Indian Journal of Agronomy **60** (1): 65–69 (March 2015)

Research Paper

Yield, water productivity and economics of rice (*Oriza sativa*) as influenced by transplanting dates, varieties and irrigation regimes in central Punjab

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Received : August 2014; Revised accepted : January 2015

ABSTRACT

A two-year (2008 and 2009) field experiment was conducted at Ludhiana (Punjab), to investigate the direct and interactive effects of 3 transplanting dates (5 June, 20 June and 5 July), 2 genotypes, viz. hybrid 'RH 257' and inbred 'PAU 201', and 2 irrigation regimes (2 days drainage period after cessation of applied water and at soil water suction of 16 kPa) on the rice (*Oriza sativa* L.) yield attributes, yield, water productivity and economics. The results revealed that adjusting the crop cycle by shifting of transplanting towards lower evaporative demand period (from 5 June to 5 July) resulted in significant improvement in yield and yield attributes of rice and saving of irrigation water. The number of tillers/m^2, biomass, harvest index and yield increased by 20, 15, 15 and 33%, respectively, by the delay in transplanting from 5 June to 5 July. Variety 'RH 257' showed 1.6, 5.6 and 4.5% higher biomass, harvest index and yield, respectively, than 'PAU 201'. In the irrigation treatment of 2-days drainage period number of tillers/m^2, biomass, harvest index and yield were 1.0, 7.8, 5.6 and 10.0% respectively more than that in soil water suction treatment. The dominant yield attributes contributing to yield were biomass and number of tillers/m^2. The maximum irrigation water productivity of 0.80 kg/m^3 was observed in treatment combination of rice transplanted on July 5, variety 'RH 257' and irrigation based on soil water suction (SWS). Irrigation-water and monitory savings were relatively more under the treatments of irrigation based on SWS, shorter crop duration and cropping cycle synchronized with lower evaporative demand

Key words : Irrigation water productivity, Rice, Transplanting date, Variety, Yield

Rice is the major cereal crop in India, which is cultivated on 44 million hectare (M ha) and contributing 105 million tonnes (Mt) grain production (Government of India, New Delhi, 2012). In Indo-Gangetic Basin of India, area under rice crop is 10 M ha, out of that 2.6 M ha falls in Punjab with a mark production touching 9.13 Mt. In the semi-arid tropical region of Punjab, the rice is grown on coarse-to fine-textured puddled soils during the rainy (*kharif*) season by transplanting 30 days old seedlings. The date of transplanting of rice is staggered from mid June to 1st week of July because of labour and energy constraints and the imposition of the groundwater act in 2009. Recommended irrigation schedule for the rice crop is irrigating at 2-days drainage period after soaking the water at the soil surface.

The effects of transplanting date, variety and irrigation regimes on yield have been reported (Mahajan *et al.*, 2008; Jalota *et al.*, 2009) with scanty information on the yield attributes (effective tillers, leaf-area index, biomass, harvest index etc.) as these determine the yield. Literature on the effect of specific single management intervention is available (Bouman and Tuong, 2001; Chahal *et al.*, 2007), but it is postulated that the integrated effects of these management interventions on yield attributes may be of higher magnitude compared to that by individual. Therefore, the present study aimed at investigating the direct and interactive effects of date of transplanting, varieties and irrigation regimes on yield and water productivity of rice.

MATERIALS AND METHODS

The field experiment was conducted at the Research Farm of Department of Soil Science, Punjab Agricultural University, Ludhiana (30°56' N, 75°52' E and 247 m above mean sea-level) during the rainy (*kharif*) season of 2008 and 2009. Soil of experimental field was deep alluvial loamy sand Typic Ustipsamment developed under hyperthermic regime (USDA classification). At the start of the experiment, surface soil physical and chemical properties of the field were determined following the standard proce-

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dures (Table 1). Daily weather data on rainfall and evaporation during the crop-growth period were obtained from meteorological station at the Punjab Agricultural University, Ludhiana. The weather of the Ludhiana is characterized by a brief spell of monsoon season, a very hot summer and a bracing winter. The south-west monsoon sets in from the last week of June and withdraws in end of September, which contributes about 78% of annual rainfall (730 mm). From June to September normal weather parameters i.e. maximum temperature, minimum temperature and rainfall varies from 33–39°C, 22–26°C and 66–232 mm, respectively.

There were 12 treatments, which were replicated thrice in 36 plots of size 10 m × 4 m in a split-plot design. The treatments included 3 dates of transplanting, viz. 5 June (D_1), 20 June (D_2) and July 5 (D_3) in the main plot, and combinations of 2 varieties, viz. hybrid 'RH 257' (V_1) and inbred 'PAU 201' (V_2) and 2 irrigation regimes, viz. intermittent irrigation at 2-days drainage (2-d D) period (I_1) and irrigation based on soil water suction (SWS) of 16 kPa (I_2), in subplot. In the climate of Punjab, the crop duration (from transplanting to harvest) for 'RH 257' and 'PAU 201' during the *kharif* season is 90–100 and 110–120 days, respectively. Thirty-days old seedlings (2/hill) were transplanted at 20 cm × 15 cm spacing on 3 dates of transplanting in twice puddled soil. Seedlings were raised in nursery following the procedure given in package of practices for crops of Punjab (www.pau.edu).

Puddling was done by running rotavator in the standing water (8–10 cm depth) followed by planking. At each date of transplanting, 40 kg N, 30 kg P_2O_5 and 30 kg K_2O/ha were applied at the time of transplanting by broadcast. Remaining N (80 kg/ha) was applied in 2 equal splits, i.e. at 3 weeks and 6 weeks after transplanting. Irrigation treatments were started following continuous flooding for 15 days after transplanting. The amount of irrigation water applied at each irrigation from transplanting till maturity was monitored with Parshal flume installed in the main channel. Each plot was embanked with earthen bund of 15 cm height to avoid runoff loss or runoff gain. Soil water suction (SWS) were measured with tensiometers installed at 15–20 cm soil depth. In each irrigation treatment, lateral movement of water was minimized by keeping a buffer strip. To control weeds (*Echinochloa crusgalli* L.), butachlor 50 EC 3,000 ml/ha was applied 2 days after transplanting. Monocrotophos (1,400 ml/ha), Chloropyriphos (2,500 ml/ha), Padan (18 kg/ha) and Tilt 25 EC (500 ml/ha) were used periodically to control insect-pests and diseases. Plant height, number of tillers, biomass and leaf-area index 90 days after transplanting were measured from 1-meter row length in each treatment. Biomass was determined after oven-drying at 60°C to constant weight. At maturity, the crop was harvested from the whole plot excluding border lines and rice yield was determined. Irrigation water productivity (IWP) was estimated as:

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

Rice yield and yield attributes were analyzed statistically using split-plot design.

Table 1. Physical and chemical properties of the experimental field soil (0–15 cm)

Soil parameter	Value
Sand (%)	61.0
Clay (%)	29.0
Bulk density (Mg/m)	1.74
Soil water content % at	
Saturation	34.3
Field capacity	23.6
Permanent wilting point	13.0
pH	7.53
EC (dS/m)	0.16
Organic carbon (%)	0.39
Ammonium-N (ppm)	3.9
Nitrate-N (ppm)	9.2
Available N (kg/ha)	196.5
Available P (kg/ha)	23.1
Available K (kg/ha)	332.3

RESULTS AND DISCUSSION

The trends in yield attributes and yield were similar in both the years; therefore, pooled analysis has been discussed.

Growth and yield attributes

Plant height and tillers/m at 90 days after transplanting as affected by date of transplanting, variety and irrigation regimes are given in Table 2. Plant height in treatment D_3 was 1.5 and 4.3 cm more than that in D_1 and D_2, treatments respectively. Higher plant height in treatment D_3 may be ascribed to favourable environmental temperature (Chahal *et al.*, 2007). In 'RH 257' plant height was 3.6 cm higher than that in 'PAU 201', respectively. The plant height in the irrigation regimes remained significantly at par at all the 3 dates of transplanting. The crop in D_3 produced 18 to 20% more tillers than that in D_2 and D_1 respectively. The higher numbers of tillers in D_3 are owing to favourable temperature, rainfall and humidity during the crop growth as reported by Baloch *et al.* (2006). In both the varieties, tillers were more by 6 tillers/m^2. The irrigation regimes influenced the number of tillers/m^2 significantly. Tillers/m^2 was 45 more under I_1 irrigation regime than that under I_2. In I_2, water stress led to lower tillers as the rice is a water-loving crop.

Like plant height, biomass was also influenced significantly by transplanting date, variety and irrigation regimes (Table 2). Dry mass was significantly higher in D_3 than that in D_1 and D_2 transplanting dates. At day 90, biomass in D_3 was 2.1 t/ha more than that in D_1 and 1.4 t/ha than that in D_2. The more dry-matter in D_3 was the result of more plant height and number of tillers/unit area compared to other dates. Biomasses were significantly higher in 'RH 257' than that in 'PAU 201'. The more dry-matter accumulation in 'RH 257' than 'PAU 201' was possibly due to faster growth rate in the hybrids than the inbred varieties (Schnier *et al.*, 1990). Biomass in I_1 was 8% more than that in I_2. Higher leaf-area index (LAI) is known to increase yield by strengthening the source-sink relationship and photosynthetic surface. LAI in D_1 compared that in D_2 and D_3 was more by 0.18 and 0.01 at day 90 respectively (Table 2). In 'RH 257' LAI were 0.07 more than that of 'PAU 201'. Higher LAI in 'RH 257' than 'PAU 201' may be due to its genetic character of faster canopy development in hybrids than that in inbred. I_1 treatments have significantly increased the LAI by 0.09 than that of I_2.

Yield

Rice yields in different treatments as influenced by transplanting date, variety and irrigation regime are presented in Table 2. The maximum yield of rice was observed in 5 July transplanted (D_3), which was significantly higher than that in 10 June (D_1) and 20 June (D_2) dates of transplanting. Irrespective of variety and irrigation, yield in D_3 was 1.9 and 1.3 t/ha higher than that in D_1 and D_2. These observations confirm the field and simulated results reported by other researchers (Singh *et al.,* 2001; Chahal *et al.*, 2007, Jalota *et al.,* 2009), who found improvement in the yield grown under relatively lower evaporative demand due to less number of days having temperature greater than 37°C (optimum) during the post-transplanting period, less incidence of physical damage of pollens by rains, less soil water stress (Wopereis *et al.,* 1996) and temperature stress during flowering to anthesis stage (De Datta, 1981) and less spikelet sterility (Jiangtao *et al.,* 2006). In addition to this, the results of the present study showed that more grain yield under D_3 than that in D_1 and D_2 accrued mainly because of enhanced plant height, effective tillers, dry-matter accumulation and lesser spikelet sterility, which support the observations of Baloch *et al.* (2006). Amongst the 2 varieties, 'RH 257' yielded 0.3 t/ha more grain than 'PAU 201', which differed non-significantly at 0.05 levels. It may be ascribed to low spikelets sterility with higher number of effective tillers and harvest index (Table 4). Among the irrigation treatments, yield in I_2 (irrigation based on SWS) decreased significantly by 0.6 t/ha than that in I_1 (2-day-drainage irrigation). In fact, in I_2 treatment gap of more than 4 days between 2 consecutive irrigation applications resulted in water stress for a longer period in the root zone and consequently the yield was decreased. Buoman and Tuong (2001) also reported reduction in yields from 10 to 40% when soil water potential in the root zone was allowed to reach from –100 to –300 m

Table 2. Effects of transplanting date, variety and irrigation regime on plant height, tillers, biomass and leaf-area index of rice (pooled data of 2 years)

Treatment	Plant height (cm)	Total tillers/ m^2	Biomass (t/ha)	Leaf-area index	Grain yield (t/ha)	Straw yield (t/ha)	1,000-grain weight (g)	Harvest index	Irrigation water productivity (kg/m^3)
Transplanting date									
05 June	117.3	414	14.2	3.92	5.7	11.0	22.4	0.34	0.50
20 June	111.5	421	14.8	3.74	6.3	10.3	21.3	0.38	0.62
05 July	115.8	497	16.2	3.91	7.6	11.8	22.7	0.39	0.74
SEm±	0.72	17.7	0.196	0.06	0.135	0.191	0.120	0.006	0.012
CD (P=0.05)	2.4	57.6	0.6	NS	0.441	1.5	0.70	0.02	0.04
Variety									
'RH 257'	115.7	441	15.4	3.89	6.7	10.8	23.0	0.38	0.63
'PAU 201'	112.1	447	15.1	3.82	6.4	11.2	21.3	0.36	0.60
SEm±	0.37	4.8	0.195	0.05	0.10	0.09	0.26	0.004	0.009
CD (P=0.05)	1.1	NS	0.6	NS	NS	0.7	0.39	0.01	0.03
Irrigation regime									
2 days drainage	114.3	446	15.6	3.90	6.8	11.2	22.6	0.38	0.60
SWS 16 kPa	113.5	442	14.5	3.81	6.2	10.7	21.7	0.36	0.63
SEm±	0.38	4.3	0.10	0.02	0.072	0.167	0.34	0.004	0.006
CD (P=0.05)	NS	NS	0.3	0.05	0.212	NS	0.57	0.01	0.02

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1,000-grain weight was significantly affected by date of transplanting, variety and irrigation regime (Table 2), being significantly more in 10 June (D_1) and 5 July (D_3) transplanted rice than that in 20 June (D_2), in 'RH 257' variety than that in 'PAU 201' and in 2-day drainage irrigation (I_1) treatment than that in irrigation based on SWS (I_2). Harvest index was significantly affected by transplanting dates, varieties and irrigation regimes (Table 2). Harvest index was significantly higher by 0.05 and 0.01 in D_3 than that in D_1 and D_2, which may be ascribed to higher biomass and tillers. Short-duration hybrid rice 'RH 257' gave significantly higher harvest index than medium duration variety 'PAU 201'. Among the irrigation regimes, I_1 gave significantly higher values (0.38) than I_2 (0.36).

Water use and productivity

The total water expense (irrigation plus rainfall) was 1,970, 1,863 and 1,758 mm in D_1, D_2 and D_3, respectively; 1,884 and 1,844 mm in 'RH 257' and 'PAU 201', respectively; 1,907 mm in I_1 and 1,820 mm in I_2. The number of irrigations applied 15 days after transplanting in D_1, D_2 and D_3 were 9, 8 and 7 in I_1 and 7, 6, 6 in I_2, respectively. The total amount of irrigation water applied was 1,147, 1,028 and 1,026 mm in D_1, D_2 and D_3, respectively; 1,070 and 1,065 mm in 'RH 257' and 'PAU 201' , respectively; 1,137 mm in I_1 and 998 mm in I_2. Irrigation water saved was 12% in D_2 and D_3 compared to that in D_1 treatments; 14% in I_2 than that in I_1. 'PAU 201' could save only 5 mm irrigation water than that in 'RH 257'. Maximum irrigation water saving of 233 mm was observed in the treatment combination of 5 July (D_3), variety 'RH 257' and irrigation based on SWS (I_2). Although irrigation water saving is considered dry saving, it is worthwhile for the farmers as the saved water can be used to irrigate extra acreage to increase total production. It also reduces the cost of production by pumping less water. In other words, it is the energy saving, which is saved by pumping less amount of water either due to reduced frequency or amount of irrigation or both. Irrigation water productivity (IWP) in rice under different date of transplanting, varieties and irrigation regimes ranged from 0.48 to 0.80 kg/m (Table 4). In an independent experiment Singh *et al.* (2001) observed IWP of 0.55 kg/m^3, which falls in the range observed in the present study. The IWP in rice was higher by 24% in D_2 and 48% in D_3 than that in D_1; 5% in 'PAU 201' than 'RH 257'; 5% in I_2 than I_1. Mahajan *et al.* (2008) also reported similar results. The maximum IWP was observed in treatment combination of transplanting date 5 July (D_3), variety 'RH 257' and irrigation based on SWS (I_2). These observations endorsed our previous results that IWP can be increased with shifting the transplanting date towards lower evaporative demand period, growing shorter-duration variety and increasing days of non-submergence (Jalota *et al*., 2009).

Interaction

There was significant interaction of transplanting date and variety in grain yield, straw yield, harvest index and IWP (Table 3). Grain yield, harvest index and IWP were significantly higher in treatment combination of rice transplanted on 5 July (D_3) and variety 'RH 257' than other

Table 4. Linear regression coefficients between rice yield and yield attributes of rice

Parameter	Coefficients of correlation (R^2)
Biomass	0.92
No. of tillers	0.66
Harvest index	0.60
Unfilled grains	0.72
Biomass + Number of tillers	0.95
Biomass + harvest index	0.93
Biomass + unfilled grains	0.93
Biomass + Number of tillers + harvest index	0.97
Biomass + harvest index + unfilled grains	0.94
No. of tillers + harvest index + unfilled grains	0.94
Biomass + Number of tillers + unfilled grains	0.95
Biomass + Number of tillers + harvest index + unfilled grains	0.97

Table 3. Interactive effects of transplanting date, variety and irrigation regimes on rice

Transplanting date	Grain yield (t/ha)		Straw yield (t/ha)		Harvest index		Irrigation water productivity (kg/m^3)			
	Variety		Variety		Variety		Variety		Irrigation regime	
	'RH 257'	'PAU 201'	'RH 257'	'PAU 201'	'RH 257'	'PAU 201'	'RH 257'	'PAU 201'	'2 days drainage	SWS 16 kPa
05 June	5.50	5.85	11.15	10.90	0.33	0.35	0.49	0.51	0.51	0.49
20 June	6.55	6.10	10.00	10.10	0.39	0.38	0.65	0.59	0.59	0.66
05 July	7.95	7.15	11.2	12.75	0.42	0.36	0.78	0.71	0.73	0.76
CD (P=0.05)	0.05		0.05		0.02		0.05		0.03	

SWS, Soil water suction

treatments. However, straw yield was significantly higher in variety 'PAU 201' transplanted on 5 July (D_3). The interaction of date of transplanting and irrigation water showed higher interaction in treatment combination of D_3 (5 July) and irrigation regime of 'SWS 16 kPa' (I_2).

The contribution of individual and in combination of different yield attributes (biomass, number of tillers, harvest index and filled grains) to yield showed that the maximum correlations (0.92) was observed with biomass (Table 4). It increased to 0.95 and 0.97 when accompanied by number of tillers and number of tillers + harvest index, respectively. These results indicated that the biomass and number of tillers found to be the most important yield attributes in assessing the yield of rice.

Economics

Averaged over other treatments rice transplanted on 20 June and 5 July gave 11 and 33% higher return than 5 June (Table 5). Similarly, the returns were more by 10% in 2 days drainage irrigation treatment than SWS; and 5% in 'RH 257' variety than 'PAU 201'. The cost of irrigation water saved in 20 June and 5 July transplanted rice than 5 June was ₹480 and 460, respectively. Irrigation treatment of SWS saved ₹544 compared to 2 days drainage treatment. The saving with 'RH 257' was negligible.

Table 5. Economics in different treatments in rice

Treatments	Return from yield (₹/ha)	Irrigation water saved (mm)*	Irrigation water cost saved (₹)
Date			
5-Jun	70,963*	-	-
20-Jun	78,663	120	482**
5-Jul	94,375	115	461
Variety			
'RH 257'	83,125	9	36
'PAU 201'	79,544	-	-
Irrigation			
2 days drainage	85,063	-	-
'SWS'	77,606	136	544

2-d D, 2 days drainage; SWS, soil water suction; *Price of rice and ** cost of irrigation water were taken as ₹12.5/kg and ₹4 ha/mm, respectively

The results of the present study indicate that biomass production, number of productive tillers, leaf-area index and plant height are influenced by management interventions (time of transplanting, varieties and irrigation regimes). Effective tillers, biomass and yield can be improved by adjusting cropping period of rice to lower evaporative demand. Adoption of integrated management of transplanting date, variety and irrigation is more efficient for sustenance of yield and enhancing irrigation water productivity in rice than single management intervention. It was concluded that transplanting of short-duration varieties 'RH 257' in the first week of July with irrigation regime of 2 days drainage period gave higher yield and crop water productivity.

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