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Production potential and water productivity of basmati rice (*Oryza sativa*)–wheat (*Triticum aestivum*) sequence as influenced by irrigation termination of basmati rice and irrigation scheduling of succeeding wheat

A S BRAR[1], S S MAHAL[2], G S BUTTAR[3] and J S DEOL[4]

Punjab Agricultural University, Ludhiana, Punjab 141 004

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ABSTRACT

A field experiment was conducted to find out the optimum time for termination of irrigation to basmati rice (*Oryza sativa* L.) and irrigation scheduling of wheat (*Triticum aestivum* L. emend Fiori & Paol) sown after basmati rice in residual moisture without pre-sowing irrigation, during 2005–06 and 2006–07. The experiment was laid out in split plot design with three cut-off time of last irrigation in basmati rice (21, 28 and 35 days after flowering) in main plot and combinations of first (14, 21 and 28 days after sowing) and subsequent irrigation schedules (1.25, 1.00 and 0.75 IW:CPE) to succeeding wheat. Cut off timings of last irrigation in basmati rice at 28 and 35 days after flowering (DAF), while being at par with each other produced significantly higher yield and yield attributes of basmati rice and succeeding wheat than at 21 DAF. In wheat, application of first irrigation at 14 and 21 days after sowing (DAS) while being mutually at par, recorded significantly higher yield and water-use efficiency than 28 DAS. Subsequent irrigation schedules of 1.25 and 1.0 IW:CPE produced significantly higher yield of wheat than 0.75 IW:CPE schedule. Total productivity of basmati rice-wheat sequence was significantly higher under 35 DAF cut off time of last irrigation to basmati rice than 28 and 21 DAF, however, both 28 and 35 DAF treatments reported almost equal water productivity with 57.4 and 60.2 g more wheat grain with each cubic metre of water than 21 DAF, respectively.

Key words: Basmati rice-wheat sequence, Scheduling of irrigation, Termination of irrigation, Water productivity

Rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L. emend Fiori & Paol) is the predominant cropping system of Punjab and being practiced on an area of about 2.7 million hectares (Anonymous 2011). There is a growing perception that agricultural production in the post green revolution era will be guided by the necessity to produce more of quality food at reduced cost from the lands and water resources marginal in quality and quantity. Cultivation of rice has created serious threats to environment, water and soil health, mainly due to high water requirement and involvement of heavily mechanized preparatory land preparation. So, there is an urgent need to divert at least a part of the area under rice with some alternative crops having comparatively low water requirement in Punjab. Basmati rice occupies a special status due to its excellent cooking and eating qualities, owing to which it fetches a hefty price in the national as well as international markets. Agro-ecologically, sub-mountainous tracts and central districts of Punjab are considered congenial for its cultivation, because its reproductive phase coincides with the prevailing mild temperature regimes, which prove synergistic in improving quality characteristics of grain. In addition, its growing season coincides with the peak rainy season and hence reduces the heavy dependence on the use of underground water resources.

Management of water is of paramount importance for higher productivity and better quality of basmati rice. Scheduling of last irrigation to basmati rice at appropriate stage may influence the moisture content in grain at harvest, which ultimately influences the head rice recovery and crude protein content of the grains. Cut off time of last irrigation to basmati rice may also influence the germination and scheduling of first irrigation to succeeding wheat crop, which is sown on left over moisture after harvesting basmati rice to avoid its delayed sowing. Hence, this study was planned with two objectives (1) to find out the optimum time for termination of irrigation to basmati rice and irrigation scheduling of wheat sown after basmati

[1]Agronomist (e mail: brarajmer@gmail.com), [2] Professor (e mail: mahalss@pau.edu), [3] Senior Agronomist (e mail: buttargs@rediffmail.com), [4] Professor (e mail: deoljs@pau.edu) Department of Agronomy

rice in the residual moisture without pre sowing irrigation, (2) To compute the water use and water productivity of basmati rice-wheat sequence under differential termination of irrigation to basmati rice and irrigation scheduling of wheat.

MATERIALS AND METHODS

A field experiment was conducted at Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, during 2005-06 and 2006-07. The experimental site is situated in trans-gangetic agro-climatic zone, representing the Indo-Gangetic alluvial plains at 30° 56' N latitude, 75° 52' E longitude and at an altitude of 247 m above mean sea level. The soil of the experimental site was loamy sand in texture with normal soil reaction (8.15) and electrical conductivity (0.27 dm), low in organic carbon (0.38 %), available nitrogen (119.4 kg/ha), medium in available phosphorus (21 kg/ha) and potassium (251.5 kg/ha). The field capacity and permanent wilting point of 0-180 cm rhizosphere were 36.89 cm and 11.88 cm, respectively. Hence, the available water in the 0-180 cm soil profile comes out to be 25.01 cm with average bulk density of 1.63 g cm. The experiment was laid out in split plot design keeping three cut off time of last irrigation in basmati rice (21, 28 and 35 days after flowering) in main plots and combination of three first (14, 21 and 28 days after sowing) and three subsequent irrigation schedules (0.75, 1.0 and 1.25 IW:CPE) to wheat in sub plot with four replications.

Transplanting of 25 days old seedlings of basmati (Basmati 386) was done in lines at 20 cm × 15 cm spacing on 18 July 2005 and 20 July 2006. After harvesting of basmati rice wheat variety PBW 502 was sown conventionally with tractor drawn drill in the residual moisture without pre sowing irrigation on 10 November 2005 and 13 November 2006. The recommended dose of N (20 kg/ha) was applied to basmati rice through urea in two equal splits at three and six week after transplanting. In succeeding wheat recommended doses of N (120 kg/ha), P_2O_5 (60 kg/ha) and K_2O (30 kg/ha) were applied through urea, DAP and MOP, respectively. Half the dose of N and whole of P and K were applied at the time of sowing while the remaining half dose of N was applied as broadcast after first irrigation. During first 15 days water was kept ponded to avoid uplifting/transplanting shock, afterwards, irrigation was applied two days after the water was absorbed in the seedbed and irrigation was suspended as per treatment of cut off time of last irrigation to basmati rice. In wheat first and subsequent irrigations were applied as per treatment of IW:CPE schedule. The weeds were controlled by applying Butachlor @ 1.2 litre/ha by mixing in 150 kg sand at 2-3 DAT in basmati rice. While in wheat Topik 15 WP @ 400 g/ha and algrip @ 25 g/ha were applied as post emergence at 35 days after sowing to control the grassy and broadleaf weeds, respectively.

RESULTS AND DISCUSSION

Performance of basmati rice

The grain yield of basmati rice manifested conspicuous impact of last irrigation to basmati rice by recording significant differences among the treatments (Table 1). The grain yield was found to be maximum under 35 DAF treatment (27.5 and 29.4 q/ha) which was at par with 28 DAF (26.7 and 28.5 q/ha) but both 35 and 28 DAF treatments emerged significantly better than 21 DAF (22.1 and 23.2 q/ha) during 2005 and 2006, respectively. The reduction in grain yield due to early withholding irrigation under 21 DAF treatment was 17.2 and 19.6% during 2005 and 18.6 and 21.1% during 2006 compared to 28 and 35 DAF, respectively. The comparatively lower grain under 21 DAF might be attributed to significantly lesser panicle length, grains per panicle and numerically less effective tillers/m^2 (Table 1) resulted from shorter supply of moisture at ripening stage than 28 and 35 DAF. Maeda and Minami (1978), Sandhu *et al.* (1982), and Reddy and Hussaini (1984) also reported significant decrease in grain yields of coarse rice and Bali (1992) of basmati rice, when irrigation was terminated earlier than 20 days after flowering.

Total water expenses and expense efficiency of basmati rice varied remarkably with the change in cut off time of last irrigation (Fig 1). The 21 DAF treatment registered 6.8 and 12.7 % less total water expenses during 2005 and 6.6 and 12.4 % during 2006 than 28 and 35 DAF, respectively. The reduced water expenses in case of 21 DAF was due to application of less number of irrigation (2 and 4 irrigation less) than 28 and 35 DAF, respectively, due to advanced withholding of irrigation during both the years. However, water expenses efficiency was increased with delay in termination of irrigation in basmati rice from 21 DAF during both the years. The increased WEE under 28 and 35 DAF

Table 1 Grain yield and yield attributing characteristics of basmati rice under three cut off time of last irrigation

Treatment	Effective tillers/m^2		Panicle length (cm)		Grains panicle		1 000-grain weight (g)		Grain yield(q/ha)		Straw yield (q/ha)	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
21 DAF	381.6	380.2	22.7	23.1	81.3	82.2	19.9	20.4	22.1	23.2	77.8	81.1
28 DAF	387.0	398.9	24.9	25.3	87.5	89.2	23.5	23.4	26.7	28.5	84.7	87.2
35 DAF	388.7	409.8	25.5	26.4	88.6	91.0	24.1	24.6	27.5	29.4	85.7	89.6
CD (P=0.05)	NS	NS	2.05	2.08	6.16	6.54	2.16	2.35	4.37	4.03	6.39	6.79

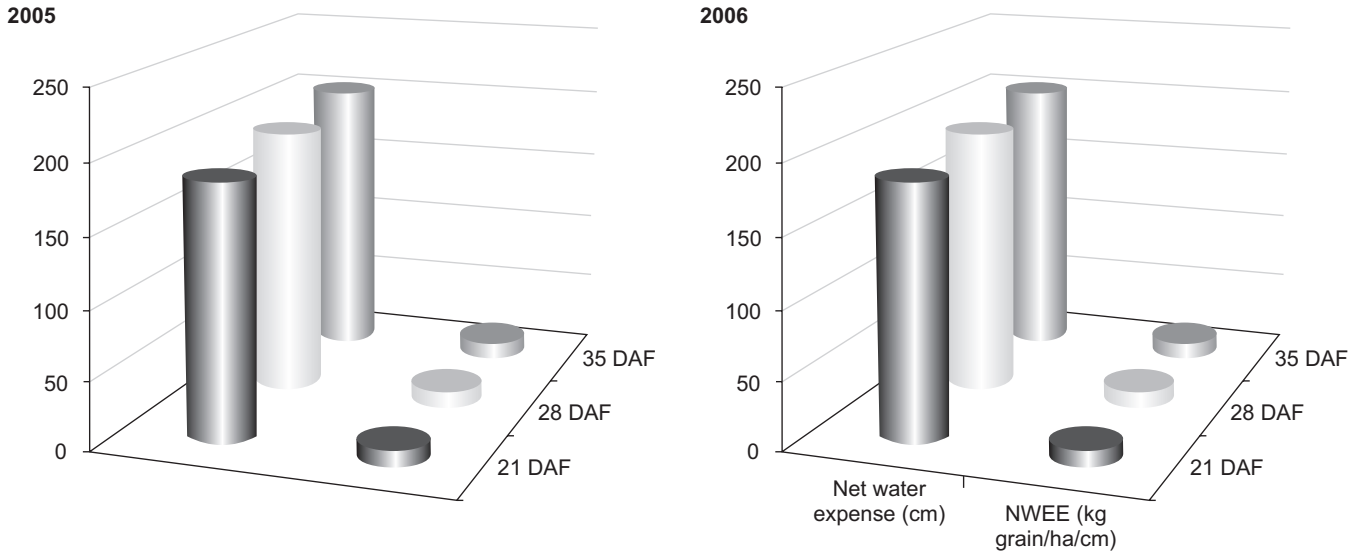

Fig 1 Net water expense and expense efficiency of basmati rice under different treatments.

might be resulted from higher grain yield realized under delayed termination of irrigation.

Performance of wheat

Cut off time of last irrigation to preceding basmati rice, significantly influenced the grain yield of succeeding wheat crop (Table 2). In general, grain yield increased with delay in time of withholding irrigation to basmati rice from 21 to 35 DAF during both the years of study. The maximum grain yield (50.9 and 52.7 q/ha) was reported under 35 DAF, which was at par with 28 DAF (49.0 and 50.8 q/ha) but significantly higher than 21 DAF (39.1 and 40.9 q/ha) during 2005–06 and 2006–07, respectively. Treatment 35 and 28 DAF while being statistically at par with each other produced 30.2 and 25.3 and 28.9 and 24.2% higher grain yield than 21 DAF treatments during the year 2005–06 and 2006–07, respectively. This might be due to significantly higher effective tillers, grains/ear and 1 000-grain weight (Table 2), resulting from favourable moisture received under delayed termination of irrigation to proceeding basmati rice.

Table 2 Grain yield and yield attributing characteristics of wheat as influenced by different treatments in basmati rice–wheat crop sequence

Treatment	Effective tillers/m^2		Ear length (cm)		Grains/ear		1 000-grain weight (g)		Grain yield(q/ha)		Straw yield (q/ha)	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Cut off time of last irrigation in basmati rice												
21 DAF	386.8	390.7	8.64	8.85	49.5	50.9	38.1	39.0	39.1	40.9	63.8	66.9
28 DAF	423.9	424.6	9.11	9.32	57.8	58.9	46.2	45.6	49.0	50.8	68.4	71.3
35 DAF	433.4	440.4	9.66	9.89	59.8	61.1	47.7	47.1	50.9	52.7	71.7	74.6
CD (*P*=0.05)	16.27	18.32	0.41	0.63	4.00	3.78	1.87	2.44	2.39	2.14	3.56	3.87
First irrigation to wheat												
14 DAS	434.5	437.0	9.35	9.56	58.1	58.7	45.4	45.3	48.3	50.2	70.2	74.7
21 DAS	426.5	427.8	9.15	9.37	57.4	58.6	44.8	44.7	47.8	49.5	68.7	72.0
28 DAS	383.0	390.9	8.91	9.13	51.6	52.7	41.8	41.7	42.9	44.7	64.9	66.1
CD (*P*=0.05)	17.54	22.99	NS	NS	5.52	3.98	2.85	2.78	3.24	3.23	4.09	4.52
Subsequent irrigation to wheat												
1.25 IW:CPE	435.4	441.5	9.84	10.06	59.7	61.1	45.7	45.6	50.8	52.1	70.0	73.7
1.0 IW:CPE	420.0	422.6	9.03	9.26	57.1	58.5	44.3	44.2	48.1	50.6	69.5	72.1
0.75 IW:CPE	388.7	391.7	8.54	8.74	50.3	51.3	42.1	42.0	40.1	41.7	64.3	67.0
CD (p=0.05)	17.54	22.99	0.75	0.52	5.52	3.98	2.85	2.78	3.24	3.23	4.09	4.52
COD × FI	39.82	30.37	NS	NS	NS	NS	NS	NS	5.61	5.59	NS	NS
Other Interactions	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

COD, Cut off time of last irrigation in basmati rice; FI, first irrigation to wheat

Table 3 Interactive effects of three cut off date of last irrigation of preceding basmati rice and first irrigation of wheat on grain yield (q/ha) of wheat in basmati rice-wheat crop sequence

Cut of date of last irrigation in basmati rice	Fist irrigation to wheat							
	2005-2006				2006-2007			
	14 DAS	21 DAS	28 DAS	Mean	14 DAS	21 DAS	28 DAS	Mean
21 DAF	44.4	40.0	32.8	39.1	46.4	41.8	34.4	40.9
28 DAF	49.9	48.8	48.2	49.0	51.9	50.5	50.0	50.8
35 DAF	50.6	54.5	47.7	50.9	52.3	56.2	49.6	52.7
Mean	48.3	47.8	42.9		50.2	49.5	44.7	
CD (P=0.05)					*2005–2006*	*2006–2007*		
	Cut off date of last irrigation to basmati rice				2.39	2.14		
	First irrigation to wheat				3.24	3.23		
	Cut off date of last irrigation to basmati rice × First irrigation to wheat				5.61	5.59		

Similarly, time of application of first irrigation reflected its effect on grain yield of wheat crop (Table 2). The highest grain yield (48.3 and 50.2 q/ha) was realized under 14 DAS treatment, which was at par with 21 DAS (47.8 and 49.5 q/ha), but significantly better than 28 DAS (42.9 and 44.7 q/ha) during 2005–06 and 2006–07, respectively. Subsequent irrigations applied at 1.25, 1.0 and 0.75 IW:CPE schedules, also significantly influenced the grain yield during both the years of experimentation. The highest grain yield was recorded under 1.25 IW:CPE (50.8 and 52.1 q/ha) treatment which was at par with 1.0 (48.1 and 50.6 q/ha), but significantly higher than 0.75 (40.1 and 41.7 q/ha) IW:CPE schedule, during 2005–06 and 2006–07, respectively. The more frequent irrigation scheduling under 1.25 and 1.0 IW:CPE registered 26.7 and 20.0 and 24.9 and 21.3% higher grain yield than 0.75 IW:CPE schedule, during 2005-06 and 2006-07, respectively.

The interaction between cut off time of last irrigation to preceding basmati rice and time of application of first irrigation to following wheat (Table 3) was found to be significant during both the years. The maximum grain yield (54.5 and 56.2 q/ha) was recorded when wheat was sown on residual moisture received from 35 DAF treatment and first irrigation was applied at 21 DAS which was at par with the wheat crop sown on residual moisture received from 28 and 35 DAF when first irrigation was applied at 14 DAS, but significantly higher than other treatment combinations, during 2005–06 and 2006–07, respectively. The highest grain yield under 35 DAF and 21 DAS combination might be ascribed to significantly higher effective tillers, grains/ear, 1 000-grain weight, resulting from more favourable soil moisture regimes available under delayed cut off time of last irrigation to preceding basmati rice. Thus, no beneficial effect of advancing the first irrigation was observed under this combination. On the other hand, advancement of first irrigation (14 DAS) improved the plant stand of wheat sown after residual moisture received from 28 DAF which resulting in statistically comparable yield to 35 DAF and 21 DAS treatment.

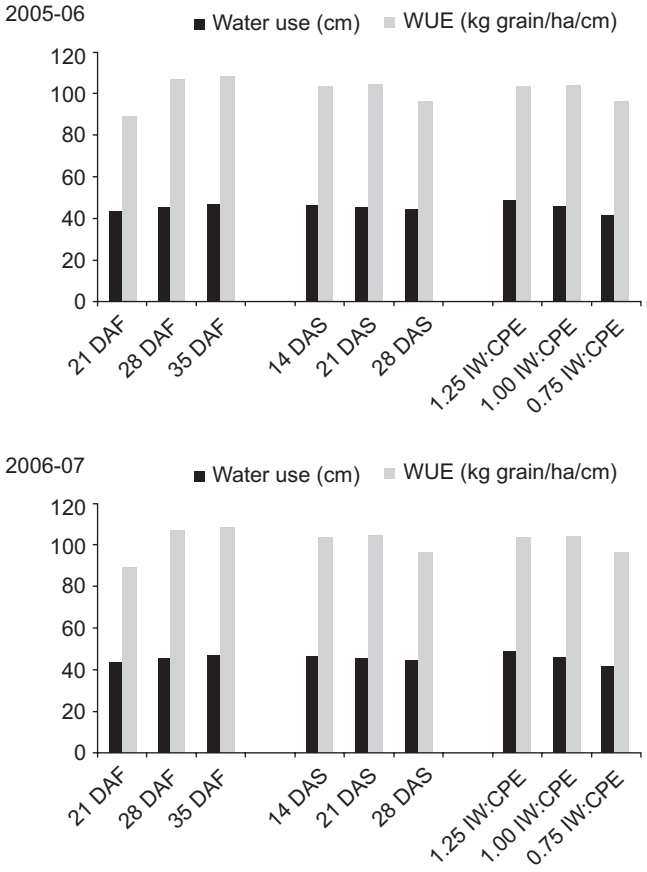

Fig 2 Water use and water-use efficiency of wheat under different treatments

The consumptive use of wheat varied with different times of cut off irrigation to preceding basmati rice crop (Fig 2). The maximum consumptive use (46.9 and 47.6 cm) was recorded under 35 DAF treatments, which was 7.3 and

2.4, and 5.9 and 1.9% higher than 21 and 28 DAF during 2005–06 and 2006–07, respectively. The time of application of first irrigation to wheat also reported difference in water use during both the years. The highest water use (46.4 and 47.2 cm) was recorded under 14 DAS treatment, which was followed by 21 DAS (45.6 and 46.5 cm) and 28 DAS (44.5 and 45.0 cm) treatments, during 2005–06 and 2006–07, respectively. These results are in line with the findings of Singh (2000). Among the subsequent irrigation schedules, 1.25 IW:CPE registered the highest consumptive water use (48.8 and 49.3 cm) which was closely followed by 1.0 IW:CPE (46.1 and 46.7 cm) and both the treatment reported 7.3 and 4.6, and 6.6 and 4.0 cm higher consumption use of water than 0.75 IW:CPE schedules during 2005–06 and 2006–07, respectively. This might be due to increasing irrigation frequency under 1.25 and 1.00 IW:CPE than under 0.75 IW:CPE schedule. Similar results were reported by Rathore *et al.* (1991).

The highest water-use efficiency (Fig 2) was realized under 35 DAF treatment (108.7 and 110.8 kg grain/ha/cm), which was closely followed by 28 DAF (107.0 and 108.8 kg grain/ha/cm) but both the treatments produced 19.4 and 17.7 and 18.9 and 16.9 kg grain/per more with each centimeter of water during the years 2005–06 and 2006–07, respectively. Among the timings of application of first irrigation to wheat, 14 and 21 DAS recorded almost identical value of water-use efficiency (104.2 and 104.8 and 106.4 and 106.4 kg grain/ha-cm) but were much better than 28 DAS (96.5 and 99.2 kg grain/ha/cm), during the years 2005–06 and 2006–07, respectively. Among the subsequent irrigation schedule to wheat 1.25 and 1.0 IW:CPE recorded almost similar water-use efficiency during both the years. The maximum water-use efficiency 104.2 and 108.3 kg grain/ha/cm was reported under 1.0 IW:CPE schedule, which was at par with 1.25 IW:CPE (104.1 and 105.6 kg grain/ha/cm) schedule, but substantially higher than 0.75 IW:CPE (96.8 and 97.6 kg grain/ha/cm) schedule during 2005–06 and 2006–07, respectively. The lowest water-use efficiency under 0.75 IW:CPE was attributable to less grain yield resulting from longer irrigation intervals.

Performance of basmati rice-wheat sequence

Sequence productivity (Table 4) in terms of wheat equivalent yield significantly influenced with cut off date of last irrigation to basmati rice, irrespective of first and subsequent irrigation schedules to wheat during both the years. The maximum wheat equivalent yield (WEY) from basmati rice-wheat sequence (100.1 and 101.1 q/ha) was obtained under 35 DAF cut off date of last irrigation to basmati rice, which was significantly better than 28 DAF (96.6 and 97.7 q/ha) and 21 DAF (78.5 and 79.1 q/ha) cut off date of last irrigation to basmati rice during 2005–06 and 2006–07, respectively. Likewise, timings of application of first irrigation to wheat also demonstrated significant impact on overall productivity of basmati rice-wheat sequence, irrespective of cut off date of last irrigation to preceding basmati rice, during both the years. The 14 and 21 DAS irrigation timings, while being at par with each other recorded

Table 4 Wheat equivalent yield, water use and water productivity of basmati rice-wheat sequence under different cut off date of last irrigation to basmati rice, first and subsequent irrigation schedules to wheat

Treatment	Wheat equivalent yield(q/ha)		Water use (m^3)		Water productivity (g/m^3)	
	2005–06	2006–07	2005–06	2006–07	2005–06	2006–07
Cut off time of last irrigation to basmati rice						
21 DAF	78.5	79.1	22 750	23 490	345.1	336.7
28 DAF	96.6	97.7	23 830	24 630	405.4	396.7
35 DAF	100.1	101.1	24 890	25 640	402.2	394.3
CD (*P*=0.05)	2.39	2.14				
First irrigation to wheat						
14 DAS	93.7	94.7	23 920	24 680	391.7	383.7
21 DAS	93.1	94.0	23 840	24 610	390.5	382.0
28 DAS	88.3	89.2	23 730	24 460	372.1	364.7
CD (*P*=0.05)	3.24	3.23				
Subsequent irrigation to wheat						
1.25 IW:CPE	96.2	96.6	24 160	24 890	398.2	388.1
1.0 IW:CPE	93.5	95.2	23 890	24 630	391.4	386.5
0.75 IW:CPE	85.5	86.2	23 430	24 230	364.9	355.8\
CD (*P*=0.05)	3.24	3.23				
Interaction	5.61	5.59				

Price (Rs/q):	2005-06	2006-07
Basmati rice	1250	1400
Wheat	700	850

Table 5 Interactive effects of three cut off date of last irrigation of preceding basmati rice and first irrigation of wheat on productivity (wheat equivalent yield q/ha) of basmati rice-wheat crop sequence

Cut of date of last irrigation in basmati rice	Fist irrigation to wheat							
	2005–2006				2006–2007			
	14 DAS	21 DAS	28 DAS	Mean	14 DAS	21 DAS	28 DAS	Mean
21 DAF	83.8	79.4	72.2	78.5	84.6	80.0	72.6	79.1
28 DAF	97.6	96.4	95.8	96.6	98.8	97.4	96.9	97.7
35 DAF	99.7	103.6	96.9	100.1	100.7	104.6	98.0	101.1
Mean	93.7	93.1	88.3		94.7	95.2	86.2	
CD (P=0.05)					*2005-2006*	*2006-2007*		
	Cut off date of last irrigation to basmati rice				2.39	2.14		
	First irrigation to wheat				3.24	3.23		
	Cut off date of last irrigation to basmati rice × First irrigation to wheat				5.61	5.59		

6.1 and 5.4, and 6.2 and 5.2% higher system productivity than 28 DAS during 2005–06 and 2006–07, respectively. Similarly subsequent irrigation schedules to wheat also evinced significant impact on system productivity during both the years (Table 4). The maximum system productivity (96.2 and 96.6 q/ha) was recorded with 1.25 IW:CPE schedule, which was at par with 1.0 IW:CPE (93.5 and 95.2 q/ha) schedule but significantly better than 0.75 IW:CPE (85.5 and 86.2 q/ha) schedule during 2005–06 and 2006–07, respectively. The interactive effect of the cut off date of last irrigation to basmati rice and first irrigation to wheat revealed (Table 5) that maximum system productivity (103.6 and 104.6 q/ha) was recorded when last irrigation to basmati rice was suspended at 35 DAF and first irrigation to wheat was applied at 21 DAS, which was at par with treatment when first irrigation to wheat was applied at 14 DAS but significantly higher than all other combinations during 2005-06 and 2006-07, respectively.

The data pertaining (Table 4) to water use revealed that water use of basmati rice-wheat sequence increased with delay in last irrigation to basmati rice during both the years. However, water productivity of the system increased only up to 28 DAF cut off date of last irrigation to basmati rice and decreased thereafter, irrespective of first and subsequent irrigation schedules to wheat during both the years. The 28 and 35 DAF cut off dates of last irrigation to basmati rice produced 60.3 and 57.1 and 60.0 and 57.6 g more wheat grain with each cubic meter (m^3) of water than 21 DAF, when grown in sequence with wheat during 2005–06 and 2006–07, respectively. First and subsequent irrigation scheduling to wheat in basmati rice-wheat system also reported increase in water use and water productivity with advancement and increase in frequency of irrigations, during both the years. The 14 and 21 DAS timings of first irrigations to wheat recorded 5.3 and 4.9% more water productivity than 28 DAS during 2005–06, while corresponding figures were 5.2 and 4.7% during 2006–07, respectively. Similarly, subsequent irrigation scheduling with 1.25 and 1.0 IW:CPE registered edge of 33.3 and 26.5 and 32.3 and 30.7 g wheat grain with each cubic meter (m^3) of water over

Thus, keeping in view the grain yield and water productivity of the sequence, last irrigation to basmati rice may be suspended at 28-35 DAF and first irrigation to wheat should be applied at 21 DAS with subsequent irrigation scheduling at 1.0 IW:CPE, when wheat was sown on residual moisture received from preceding basmati rice.

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