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Yield and Water Productivity of Rice Cultivars as Influenced by Transplanting Dates and Seedling Age in Irrigated Semi-Arid Subtropical Environment

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ABSTRACT

In order to study water and crop productivity in rice, a field experiment was conducted to see the effect of rice cultivars in relation to age of seedling and transplanting dates for a period of two years at Punjab Agricultural University, Ludhiana, India. The study revealed that shifting the date of transplanting from the 15th June to the 5th July resulted in a saving of 212 mm irrigation water without compromising rice yield. Crop water productivity was not significantly influenced by seedling age. Grain yield, however, declined significantly when the crop was transplanted with 60-days-old seedlings rather than 30 or 45-days-old seedlings. Cultivar 'PAU-201' showed the highest yield among all the cultivars and the mean yield increased to the extent of 17.8, 11.5 and 12%, compared with cvs. 'PR-115', 'PR-116' and 'PR-118' respectively. The early maturing cultivar 'PR-115' saved 19.5, 22.4 and 21.9% more irrigation water than cvs. 'PR-116', 'PR-118' and "PAU-201", respectively. Crop water productivity was highest in cv. 'PAU-201' (33.73 kg ha^{-1} cm^{-1}) transplanted on 5th July followed by cv. 'PR-115' (33.59 kg ha^{-1} cm^{-1}). When transplanted on the 15th June, crop water productivity was highest in early maturing cv. 'PR-115' (32.89 kg ha^{-1} cm^{-1}) followed by cv. 'PAU-201' (29.34 kg ha^{-1} cm^{-1}). Crop water productivity was significantly less in cv. 'PR-116' and late maturing cv. 'PR-118' than in cvs. 'PR-115' and 'PAU-201' on all transplanting dates.

Keywords: crop water productivity, rice cultivar, seedling age, transplanting date

INTRODUCTION

The productivity and production of rice in Indian Punjab is vital for the food and livelihood security of India, as it contributes 40-50% rice to the central pool. However, yields are either declining or stagnant, and there are grave concerns about the sustainability of rice production in Indian Punjab to keep pace with population growth (Pingali and Shah 1999; Ladha *et al*. 2003). Irrigated rice cropping has been practiced in alluvial coarse-textured soils of Indian Punjab since the early 1970s, there has been an alarming scarcity of ground water resources due to early transplanting of rice in May/June during the period of peak evaporative demand. Poor infrastructure systems and greater reliance on groundwater have led to water table decline of 0.1 to 1.0 m yr^{-1}, resulting in a scarcity and higher cost of pumping water (Gill 1994; Harrington *et al*. 1993; Sharma *et al*. 1994; Sondhi *et al*. 1994; Hira *et al*. 2004). In central Punjab having good quality ground waters, the areas with water table below 10 m depth increased from 3% in 1973 to 76% in 2002 (Hira *et al*. 2004), thereby threatening the sustainability of rice culture. Therefore, there is an urgent need to develop suitable rice cultivation technology capable of producing more grains while using less water in Punjab. Many technologies appear to be promising in saving substantial amounts of water through reduced irrigation in rice but whether these are true water saving is uncertain (Humphry *et al.* 2005). One of the approaches could be maximization of WP_I, WP_{I+R} and WP_{ET} [the amount of grain (rice or wheat) produced per unit of water consumed as evapotranspiration (WP_{ET}), or supplied as irrigation (WP_I), or the total input of irrigation and rainfall (WP_I+R)] by growing cultivars of rice having different growth duration in the period of least evaporation demand or by altering the age of nursery so that duration of the crop in the main field could be reduced without any loss in crop productivity. In the past the majority of farmers in the region used to plant rice crop earlier than the recommended time (15th June transplanting), because of external factors such as increased pest pressure on timely planted crop, availability of labour and canal water/electricity for pumping ground water. This increased the water requirement of rice, because of high evapotranspiration demand, which is met through the underground water resource. As a result the water table started to decline alarmingly. The optimum time of transplanting may therefore, improve the water as well as crop productivity of rice. Although delayed rice planting could save water but it could also delay planting of wheat in the predominant rice-wheat system of this region beyond the optimum time of wheat sowing (25th October to 15th November), causing yield losses around 1-1.5% day^{-1} due to poor grain filling at higher temperatures (Ortiz-Monasterio *et al.* 1994). Water may also be saved by using short duration cultivars of rice by transplanting them late in the season when the evapotranspiration rates are low, provided this does not reduce yield and hence water productivity. Further, late transplanting of early maturing rice cultivars may allow a timely harvest, increasing the chances of a timely establishment of the wheat crop after rice and may make the rice-wheat cropping system more productive. Observations from a farmer field trial revealed that crowding rice seedlings in the nursery and ageing them up to 50 days led to a delay in the formation of the first node resulted in saving of water equivalent to peak evapotranspiration demands of almost two weeks (220 mm) without any adverse effect on tillering (Khan *et al.* 2004). Thus, ageing seedling in the nursery bed and its late planting at less evaporative demands could be an important strategy for saving water provided it does not result in any yield decline due to reduced tillering. According to Matsuo and Hoshikawa (1993), however, when seedlings

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Table 1 Mean air temperature, rainfall, sunshine hours and relative humidity in 2006 and 2007.

Month	Mean air temperature (°C)*		Rainfall (mm) and number of rainy days		Sunshine hours		Relative humidity (%)	
	2006	2007	2006	2007	2006	2007	2006	2007
June	31.5	32.3	40.5 (4)	89.2 (5)	7.9	9.3	53.0	40.0
July	30.8	30.8	209.2 (8)	150.7 (5)	5.9	8.1	77.0	62.0
August	30.0	30.4	142.7 (10)	110.6 (5)	7.3	7.1	77.0	77.0
September	28.0	28.4	103.6 (2)	56.8 (7)	8.0	6.5	76.0	80.0
October	25.3	23.8	6.8 (1)	0.0 (0)	7.4	6.5	68.0	80.0

*Mean of max. and min. temperature. Numbers in parentheses represent number of rainy days.

stay longer in the seed nursery bed, primary tiller buds on the lower nodes of the main culm often degenerate. The age of seedlings at the time of transplanting is an important factor for a uniform stand and establishment of a crop. If the age of a seedling is less than optimum, the tender seedlings may die in greater numbers due to high temperature, resulting ultimately in a reduced plant population. On the other hand, if the age of seedlings is more than optimum, the seedling produces fewer tillers due to reduced vegetative period resulting in poor yield. Hence, we planned to study the genotypic behaviour of different rice cultivars under varied transplanting dates and age of nursery and their interaction in relation to crop and water productivity in the northwestern state of Indian Punjab.

MATERIALS AND METHODS

Experimental site

An experiment was conducted on loamy sand soil at the research farm of rice section, Punjab Agricultural University (PAU), Ludhiana (30°56′N, 75°52′E and 247 m a.s.l.), in India during the *kharif* season of 2006 and 2007. The field had a history of rice-wheat rotation for more than 20 years and had a hard pan below 25 cm. The climate of the area is semi-arid with an average annual rainfall of 400-700 mm (75-80% of which is received during July to September), minimum temperature of 0 to 4°C in January, maximum temperature of 41 to 45°C in June. The experimental soil (0-15 cm) was loamy sand in texture, with a bulk density of 1.52 Mg m^{-3}, pH 8.0, EC (saturation extract) 0.19 dS m^{-1}, organic nitrogen 220 mg kg^{-1}, organic matter 0.27%, Olsen P 8.1 mg kg^{-1}. The climatic parameters were recorded at a meteorological observatory at a distance of 500 m from the experimental field. The mean monthly air temperature, rainfall, sunshine hours and relative humidity during the cropping seasons are presented in **Table 1**.

Experimental treatments and observations

The treatments included three dates of transplanting (D_1: 15th June, D_2: 25th June and D_3: 5th July) in main plots and combination of four cultivars ('PR-115', 'PR-116', 'PR-118' and 'PAU-201') and three age of nursery treatments (30, 45 and 60 days-old) in subplots. So, a total of 36 treatments in 108 plots of size 2.5 × 4 m were tested in a Factorial Split plot design replicated thrice. The cultivars 'PR-115', 'PR-116', 'PR-118' and 'PAU-201' were chosen because of their contrasting maturity characteristics. Cv. 'PR-115' is categorized in the early maturing group (120-125 days duration), 'PR-116' and 'PAU-201' in the medium maturing group (140-145 days duration), while 'PR-118' was categorized in the late maturing group (155-160 days duration). Irrigation comprised of continuous flooding for 15 days after transplanting followed by intermittent irrigation at 3-days' interval up to 14 days before harvest. The depth of irrigation water was computed by monitoring the water level before and after irrigation using fixed scales in the field plots. Thirty days-old nursery of each cultivar was transplanted on respective dates of transplanting as two seedlings/ hill with a row-to-row spacing of 20 cm and a hill-to-hill distance of 15 cm in the puddled field. Puddling was done by running cultivator in standing water (75 mm) followed by planking. At each date of transplanting, 40 kg N was applied 5 days after transplanting. Second and third doses of nitrogen (40 kg ha^{-1} each) were applied at 21, 42 days after transplanting in D_1, D_2 and D_3 dates respectively. To control weeds, herbicide Rifit at 1.5 kg ha^{-1} (Pretilachlor) was applied two days after transplanting. Chlorpyriphos at 2.5 l ha^{-1}) and Tilt 25 EC at 500 ml/ha were used to control insect pests and diseases. The rice cv. 'PR-115' was harvested in the third week of September. Cvs. 'PR-116' and 'PAU-201' were harvested in the second week of October and 'PR-118' was harvested in the last week of October. At harvest, grain yield was measured at 14% grain moisture content. At the same time, five hills were selected randomly from each plot for measuring agronomic parameters including plant height, number of productive tillers $sqm.^{-1}$, grains $panicle^{-1}$ and sterility. For calculating the crop water productivity, grain yield in kg ha^{-1} divided by the water expenses in cm was expressed as kg grain yield per cm irrigation water. The water expenses were calculated for different treatment combinations. The water expense is sum total of irrigation water applied and rainfall during the growing season of the crop.

Statistical analysis

The data were analyzed statistically using analysis of variance technique and significant means were separated using least significance difference test (LSD) for comparing the treatment means (Gomez and Gomez 1984).

Table 2 Plant height, days to 50% flowering after transplanting and number of productive tillers m^{-2} across different treatments.

Treatments	Plant height (cm)			Days taken to 50% flowering			Number of productive tillers m^{-2}		
	2006	2007	Mean	2006	2007	Mean	2006	2007	Mean
Date of transplanting									
15th June	104.3	105.3	104.8	73	70	71.5	389	357	373.0
25th June	101.7	102.2	101.9	69	69	69.0	352	355	353.5
5th July	95.7	101.3	98.5	66	67	66.5	347	323	335.0
LSD (0.05)	1.8	1.9	-	-	-	-	15.6	24.1	-
Age of seedlings (days)									
60	99.6	101.5	100.5	62	66	64.0	355	347	351.0
45	100.0	102.9	101.4	69	70	69.5	359	343	351.0
30	102.2	104.4	103.3	74	72	73.0	373	344	358.5
LSD (0.05)	1.8	1.9	-	-	-	-	NS	NS	-
Cultivars									
PR-115	98.5	98.3	98.4	57	57	57.0	351	338	344.5
PR-116	107.1	108.0	107.5	73	72	72.5	350	314	332
PR-118	97.7	103.4	100.5	78	79	78.5	366	356	361
PAU-201	99.1	102.0	100.5	70	70	70.0	382	372	377
LSD (0.05)	1.6	1.7	-	-	-	-	20.0	22.0	-

RESULTS AND DISCUSSION

Phenology

Date of transplanting, seedling age and cultivars significantly influence the plant height, but their interaction was found to be non-significant (**Table 2**). The crop transplanted on the 15th June attained more height as compared to delayed transplanting dates (25th June or 5th July). Plants transplanted with younger seedlings were significantly taller than older ones. The data in **Table 2** elucidated that crop plant height with the 30 days old nursery increased to the extent of 2.2% and 2.6% over 45 and 60 days-old nursery, respectively. This may be due to less root damage in the young seedlings during uprooting which leads to full utilization of the root structure in absorption of nutrients which ultimately caused vigorous growth of plants. The older seedlings might have utilized their stored carbohydrates for repairing damaged roots in early growth stages, so their percent increase in plant height might be slower than that of the younger ones. These results are in conformity with the study of Abdul (2005), who reported that older rice seedlings, with the exception of root dry weight, did not perform well compared to young seedlings in all physiological and morphological aspects. 'PR-116' registered tallest plants among all the tested cultivars. The cultivars 'PR-115', 'PR-116', 'PR-118' and 'PAU-201' registered mean plant height 98.4, 108, 103.4 and 102 cm respectively. Rice seedling transplanted on 15th June took maximum days for 50% flowering (71.5 days) followed by 25th June transplanting (69.0 days) and minimum in 5th July transplanting (66.5 days). The crop transplanted with 60 days old nursery took only 64 days as compared to 73 days with 30 days old nursery. Among cultivars, 'PR-115' flowered early and took only 57 days for 50% flowering compared to 72.5, 78.5 and 70 days taken by cultivars 'PR-116', 'PR-118' and 'PAU-201', respectively.

Number of productive tillers (m^{-2})

Among yield components, productive tillers are very important because the final yield is mainly a function of the number of panicle bearing tillers per unit area. The data presented in **Table 2** indicate that the productive tillers m^{-2} differed significantly by varied transplanting dates during both the years of study. The mean data (**Table 2**) revealed that the crop transplanted on the 15th June resulted in most productive tillers (373 m^{-2}), followed by the crop transplanted on the 25th June with 353.5 productive tillers m^{-2}. The lowest tillers (335 m^{-2}) were recorded during 5th July transplanting. These results are in conformity with those of Hassan *et al.* (2003) who also found that maximum tillers were formed in the crop transplanted in June during his study in the *trans*-Indo-Gangetic Plains. The age of seedling failed to influence the effective tillers m^{-2} significantly. Similarly, Chandra and Manna (1988) observed no difference in tillering behaviour with the use of 30- and 60-days-old seedlings. As regards to cultivars, the maximum numbers of productive tillers m^{-2} (377) was found in cv. 'PAU-201' during both the years of study. Cvs. 'PR-115' and 'PR-116' produced significantly fewer effective tillers m^{-2} than 'PAU-201'. However, cv. 'PR-118' statistically had the same number of productive tillers m^{-2} as 'PAU-201'. In general, the number of productive tillers found to be higher during 2006 might be due to comparatively lower temperature, higher rainfall and humidity than the following year (**Table 1**).

Grain yield

Grain yield is a function of the interplay of various yield components such as the number of productive tillers, spikelets per panicle and 1000-grain weight (Hassan *et al.* 2003). The data in **Table 3** revealed that transplanting dates influenced the grain yield significantly during both years of study. During 2006, the grain yield decreased significantly when the crop was transplanted on the 15th June, while a reverse trend was observed during 2007, in which grain yield increased significantly under the 15th June transplanting date compared to the 25th June and the 5th July. This was due to an inconsistency of weather parameters (**Table 1**), as there was erratic rainfall at the flowering time (during September 2006) which resulted in washing away of pollen thus causing a reduction in yield. We also noticed that in 2006, rains were accompanied with a wind speed of 16 km h^{-1} on the 2nd September, which coincided with the flowering time of the crop that was transplanted on the 15th June, resulting in damage to the pollen grains and stigma. The treatment means did not differ significantly, however, when the data was pooled. Earlier, Chahal *et al.* (2007) reported that weather parameters and rainfall affecting rice yield are temperature (affecting germination of pollen) and rainfall (damaging or washing of pollens) during flowering to anthesis period. Further, grain yield of the crop with delayed transplanting from 15th June (25th June and 5th July) remained statistically the same during both years of study. Hassan *et al.* (2003) also obtained a higher paddy yield of IR-6 on the 25th June transplanting compared to the 5th and 15th of July in Dera Ismail Khan. In another study, Pal *et al.* (1999) and Baloch *et al.* (2006) also reported higher paddy yield when rice was transplanted on the 15th or 29th of June. More effective tillers sqm^{-1} for mid June transplanted crop have a huge influence on growth, development and grain yield of rice as compared to July transplanted crop (Singh *et al.* 1996; Arora 2006). The crop transplanted with 60-days-old nursery plants caused a significant reduction in yield compared to the crop transplanted with 30-days-old nursery plants; however, the grain yield remained statistically the same when the crop was transplanted with 30- and 45-days-

Table 3 Water use, grain yield and water productivity across different treatments.

Treatments	Water use (cm)			Grain yield (t ha^{-1})			Water productivity (kg ha^{-1} cm^{-1})		
	2006	2007	Mean	2006	2007	Mean	2006	2007	Mean
Date of transplanting									
15th June	237.3	267.9	252.6	6.500	7.712	7.090	27.59	29.14	28.37
25th June	234.8	259.7	247.2	7.240	7.231	7.236	30.95	28.08	29.43
5th July	224.3	238.5	231.4	7.461	6.958	7.198	33.49	29.26	31.25
LSD (0.05)				0.315	0.379	NS	1.44	NS	1.03
Age of seedlings (days)									
60	226.7	248.3	237.5	6.857	7.008	69.31	30.43	28.39	29.37
45	234.8	256.3	245.5	7.079	7.400	72.24	30.50	29.09	29.75
30	234.8	261.5	248.1	7.266	7.495	73.69	31.0	29.00	29.93
LSD (0.05)				0.315	0.379	2.44	NS	NS	NS
Cultivars									
PR-115	194.4	216	205.2	6.406	6.985	6.695	33.02	32.32	32.64
PR-116	244.5	266	255.2	6.873	7.280	7.076	28.16	27.37	27.77
PR-118	251.8	276.8	264.3	7.041	7.084	7.042	28.05	25.61	26.74
PAU-201	237.8	262.7	250.2	7.948	7.853	7.887	33.35	30.01	31.59
LSD (0.05)				0.266	0.263	0.198	2.14	1.00	0.84

Table 4 Interactive effect of transplanting dates and rice cultivars on pooled paddy yield and crop water productivity.

	PR-115	PR-116	PR-118	PAU-201
Paddy yield (t ha^{-1})				
15th June	6.93	7.16	6.63	7.65
25th June	6.47	7.14	7.28	8.05
5th July	6.68	6.93	7.22	7.96
LSD (0.05)	0.34			
Crop water productivity (kg ha^{-1} cm^{-1})				
15th June	32.89	27.46	23.81	29.34
25th June	31.43	27.44	27.11	31.75
5th July	33.59	28.41	29.31	33.73
LSD (0.05)	1.45			

Table 5 Interaction effect of age of nursery and rice cultivars on pooled crop water productivity.

	Crop water productivity (kg ha^{-1} cm^{-1})			
	PR-115	**PR-116**	**PR-118**	**PAU-201**
60 days	31.60	28.24	26.51	31.14
45 days	33.76	26.76	27.00	31.48
30 days	32.54	28.31	26.72	32.20
LSD (0.05)	1.45			

old nursery plants. The highest yield was recorded when the crop was transplanted with 30-days-old nursery plants. The mean data of two years' study (**Table 3**) revealed that the crop transplanted with 30-days-old seedlings gave 6.32 and 2.0% more yield than the crop transplanted with 60 and 45-days-old seedlings, respectively. This may be due to vigorous and healthy growth of the crop raised with the 30-days-old nursery plants as reflected by the data on mean plant height and number of effective tillers m^{-2} (**Table 2**). It was noticed that the crop transplanted with 30-days-old nursery plants recovered earlier from the shock than the crop raised with 60-days-old nursery plants resulting in a better root system and enhanced root activity and as a result registered higher yield. Earlier Sasaki (2004) and Pasuquin *et al.* (2008) reported higher grain yield of rice with transplanting of younger seedling due to higher plant vigour and growth. The positive impact of early crop vigour on grain yield was also clearly supported by the results of San-oh *et al.* (2004). These results are also in conformity with Paddalia (1980), Ashraf *et al.* (1999) who also reported higher yield in rice crop transplanted with 30- or 45-days-old seedlings. The grain yield was significantly influenced in relation to cultivars during both years of study. Cv. 'PAU-201' was superior among all the tested cultivars and the mean grain yield increased by around 17.8, 11.5 and 12% more than in cvs. 'PR-115', 'PR-116' and 'PR-118', respectively. The early maturing cv. 'PR-115' recorded the lowest yield among all cultivars. However, cvs. 'PR-116' and 'PR-118' behaved similarly with respect to grain yield.

The interaction effect of transplanting dates and cultivars was found to be significant (**Table 4**). The pooled yield data revealed that among the tested cultivars, 'PAU 201' recorded the highest yield in all the transplanting dates. 'PR-115' registered the highest yield when transplanted on the 15th June and delayed transplanting from the 15th June caused a significant reduction in grain yield. The grain yield of 'PR-115', however, was found to be statistically the same on 25th June and 5th July transplanting dates. 'PAU-116' registered statistically the same yield on all the transplanting dates. The grain yield of 'PR-118' improved under late transplanting dates and yield during the 25th June transplanting, increased to about 9.8% more than the crop transplanted on the 15th June. It was interesting that 'PAU-201' under late transplanting condition (5th July) registered significantly higher yield than other cultivars even when these were transplanted at their optimum time of transplanting (**Table 4**).

Water use and crop water productivity

The mean data in **Table 3** revealed that water use by the crop varied from 231.4 to 252.6 cm for rice crop transplanted from 15th June to 5th July. The decreased water use with delayed transplanting from the 15th June was associated with lower potential evapotranspiration demand by the atmosphere. Hira and Khera (2000) reported that the ET requirement of rice declined from around 800 to 500 mm as the date of transplanting was delayed from 1st May to 30th June, without compromising rice yield at the same location. The data in **Table 3** revealed that by shifting the date of transplanting of rice from the 15th June to the 5th July, there was 9.2% water saving without compromising yield. These findings are in conformity with those of Chahal *et al.* (2007), who were also of the same opinion that shifting the rice transplanting dates resulted in a saving of 192 mm as wet (evapotranspiration) and 590 mm as dry water (irrigation). The transplanting of 60-days-old seedlings resulted in a saving of 10.6 cm of water. The early maturing cv. 'PR-115' resulted in saving of water to the tune of 19.5, 22.4 and 21.9% over cvs. 'PR-116', 'PR-118' and 'PAU-201', respectively. The real crop water productivity was significantly more in the late compared to early transplanted rice. This was due to statistically the same yield under all the dates of transplanting and less ET in the late compared to earlier transplanted rice. However, the age of seedlings failed to influence the crop water productivity significantly. It was seen that the crop water productivity in cvs. 'PR-115' and 'PAU-201' was statistically the same, although significantly higher than that of cvs. 'PR-116' and 'PR-118'. The interactive effect of date of transplanting and cultivars was found to be significant with respect to water productivity (**Table 4**). The water productivity in 'PR-115' and 'PAU-201' was higher than cvs. 'PR-116' and 'PR-118' on all the transplanting dates. The water productivity of 'PR-116' remained statistically the same on all the transplanting dates, while in cvs. 'PR-118' and 'PAU-201', it increased with delayed transplanting from the 15th June. This was due to the sensitive nature of the photoperiod of cvs. 'PR-118' and 'PAU-201'. As a result, these gave higher yield and matured earlier during late transplanting than in early transplanting conditions. These findings confirmed the view of Bennett (2003) who stated that water productivity may be increased through short duration or photoperiod-sensitive rice cultivars by reducing transpiration without compromising grain yield. Further, the interactive effect of the age of seedling and cultivars was also found to be significant (**Table 5**). Crop water productivity of 'PR-115' decreased significantly when transplanted with 60-days-old rather than 60-days-old nursery plants. However, it remained statistically the same in cvs. 'PR-116', 'PR-118' and 'PAU-201' when transplanted with 30-, 45- or 60-days-old nursery plants.

CONCLUSION

With the shifting of transplanting dates of rice from the period of higher (15th June) to lower (end of June onwards) evaporative demand, both crop and water productivity improved. An early maturing cultivar ('PR-115') helped to save water especially during the period of peak evaporative demand (15th June). The crop transplanted with 60-days-old nursery plants not only resulted in a significant reduction in yield and also failed to influence the water productivity significantly. Photoperiod-sensitive cv. 'PAU-201' gave highest water productivity under delayed transplanting (5th July) due to less ET demand and stable yield under late transplantation conditions.

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