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Yield and Water Productivity of Direct Dry Seeded Rice (*Oryza sativa* L.) in Relation to Cultivars and Irrigation Regimes in North-West India

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Abstract Ground water depletion and increasing labor scarcity and cost are major concerns for future rice production in Northwest India. The direct seeded rice has been proposed as an alternative to overcome these problem. To test this hypothesis the field investigation was carried out at research farm of the Department of Soil Science, Punjab Agricultural University Ludhiana, Punjab, India during *kharif* of 2010. The experiment comprised of 12 treatments combination viz., three cultivars in main plot (PR 114, PR 115 and PR 120) and four irrigation regimes (10, 20, 30, kPa and fixed 6 days interval) in sub plots. Irrespective of cultivars, the profile moisture storage at 90 days after sowing (DAS) was highest in 10 kPa plots and lowest in 30 kpa plots. The average root mass density (RMD) was highest in PR 120 followed by PR 115 and PR 114 at all the depths. The total RMD in PR 120 and PR 115 was higher by 29 and 12%, respectively over cultivar PR 114. THe RMD increased as soil matric suction increased from 10 to 30 kPa irrigation levels at all the depths. The highest plant height was recorded in PR 120 followed by PR 115 and PR 114. Among irrigation treatments plant height was highest in 10 kPa followed by 20 kPa plots and in case of 6 DI and 30 kPa plots it was similar. The cultivar PR 120 was found to be highest yielder for direct dry seeded rice among the tested cultivars. The paddy yield improvement with PR 120 and PR 115 was 16.3 and 9.6%, respectively over PR 114 (4.9 t ha^{-1}), The optimum irrigation schedule for direct dry seeded rice was found to be 20 kPa matric suction. The irrigation water productivity irrespective of cultivars was highest in 30 kPa plots and lowest in 10 kPa irrigation regimes. However, it was decreased to 0.80 g kg^{-1} in plots irrigated at 20 kPa soil matric suction and 0.65 g kg^{-1} when irrigation at fixed interval of 6 days. The mean irrigation water productivity was maximum in PR 115 (0.88 g kg^{-1}), followed by PR 120 (0.82 g kg^{-1}) and PR 114 (0.58 g kg^{-1}).

Keywords Direct dry-seeded rice, Rice cultivars, Irrigation regimes, Water productivity, Paddy yield.

Introduction

Traditional transplanting of rice leads to high water requirement for puddling, surface evaporation and

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Table 1. Irrigation water applied and total water input used under different irrigation regimes and cultivars. *Amount of rainfall received during the growing period was 619 mm.

	Cultivars							
Irrigation scenario	PR114	PR115	PR120	Mean	PR114	PR115	PR120	Mean
	Irrigation water (mm)				Total water input* (mm)			
10 kPa	1190	910	980	1027	1809	1529	1599	1646
20 kPa	840	560	700	700	1459	1179	1319	1319
30 kPa	630	420	490	513	1249	1039	1109	1132
6 DI	910	630	770	770	1529	1249	1389	1389
Mean	893	630	735		1511	1249	1354	

percolation. Water resources, both surface and underground are shrinking and water has become limited factor in rice production [1]. Increasing water scarcity, water-intensive nature of rice cultivation and increasing labor cost have necessitated the search for alternative management method to increase water productivity in rice cultivation. Current levels of groundwater extraction are more in Northwest India. Therefore, there is an urgent need to develop a system capable of producing more grain while using less water. In central Punjab, the rate of fall in ground water increased from 0.2 m y^{-1} during 1973–2000 to about 1 m y^{-1} during 2001–2006 [2]. This fall has resulted in an increased energy requirement and cost of pumping ground water, increased tube well installation cost and deteriorated the groundwater quality [3]. In south Asia, common practice of establishing rice is through puddling followed by seedling transplanting. Puddling help in reducing water losses through percolation and controlling weeds by water stagnation in rice fields [4]. But being costly, cumbersome and time and water-consuming, it results in degradation of soil and other natural resources and subsequently poses difficulties in seedbed preparation for succeeding crop in rotation. Breaking of soil aggregates, alteration of particle orientation and development of hard pan at a depth of 15—25 cm [5, 6] impede root growth of wheat [7]. Also labor scarcity and drudgery among women workers are some of the other disadvantages associated with puddle-transplant rice. Therefore, to get rid of puddling or transplanting or both, efforts are required to explore the possibilities for adopting other crop establishment techniques in rice like direct seeding under unpuddled conditions. Direct seeding rice (DSR) has received much attention because of low water-input demand. Direct seeding has been principal method of rice establishment since 1950's [8]. It refers to the process of establishing a rice crop from seeds sown in the field rather than by transplanting from the nursery. The DSR is a resource conservation technology as it uses less water with high efficiency and incurs low labor expenses. An ideal type cultivar has contributed remarkably to increase rice yield. Rice cultivars with fewer tillers, lower panicle weight with thick roots and culms are suitable for DSR. Early heading rice varieties with better drought tolerance are better suited for dry-seeded rice. Photoperiod-insensitive cultivars for drought-prone areas may also perform well under the DSR system. Till date, no specific cultivars have been found suitable for DSR. Existing varieties used for puddle transplanted rice (PTR) do not appear to be well suited for seedling growth. As a result it requires 2—3 times higher seed rate to obtain optimal plant population. The DSR is a major opportunity to change production practices to attain optimal plant density and high water productivity in water scare areas. However, appropriate water management, optimum plant population, short duration varieties and more efficient weed management particularly during early growth stages are some of the factors to achieve satisfactory yields. Keeping these points in mind a study was carried out to test the performance of cultivars and irrigation regimes under direct dry-seeded rice in medium textured soil.

Table 2. Profile moisture storage (cm in 0–60 cm soil depth) at 90 DAS and at harvest as affected by different irrigation regimes and cultivars.

	Cultivars							
Irrigation scenario	PR 114	PR 115	PR 120	Mean	PR 114	PR 115	PR 120	Mean
	90 DAS				At harvest			
10kPa	12.2	10.9	10.7	11.3	7.7	7.9	7.8	7.8
20 kPa	11.2	10.7	10.2	10.7	7.6	8.1	7.8	7.8
30kPa	10.0	10.5	10.3	10.3	7.6	7.9	7.7	7.7
6 DI	10.8	10.1	10.3	10.4	7.4	7.3	7.1	7.3
Mean	11.1	10.6	10.4		7.6	7.8	7.6	
LSD (0.05)	V=NS, I=0.45, V × I=0.79				V=NS, I=0.364, V × I=NS			

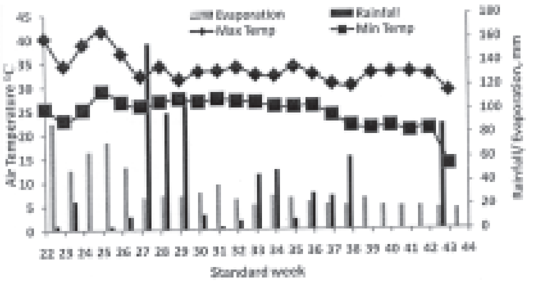

Fig. 1. Weekly total rainfall, pan evaporation and maximum & minimum temperature during crop growing season (June to October 2010).

Materials and Methods

The field study was conducted at Research Farm, Department of Soil Science, Punjab Agricultural University, Ludhiana, during *kharif* 2010. The site is situated at 30° 56´ N latitude and 75° 52´ E longitude with a mean height of 247 meter above the mean sea level. The average annual rainfall of the area is 600–700 mm, of which about 80% is received during July to September. The meteorological data collected from observatory situated about 2 km away from the research experiment (Fig. 1), The experimental field was under rice-wheat rotation for the last three years. After wheat harvest field was irrigated in the last week of May and disked once and cultivated twice followed by planking at field capacity so as to get good seed bed. Pre-sowing irrigation was given four days peior to sowing. The treatments comprised of different cultivars viz. (i) PR 144 (long duration) (ii) PR115 (short duration) and (iii) PR120 (medium duration) as main plots and intermittent irrigation on the basis of soil matric suction viz. (i) 10 kPa, (ii) 20 kPa, (iii) 30 kPa and (iv) on fixed six day interval (6 DI) as sub-plots. The treatments were replicated thrice in split plot design with plot size was 4.6 m ×4.1 m. The surface soil of the experimental site contained 77% sand and 11.8% silt, had pH 8.0, EC 0.3 dS m^{-1}, organic carbon content 0.38%, available P and K contents 12.9 and 146.1 kg ha^{-1}, respectively. The sowing of direct dry-seeding was done on June 9th, 2010. Fertilizers and other agronomic practices were followed as per the package of practices recommended by PAU. Sowing was done manually by a hand drill at depth of 3–4 cm. The vacuum gauge tensiometers were installed in different treatments at 15–20 cm depth for monitoring soil matric suction. Soil moisture samples were taken from 0–15, 15–30, 30–45 and 45–60 cm profile layers at different stages of crop growth by thermo-gravimetric method. Moisture storage in different soil layers was computed by multiplying the mass water content with bulk density and depth of a particular layer. It was summed up for all the layers to get profile moisture storage in cm.

The plant height was recorded from ground level to the base of the panicle at the time of 20 days before harvesting. It was recorded from five randomly selected plants in each plot. For determine root mass density, the soil cores were collected using an iron auger of 7 cm inner diameter hammered to different soil depths at 0–15, 15–30 and 30–45 cm in each plot. Three core samples were collected from each plot, at the base of plant. The sampling was done at 90 DAS. The core was washed in running water by providing gentle flushing in a net cloth having pore size of 1 mm. The flushing was continued until the soil particles were washed out of the net. Each root sample was pressed in filter paper to remove extraneous water. The roots were transferred to petri dishes and cleaned for weed roots and other inert materials. The

Table 3. Plant height (cm) and paddy yield (t ha^{-1}) of different cultivars as affected by irrigation regimes.

Irrigation scenario	Cultivars PR114	PR115	PR120	Mean	PR114	PR115	PR120	Mean
		Plant height				Paddy yield		
10 kPa	120.6	115.1	119.5	118.4	5.1	5.5	5.7	5.4
20 kPa	116.2	111.9	120.3	116.1	5.1	5.5	5.6	5.4
30 kPa	96.9	108.5	114.1	106.5	4.8	5.0	5.6	5.1
6 DI	97.2	108.0	115.8	107	4.5	4.6	5.7	4.9
Mean	107.7	110.9	117.4		4.9	5.2	5.7	
LSD (0.05)	V=1.46, I=2.61, V × I=4.5				V=0.37, I=0.21, V × I=0.36			

roots were then oven dried at 60°C and weighed with the help of precise balance. The ratio of dry mass of roots and the core volume was expressed as root mass density. The crop was harvested manually when grain almost matured and straw had turned yellow. The PR115 was harvested on October 31, 2010, PR120 on October 18, 2010 and PR114 was harvested on October 31, 2010. The paddy yield was expressed as t ha^{-1} after adjusting grain moisture content at 14%. The straw yield was also recorded and expressed as t ha^{-1} on sundry basis. Treatments effects were judged by using ANOVA in split-plot design.

Results and Discussion

Irrigation water used

The amount of irrigation water used (IWU) was highest in 10 kPa followed by 6 DI, 20 kPa and lowest in 30 kPa plots (Table 1). However, the irrigation water input was 70 mm more in 6 DI as compared to plots irrigated at 20 kPa soil matric suction. It decreased from 1027 mm in 10 kPa plots to 513 mm in 30 kPa plots. Irrigation water in 10 kPa plots utilized double the amount of irrigation water over 30 kPa matric suction treatments while 6 DI and 20 kPa matric suction treatments required 45 and 36% higher irrigation water, respectively than 30 kPa. It is clear from the data that with the increase in matric suction there was decrease in irrigation water inputs. The irrigation water applied in DSR was 33% less as matric suction increased from 20 to 70 kPa plots [9]. The mean irrigation water applied was highest in PR114 (892.5 mm), followed by PR120 (735 mm) and PR115 (630 mm). The higher amount of irrigation water use in PR114 was attributed to more number of days required to complete its life cycle (144 days) as compared to PR120 (136 days) and PR115 (125 days). Longer duration of the crop leads to higher number of irrigation and hence the irrigation water input. The total amount of irrigation water increased with the duration of the cultivars grown under puddled transplanted condition. The trend observed for total amount of water input (Irrigation + rainfall) was similar as obtained in case of irrigation water use due to similar amount of rainfall received (619 mm) for all the cultivars during cropping season.

Profile moisture storage

The crop irrigation on the basis of 10 kPa matric suction recorded significantly higher profile moisture storage (11.3 cm) at 90 DAS, than other treatments (Table 2). The irrigation on the basis of 20 kPa, 30 kPa and 6 DI plots recorded similar storage. The lowest soil moisture storage in 30 kPa may be due to more exploitation of profile moisture by plant root and also due to delayed irrigation. Due to water stress in 30 kPa plots the root might have struggled to explore the deeper layers (15–30 and 30–45 cm) for want of water and nutrients, thereby exhausting the stored water in

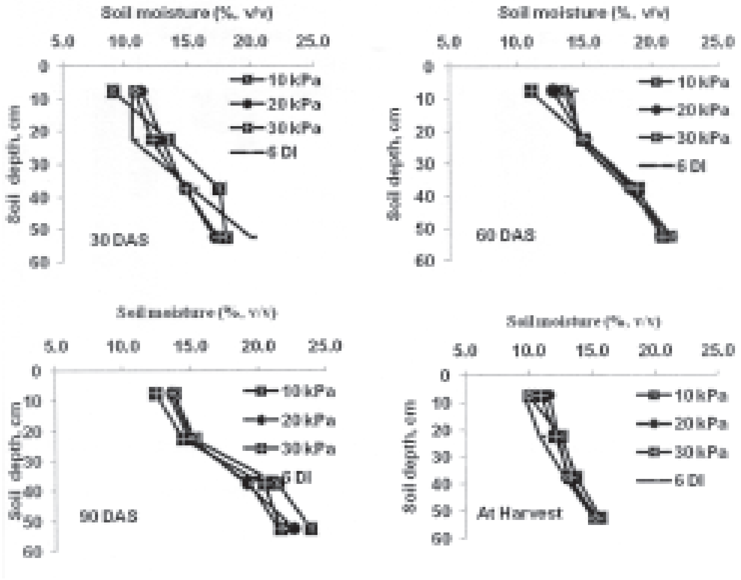

Fig. 2. Soil moisture distribution as affected by irrigation treatments at various growth stage.

soil profile. The better soil water retention responds good root growth; otherwise it goes deep in the soil profile under soil moisture stress conditions [10]. At 90 DAS the interaction was significant with respect to cultivar and irrigation levels. Interaction was due to variable water use among varieties and revealed that water efficiently used by cultivars PR 120 and PR 115. At harvest, the profile moisture storage recorded in 0–60 cm profile depth did not vary significantly with respect to the cultivars. The profile moisture storage was the highest (7.8 cm) in 20 kPa plots and the lowest (7.3 cm) in 6 DI plots. The profile moisture storage in 10, 20 and 30 kPa was statistically similar but significantly higher from that in 6 DI plots. Almost similar amount of profile moisture storage in different irrigation treatments at harvest stage could be due to the reason that the irrigation was ceased two weeks before the crop harvest. The profile moisture storage was always lowest in PR 120 plots at all the irrigation levels whereas; it was highest in PR 115.

Soil moisture distribution

The moisture content was found to be highest at 90 DAS followed by 60 DAS, 30 DAS and lowest at harvest (Fig. 2). The mean soil moisture content varied from 13.4–22.5, 12.9–21.1, 10.5–18.1 and 10.6–15.3% at 90, 60, 30 DAS and at harvest, respectively. The soil moisture content in frequently irrigated plots on the basis of 10 kPa varied from 9.1–23.9% while it was observed 11.4–22.7% in 20 kPa, 10.8–21.7% in 30 kPa and 9.7–21.5% in 6 DI during cropping season. It was observed that at 90 DAS frequently irrigated plots attain 1.3–2.2% more soil moisture in the profile as compared to 30 kPa plots. It is clear from the figure that profile moisture depletion at various growth stages was higher in PR 120. It showed that this cultivar utilized profile moisture efficiently.

Root mass density

The root mass density was highest in PR 120 followed by PR 115 and PR 114 at all the depths (Fig. 3). The total RMD observed in PR 120 and PR 115 was higher by 29 and 12%, respectively over PR 114 cultivar which recorded 1164 µg cm^{-3}. In top 0–15 cm soil layer mean RMD recorded with PR 120, PR 115 and

Table 4. Irrigation water productivity (g kg^{-1}) and total water input productivity of different cultivars as affected by various irrigation regimes.

Irrigation scenario	PR 114	PR 115	PR 120	Mean	PR 114	PR 115	PR 120	Mean
	Cultivars							
	Irrigation water productivity (g kg^{-1})				Total water input productivity (g kg^{-1})			
10 kPa	0.43	0.60	0.58	0.54	0.30	0.36	0.35	0.34
20 kPa	0.61	0.98	0.81	0.80	0.35	0.47	0.43	0.42
30 kPa3	0.76	1.20	1.14	1.03	0.40	0.50	0.50	0.47
6 DI	0.50	0.73	0.73	0.65	0.30	0.37	0.41	0.36
Mean	0.58	0.88	0.82		0.34	0.43	0.42	

PR 114 was 1253, 1123 and 1002 µg cm^{-3}, respectively. The subsequent corresponding values for 15–30 cm soil layer were 199, 148 and 136 µg cm^{-3} and for 30–45 cm it was 49, 34 and 25 µg cm^{-3}. It is clear from the data that RMD was relatively higher in lower layers with PR 120 compared to other cultivars. The most of the roots were found to be in 0–15 cm soil layer and it varied from 77—89% in PR 120 and 80—92% in other two cultivars among various irrigation regimes. As usual RMD decreased with increase in depth of soil. The total RMD was observed to be highest in plots irrigated with 30 kPa matric suction and lowest with 6 DI plots. The RMD for PR 114, PR 115 and PR 120 values varied from 1242, 1458 and 1730 µg cm^{-3}, respectively in 30 kPa plots while corresponding values for 6 DI plots was 1022, 1154 and 1284 µg cm^{-3}. In general, it is clear from the figure that RMD increased as soil matric suction increased from 10 to 30 kPa at all the soil depths. The highest RMD in 0–45 cm profile in 30 kPa plots could be due to delayed irrigation which has created stress forcing the roots to expand and grow in deeper layers to absorb available soil moisture. Many rice genotypes have the potential for deep root growth compared with other rice genotypes but this is strongly controlled by the environment [11]. The lowest RMD in 6 DI plots indicate that the irrigation interval of 6 days was not a good indicator of irrigation scheduling as the fixed interval may not indicate the exact status of soil moisture depletion.

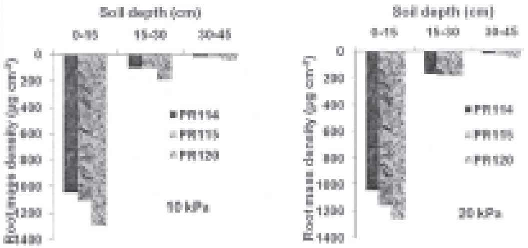

Fig. 3 (a).

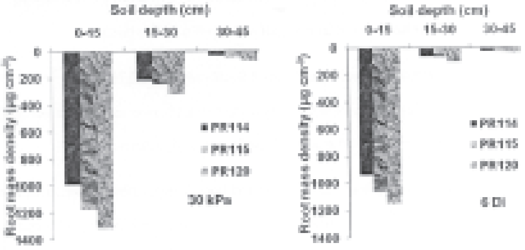

Fig. 3 (b).

Fig. 3 (a, b). Root mass density (RMD) in different soil layers under various cultivars for different irrigation treatments.

Plant height and paddy yield

The plant height was significantly influenced by cultivars and irrigation levels (Table 3). The highest plant height was recorded in case of PR 120 (117.4 cm) followed by PR 115 (110.9 cm) and lowest in PR 114 (107.7 cm). It was significantly higher in 10 kPa plots followed by 20 kPa plots and was recorded at par in case of 6 DI and 30 kPa plots. The crop irrigated on the basis of 10 and 20 kPa matric suction recorded 11.2 and 10.3% higher plant height, respectively over 30 kPa matric suction (106.5 cm). The paddy yield was significantly highest in PR 120 as compared to PR 115 and PR 114, which were at par (Table 3). The crop irrigated on the basis of 10 and 20 kPa produced significantly higher paddy yield as compared to 30 kPa and 6 DI irrigation treatments. Irrigation applied on the basis of 30 kPa matric suction and 6 DI produced 6 and 10% lower paddy yield, respectively than recorded in 10 and 20 kPa plots (5.4 t ha^{-1}). The paddy yield recorded in 30 kPa (5.1 t ha^{-1}) and 6 DI plots (4.9 t ha^{-1}) was at par statistically. It is thus clear from the data that rice should be irrigation on the basis of 20 kPa matric suction for optimum yield in direct dry-seeded rice. The lowest yield in 6 DI plots indicates that the fixed day interval irrigation schedule does not supply sufficient moisture to the crop plants as per their requirement. This could be the situation particularly during hot and high evapo-transpiration period where the soil remains dry during the fixed interval period. However, the soil matric tension proves to be a better index of irrigation scheduling. The tensiometers indicate the soil moisture status continuously and results in need based water application to the fields. The paddy yield of both PTR and DSR were optimum at 20 kPa [12]. The cultivars and irrigation interacted significantly to affect the paddy yield (Table 3). The paddy yield of PR 120 was not significantly affected by the differential irrigation regimes whereas, in case of PR 114 and PR115, the paddy yield decreased significantly with increases in soil matric suction from 20 to 30 kPa and 6 DI plots. This indicates that PR 120 is more resistant to soil moisture stress condition and found suitable for direct dry-seeding rice.

Water productivity

Water productivity decreased progressively with increase in irrigation water inputs (Table 4). It was highest in 30 kPa plots and lowest in 10 kPa plots. The values decreased from 1.03 g kg^{-1} in 30 kPa plots to 0.54 g kg^{-1} in 10 kPa plots. However, it decreased to 0.80 g kg^{-1} in plots irrigation at 20 kPa soil matric suction and 0.65 g kg^{-1} when irrigated at fixed interval of 6 days. The water productivity varied from 0.43—1.20 g kg^{-1} among various treatments. In sandy loam soil the water productivity under DSR with 20 kPa irrigation was higher than in daily irrigated plots [13, 14]. The mean irrigation water productivity was highest in PR115 (0.88 g kg^{-1}), followed by PR 120 (0.82 g kg^{-1}) and PR114 (0.58 g kg^{-1}). The higher irrigation water productivity in PR 115 is due to its shorter duration (125 days) as cpmpared to other cultivars. The irrigation water use efficiency decreased with the duration of the cultivars. Longer duration of the crop leads to higher number of irrigations hence lower irrigation water productivity. The total input water productivity also followed the same trend as observed in case of irrigation water productivity. It was lower than irrigation water productivity in respective treatments/cultivars due to similar amount of rainfall received. The total input water productivity was 0.47 g kg^{-1} in 30 kPa as compared to 0.34 g kg^{-1} in 10 kPa plots (Table 4). However, input water productivity values of 20 kPa and 6 DI irrigation treatments remain between these two. Input water productivity with cultivar PR 114 was lowest while PR 115 and PR 120 showed similar values.

Conclusion

The cultivar PR 120 was found to be suitable for direct dry-seeding rice being highest yielder among the tested cultivars. The paddy yield improvement with PR 120 and PR 115 was 16.3 and 9.6%, respectively over that in PR 114 (4.9 t ha^{-1}). The optimum irrigation schedule for direct dry-seeded rice was found to be 20 kPA matric suction. The irrigation water productivity irrespective of cultivars was highest in 30 kPa plots and lowest in 10 kPa plots. However, the irrigation water productivity decreased to 0.80 g kg^{-1} in plots irrigated at 20 kPa soil matric suction and 0.65 g kg^{-1} when irrigated at fixed interval of 6 days. The mean irrigation water productivity was maximum in PR 115 (0.88 g kg^{-1}), followed by PR 120 (0.82 g kg^{-1}) and PR 114 (0.58 g kg^{-1}).

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