PR 126	0.265	0.271	0.195	0.118	0.266	0.277	0.232
Mean	0.222	0.224	0.154	0.099	0.250	0.258	
Specific energy (MJ/kg)							
PR 115	4.64	4.57	7.03	10.90	4.37	4.23	5.96
PR 124	5.34	5.46	7.96	11.47	3.93	3.82	6.33
PR 126	3.77	3.68	5.14	8.48	3.75	3.61	4.74
Mean	4.59	4.57	6.71	10.28	4.02	3.89	
Net returns (₹ × 10^3/ha)							
PR 115	58.1	56.3	25.7	6.8	66.5	65.6	46.5
PR 124	48.2	44.2	20.2	5.8	78.5	77.4	45.7
PR 126	77.7	76.2	44.4	15.8	81.9	81.4	62.9
Mean	61.4	58.9	30.1	9.5	75.6	74.8	
B:C							
PR 115	2.2	2.2	1.0	0.3	2.5	2.5	1.8
PR 124	1.8	1.7	0.8	0.2	2.9	2.9	1.7
PR 126	2.9	2.9	1.8	0.6	3.1	3.1	2.4
Mean	2.3	2.3	1.2	0.4	2.8	2.9	

*Days after infiltration of ponded water, **Establishment-irrigation regimes yield and less irrigation water requirement of PR 126 cultivar over PR 124. Among establishment-irrigation regimes, maximum ACWP of rice was obtained in puddled transplanted conditions with irrigation at 3 DAIPW (0.672 kg/m^3) followed by direct seeding with irrigation at 4 DAIPW (0.651 kg/m^3). In case of TCWP of rice, similar trend was observed. Delay in application of irrigation water from 2 to 3 DAIPW in PTR enhanced the mean ACWP and TCWP to the tune of 18.3 and 13.4%, respectively. Similarly, increase in waiting period of irrigation from 2 to 4 DAIPW in DSR improved mean ACWP and TCWP, however further delay in irrigation to 6 and 8 DAIPW resulted in decrease in ACWP and TCWP.

Significant interaction between cultivars and establishment-irrigation regimes for ACWP revealed that maximum ACWP was recorded in PR 126 (0.802 kg/m^3) when direct seeded and irrigated at 4 DAIPW, which was significantly better than all other treatment combinations. Though, the cultivar PR 126 irrigated at 2 and 4 DAIPW had statistically identical grain yield in direct seeded conditions but 18.9% less amount of irrigation applied at 4 DAIPW was the reason of higher ACWP than at 2 DAIPW. Similarly, cultivars PR 126 and PR 124 gave statistically equal grain yield in puddled transplant conditions when irrigated at 3 DAIPW but ACWP and TCWP of PR 126 was significantly higher than PR 124. Maximum TCWP (0.857 kg/m^3) was found for PR 126 when direct seeded and irrigated at 4 DAIPW, and it was statistically at par with same cultivar when puddled transplanted and irrigated at 3 DAIPW. In puddled transplanted conditions, PR 124 when irrigated at 3 DAIPW and PR 126 when irrigated at 2 DAIPW had statistically equal ACWP and TCWP. Brar *et al.* (2018) reported that ACWP of PTR was more when irrigated at 3 DAIPW as compared to the other frequent irrigation schedules.

Energy and economic analysis: Maximum energy input was recorded from cultivar PR 124 (26.6×10^3 MJ/ha), whereas maximum energy output was observed from PR 126 (90.0×10^3 MJ/ha) (Table 2). Maximum energy use efficiency (EUE) and energy productivity (EP) were observed in case of PR 126, which was 26.6 and 26.8% higher than PR 124 owing to higher grain yield of PR 126 than PR 124. Whereas, specific energy was maximum in PR 124 (6.33 MJ/kg), which was 6.2 and 33.5% higher over PR 115 and PR 126. The energy input and output decreased with increase in interval of irrigation from 2 to 8 DAIPW in DSR and from 2 to 3 DAIPW in PTR. The higher EUE and EP were observed from PTR irrigated at 3 DAIPW followed by PTR irrigated at 2 DAIPW. This resulted from almost equal energy output but lesser energy input in PTR irrigated at 3 DAIPW than 2 DAIPW. Puddled transplanted PR 126 irrigated at 3 DAIPW recorded the highest EUE, highest EP (277 kg/MJ) and lowest specific energy (3.61 MJ/kg) among all treatment combinations. PR 126 when direct seeded and irrigated at 4 DAIPW proved more energy efficient and productive as compared to same cultivar when puddled transplanted and irrigated at 2 DAIPW.

The data on economic analysis revealed that gross returns, net returns and benefit cost ratio were the highest for cultivar PR 126 when averaged over establishment-irrigation regimes (Table 2). Cultivar PR 126 irrigated at 2 DAIPW and 3 DAIPW in puddled transplanted conditions recorded almost equal net returns (81.9 and 81.4×10^3 ₹/ha) and B:C (3:1), which were highest among all the combinations. Direct seeded PR 126 when irrigated at 2 DAIPW gave net returns of ₹ 77.7×10^3 per ha that decreased with increase in irrigation interval from 2 to 8 DAIPW due to numeric decrease in grain yield, however direct seeded PR 126 irrigated at 2 DAIPW and 4 DAIPW recorded equal B:C (2.9). Brar *et al.* (2015) also reported highest net returns and B:C from puddled transplanted rice irrigated at 2 DAIPW

Thus, it can be concluded that direct sowing of PR 126 irrigated at 4 DAIPW should be recommended for higher crop, water and energy productivity in rice.

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