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Standardizing irrigation and planting schedule of salt tolerant rice (*Oryza sativa*) and wheat (*Triticum aestivum*) varieties for higher water productivity and yield in reclaimed sodic soils of Indo-Gangetic plains of India

PARVEEN KUMAR[1], AJAY SINGH[2], S K CHAUDHARI[3]*, P C SHARMA[4] and D K SHARMA[5]

ICAR-Central Soil Salinity Research Institute, Karnal 132 001, India

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ABSTRACT

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system (RWS) grown on 10 m ha in the Indo-Gangetic Plains (IGP), is essential for food security of India. In IGP soil sodicity is very common and reclamation with gypsum is very expensive, so adoption of salt tolerant varieties of rice and wheat could be a better option. A field experiment was, therefore conducted for three years (2012-2015) in RWS to evaluate the performance of salt tolerant varieties under different dates of transplanting/sowing and irrigation scheduling. In *kharif* season, three irrigation scheduling, i.e. complete submergence/farmers practice (CS/FP), 3 days after disappearance of ponded water (DAD), and 5 DAD as horizontal factor and four transplanting dates (21 June, 1 July, 11 July, 21 July) as vertical factor conducted in strip plot design replicated thrice. In *rabi* season, three irrigation schedules, i.e. IW/CPE = 1.0, 0.8, and 0.6 as horizontal factor and four dates of sowing, i.e. 10 November, 20 November, 30 November, 10 December, as vertical factor and two salt tolerant wheat varieties, *viz.* KRL 210 and KRL 213 in subplots was conducted in strip split plot design, replicated thrice. Results indicated that salt tolerant rice variety Basmati CSR-30 can be transplanted on 1 July to get better yield attributes, highest grain yield (3.63 t/ha) and water saving (32.5%) by adopting irrigation scheduling of 5 DAD with highest irrigation water productivity (0.522 kg/m^3). In *rabi* season, salt tolerant wheat varieties can be sown on 20 November following irrigation schedule of IW/CPE=1.0 (KRL-210: 6.76 t/ha and KRL-213: 6.88 t/ha) to get highest grain yield.

Key words: Grain yield, Irrigation water productivity, IW/CPE, Salt tolerant varieties, Water saving

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system, grown on 12.3 (million ha) Mha of which 10 Mha is in the Indo-Gangetic Plains (IGP), is essential for food security of India (FAO 2017). In IGP, soil sodicity is very common and reclamation with gypsum is very expensive that deters small and marginal farmers to use gypsum. In these circumstances, the use of salt tolerant varieties of rice and wheat can be a boon for small and marginal farmers. Also, the area under salt-affected soils is projected to increase from 6.73 in 2008 to 15 Mha in 2030 (Mandal *et al*. 2011).

At the current rate of depleting water resources, the sustainability of rice-wheat system in IGP is under tremendous pressure. To feed ever increasing population with limited resources is a challenge. As predicted by English *et al*. (2002), irrigated agriculture will need to produce 2/3rd more food grains to feed ever burgeoning population. The water table in north Indo-Gangetic plain (IGP) is declining at an alarming rate of ~0.33 m/yr (Narjary *et al.* 2014) under water intensive rice-wheat cropping system, posing a great challenge for agricultural sustainability in the region. Continuous submergence (farmers' practice) of conventional puddle transplanted rice consumes large volume of water (~2000 mm) with low water productivity (Mandal *et al*. 2019). Also, proper irrigation scheduling in wheat saved irrigation water with higher grain yield (Maurya and Singh 2008). Beside current annual water deficit of 1.27 m ha-m (Jain and Kumar 2007) owing to escalated water demand from 2.76 to 4.76 M ha-m during the last four decades (Minhas *et al.* 2010), there is a need to address the issues relating to sustainable crop production, rational water use and develop alternative efficient approaches for water use in irrigated rice based cropping system.

Pragmatic solution of the aforesaid concerns is adopting irrigation scheduling such as irrigation in rice at 2/3 days after receding of applied water (Gill 2008), alternate wetting and drying (Sujono *et al*. 2011), cut-off of last irrigation 28/35 days after 50% flowering (Brar *et al*. 2009), and

*Corresponding author e-mail: surchaudhari@hotmail.com
[1]Principal Scientist (pkumarcssri@gmail.com), [2]Research Scholar (ajayyadavhau@gmail.com), [3]*Deputy Director General (surchaudhari@hotmail.com), ICAR, New Delhi 110 012; [4]Director (director.cssri@icar.gov.in), [5]Ex-Director (ds5550@gmail.com)

irrigation in wheat based on IW/CPE (Maurya and Singh 2008) or critical stages (Nand *et al*. 2011) to save irrigation water with similar or higher grain yield.

Genotype and sowing time are two important factors determining grain yield of a crop. In rice-wheat system, grain yield of wheat is determined by sowing time of wheat crop as well as previous rice crop (Kumar *et al*. 2005). Planting time and maturity period of rice crop significantly influence growth and yield of succeeding wheat crop. Therefore, selection of suitable varieties as well as proper planting/ sowing time for both rice and wheat crops are pre-requisite for getting higher yields.

Keeping above facts in mind, the present study was undertaken to optimize the water requirement of salt tolerant rice variety Basmati CSR-30 and wheat varieties KRL-210 and KRL-213 in relation to different dates of planting with a hypothesis to develop input efficient and cost-effective intervention to achieve higher factor productivity with low irrigation water requirement under rice-wheat cropping system.

MATERIALS AND METHODS

A field experiment was conducted for three years during *kharif* 2012 to 2014 and *rabi* 2012-13 to 2014-15 at ICAR-Central Soil Salinity Research Institute, Karnal. The experimental site was typical reclaimed sodic soil (pH 7.92 and EC 0.28 dS/m in top 0-15 cm soil depth) and subtropical monsoonal climate with 700 mm average rainfall, of which 70% precipitation received within a short span of July to September months. The soil physico-chemical properties at the initiation of field experiment are given in Table 1.

The experiment was conducted in strip plot design with 3 irrigation schedules, i.e. I_1 = continuous submergence/ farmers, practice (CS/FP), I_2 = irrigation 3 days after disappearance of ponded water (3 DAD), and I_3 = 5 DAD, as horizontal factor and 4 transplanting dates, i.e. D_1 = 21 June, D_2 = 1 July, D_3 = 11 July, and D_4 = 21 July as vertical factor replicated thrice in the *kharif* season. In *rabi* season, the experiment was conducted in strip split plot design with three irrigation schedules, i.e. I_1 = IW/CPE = 1.0 (CPE = 60 mm), I_2 = IW/CPE = 0.8 (CPE = 75 mm), and I_3 = IW/CPE = 0.6 (CPE = 100 mm), as horizontal factor and four date of sowing i.e. D_1 = 10 November, D_2 = 20 November, D_3 = 30 November, and D_4 = 10 December, as vertical factor and two salt tolerant wheat *viz.,* KRL 210 and KRL 213 in subplots, replicated thrice.

Table 1 Initial chemical and physical characteristics of soil

Soil property	Depth (cm)	
	0-15	15-30
pH (1:2)	7.92	8.32
EC (dS/m) (1:2)	0.28	0.35
Organic carbon (%)	0.37	0.24
Texture	Silty clay loam	Silty clay loam
Available N (kg/ha)	120	114
Available P (kg/ha)	14.2	7.2
Available K (kg/ha)	216	219
Bulk density (g/cm^3)	1.50	1.53

For rice crop, first nursery was raised and then 30 days old seedlings were transplanted at crop geometry of 20 × 20 cm on different dates according to respective treatment. The rice crop was fertilized with 60 kg N, 30 kg P_2O_5, and 25 kg $ZnSO_4$/ha. The 1/3rd dose of nitrogen and full dose of phosphorus and Zinc sulphate were applied at the time of transplanting and remaining 2/3rd nitrogen in two equal splits at 3 and 6 weeks after transplanting. Wheat crop was sown using seed rate of 100 kg/ha with 20 cm row spacing on different dates according to respective treatment. The crop was fertilized with 150 kg N, 60 kg P_2O_5 and 30 kg K_2O per hectare with 1/3rd nitrogen and full dose of phosphorus and potash as basal dose and rest nitrogen in equal splits at 1st and 2nd irrigation during each year. In both rice and wheat crops, plots were kept free from weeds, and insects and pests using recommended practices.

In rice crop, for first 30 days after transplanting, fields were kept flooded for better establishment of seedlings and after that irrigation scheduling was followed for rest of the crop growth period. In wheat crop, irrigation was given based on irrigation scheduling throughout the crop growth period. In both the crops, a fixed depth of 60 mm irrigation water was applied.

The irrigation water productivity (IWP, kg/m^3) and total water productivity (TWP, kg/m^3) were calculated as the yield per unit of irrigation and total water use (irrigation water + rainfall).

IWP= Grain yield (kg/ha)/Irrigation water use (m^3/ha)

TWP= Grain yield (kg/ha)/Total water use (m^3/ha)

Photosynthetic rate (P_N) and stomatal conductance (gS) was measured with an infrared open gas exchange system (LI-6400, LICOR Inc., Lincoln, NE, USA). The canopy temperature was measured with infrared thermometer (Mextech IR-2200), while soil temperature was recorded with soil temperature sensors.

RESULTS AND DISCUSSION

Rainfall and cumulative evaporation (E_0): The average rainfall received in rice crop under different treatments varied from 352-464 mm with respect to different transplanting dates. The corresponding E_0 values were 378-565 mm (Table 2). The average seasonal rainfall and E_0 under different treatments in wheat crop varied from 127-133 mm and 350-382 mm, respectively.

Physiological parameters: In wheat crop, no significant effect of different irrigation scheduling and varieties was found on photosynthetic rate and stomatal conductance, while different sowing dates significantly influenced these two physiological attributes at 80 and 110 days after sowing (DAS) (Table 3). Highest photosynthetic rate (31.4 and 29.4 µmol/m^2/s at 80 and 110 DAS, respectively) was recorded under wheat sown on 10 November, and photosynthetic rate declined significantly with subsequent late sowing.

Table 2 Rainfall and evaporation during rice and wheat growing season (Pooled data of 3 years)

Date of transplanting/sowing	Rainfall (mm)	No. of rainy days	Evaporation (mm)
Kharif season			
21 June	464	28	565
1 July	425	25	488
11 July	390	22	430
21 July	352	21	378
Rabi season			
10 Nov	127	13	350
20 Nov	127	13	352
30 Nov	129	14	364
10 Dec	133	15	382

Lowest photosynthetic rate was recorded (80 and 100 DAS) under wheat sown on 10 December. This can be explained on the fact that timely sowing of wheat (10 November) results in better vegetative growth which results in higher photosynthetic rate during later vegetative phase. Similar results were also reported by Ma *et al.* (2018). The stomatal conductance also followed similar trend, the highest under wheat sown on 10 November (1.49 and 2.26 µmol/m^2/s, at 80 and 110 DAS, respectively) and declined significantly with subsequent late sowing, and minimum under wheat sown on 10 December.

The canopy temperature was slightly lower when irrigation was given based on IW/CPE=1.0, at par with IW/CPE of 0.8 and 0.6 (Fig 1). Among different dates of sowing, canopy temperature was lower in late sown wheat condition than early sown. Both the varieties of wheat (KRL-210 and KRL-213) behaved similarly in terms of canopy temperature. Higher availability of soil moisture in treatment IW/CPE=1.0 promotes roots to absorb more water with higher evaporation, which maintains the canopy temperature.

The soil temperature at the depth of 5 cm was measured regularly in wheat crop from 18 February to 1 April (Fig 2). The soil temperature was higher under reduced irrigation frequency (IW/CPE 0.8 and 0.6) than IW/CPE=1.0. Higher evaporative loss of water from soil maintains the hydrothermal regime in soil. However, different sowing time and varieties of wheat had no effect on soil temperature.

Table 3 Effect of different irrigation regimes, date of sowing and variety on photosynthetic rate and stomatal conductance of wheat (Data pooled over 3 years)

Treatment	Photosynthesis rate (µmol/m^2/s)		Stomatal conductance (µmol/m^2/s)	
Irrigation schedules	80 DAS	110 DAS	80 DAS	110 DAS
IW/CPE = 1.0	21.2	15.3	1.07	0.754
IW/CPE = 0.8	22.0	17.0	0.99	0.975
IW/CPE = 0.6	22.2	16.5	0.93	1.289
CD (P=0.05)	NS	NS	NS	NS
Date of sowing				
10 November	31.4	29.4	1.49	2.26
20 November	21.5	17.6	1.08	0.97
30 November	18.9	10.1	0.78	0.68
10 December	15.5	7.94	0.62	0.15
CD (P=0.05)	3.99	2.66	0.34	0.46
Variety				
KRL 210	21.0	16.4	0.98	1.07
KRL 213	22.6	16.1	1.01	0.94
CD (P=0.05)	NS	NS	NS	NS

Yield and yield attributes of rice and wheat crop: Based on pooled data of three years, different irrigation schedules did not but dates of transplanting in rice significantly influenced grain yield and yield attributing characters except 1000-grain weight (Table 4). Maximum 1000-grain weight was recorded in continuous submergence at par with irrigation at 3 DAD, while significantly higher than 5 DAD. The 1000-grain weight of rice was statistically similar between irrigation schedules of 3 and 5 DAD.

Maximum grain yield was recorded when transplanting was done on 1 July (3.69 t/ha) by following CS/FP which was statistically at par with 5 DAD (3.63 t/ha) by saving of 32.5% irrigation water. Across irrigation regimes grain

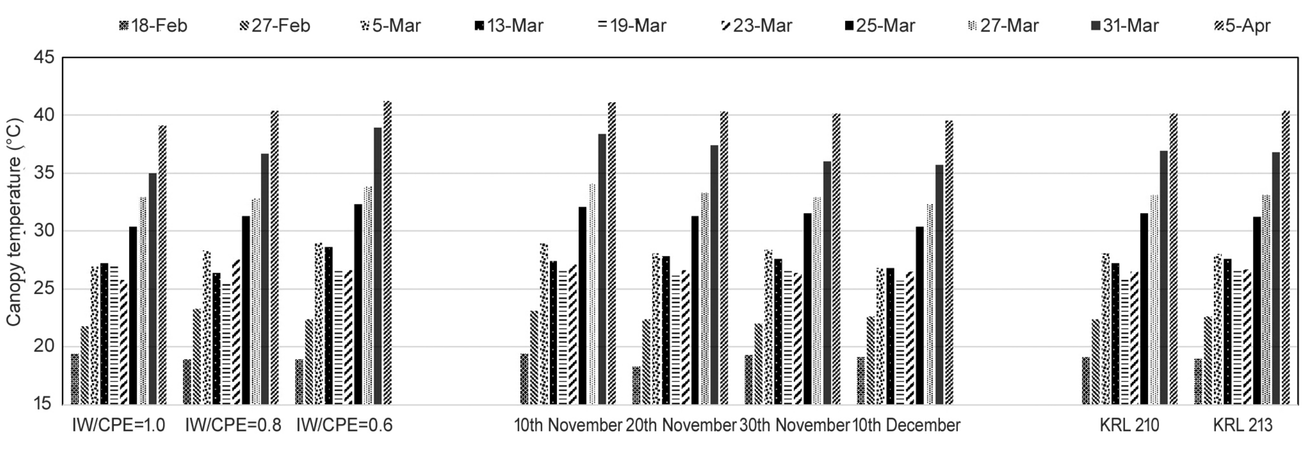

Fig 1 Canopy temperature of salt tolerant wheat varieties under different irrigation schedule and date of sowing.

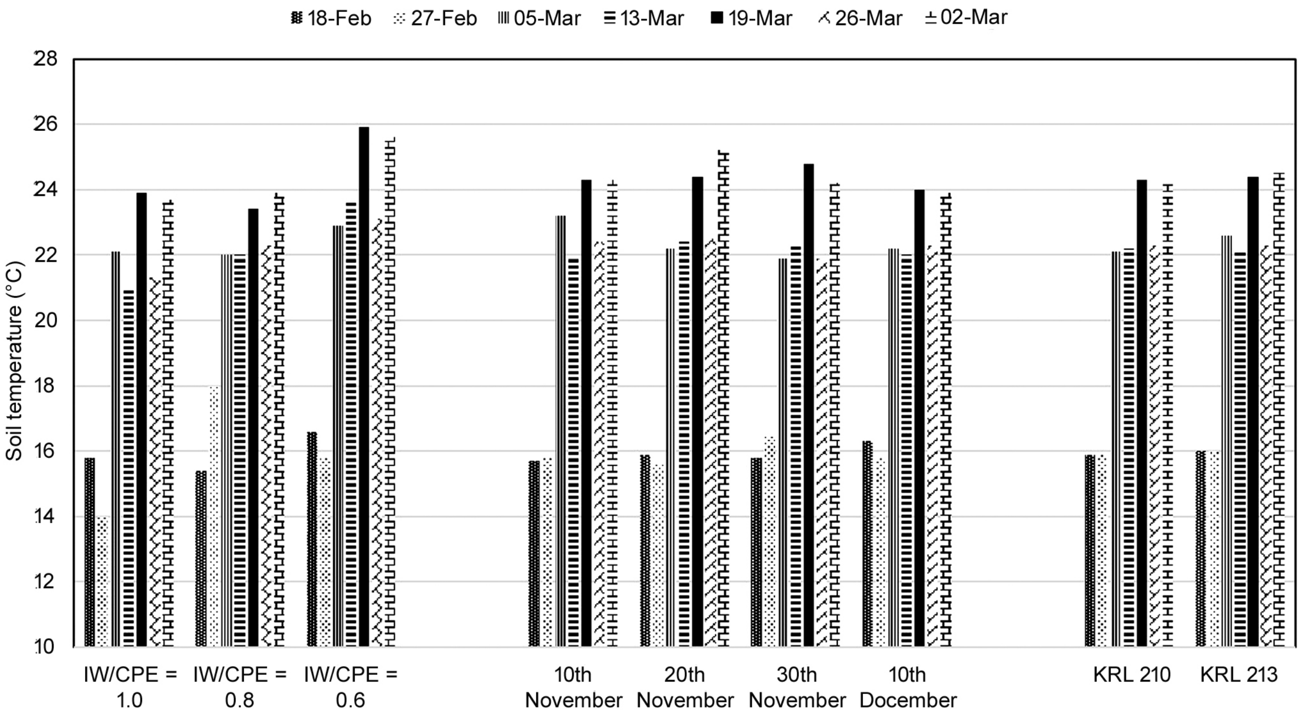

Fig 2 Soil temperature in wheat crop as influenced by different irrigation schedule, date of sowing and varieties.

Table 4 Effect of irrigation scheduling and date of transplanting on yield attributes and yield of rice (Pooled over 3 year)

Treatment	Effective tillers/m^2	Grains/ panicle	1000-grain weight (g)	Grain yield (t/ha)
Irrigation schedules				
CS/FP	386.5	79.9	26.0a	3.40
3DAD	381.3	80.9	25.0ab	3.29
5DAD	389.1	80.8	24.5b	3.35
CD (P=0.05)	NS	NS	1.4	NS
Date of transplanting				
21 June	402.6	85.3	25.3	3.47
1 July	384.4	82.5	25.2	3.60
11 July	378.8	76.9	25.1	3.17
21 July	376.6	77.5	25.1	3.13
CD (P=0.05)	28.3	4.4	NS	0.21

yield was also maximum with 1 July transplanting (3.60 t/ha) followed by 21 June (3.47 t/ha) and significantly higher than 11 July and 21 July (Table 4). Higher number of effective tillers/m^2 and grains/panicle were recorded with transplanting on 21 June followed by 1 July and significantly higher than 11 July and 21 July. The effect of different dates of transplanting was non-significant on 1000-grain weight. Transplanting after 1 July led to significant reduction in yield attributes and eventually grain yield of Basmati CSR-30. The highest yield attributes were recorded with sowing on 21 July while grain yield with sowing on 1 July. This may be attributed to the fact that lodging percent (Fig 3) was higher under 21 June (35.3%) transplanted rice than 1 July (20.9%). Similar results of higher grain yield in direct seeded rice with optimum sowing time was reported by Bashir *et al.* (2010).

Like rice crop different irrigation schedules had no significant effect while dates of sowing and varieties had significant effect on yield attributes and grain yield of wheat (Table 5). Scheduling irrigation in wheat crop had no significant effect on yield attributes and grain yield, except 1000-grain yield which was significantly higher at IW/CPE = 1.0 than IW/CPE = 0.8 and 0.6.

Different dates of sowing had significant effect on yield attributes (except effective tillers/m^2 and 1000-grain weight) and grain yield. Significantly more spike length, grains/spike, and grain yield were recorded with wheat sown on 10 and 20 November compared to 30 November and 10 December. Across irrigation regimes and varieties highest grain yield was recorded with sowing done on 10 November (6.48 t/ha), with subsequent reduction of grain yield to the tune of 0.38, 0.88, and 1.53 t/ha with sowing on 20 November,

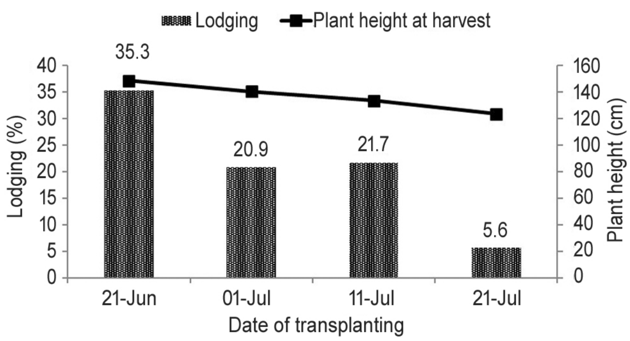

Fig 3 Lodging and plant height of Basmati CSR-30 under different dates of transplanting.

Table 5 Effect of different irrigation scheduling, date of sowing, and variety on yield and yield attributes of wheat (Data pooled over 3 years)

Treatment	Effective tillers/ m^2	Spike length (cm)	Grains/ spike	1000-grain weight (g)	Grain yield (t/ha)
Irrigation schedules					
IW/CPE = 1.0	466.3	14.6	52.0	37.8	6.03
IW/CPE = 0.8	466.0	14.5	50.5	36.9	5.75
IW/CPE = 0.6	461.2	14.6	52.1	36.6	5.57
CD (P=0.05)	NS	NS	NS	0.8	NS
Date of sowing					
10 November	480.9	14.8	50.4	37.4	6.48
20 November	460.0	14.9	54.2	37.0	6.10
30 November	463.3	14.3	51.6	36.2	5.60
10 December	453.7	14.2	49.8	36.4	4.95
CD (P=0.05)	NS	0.32	2.5	NS	0.42
Variety					
KRL 210	466.8	14.9	48.2	39.5	5.74
KRL 213	462.1	14.2	54.8	34.0	5.82
CD (P=0.05)	NS	0.2	1.5	0.9	NS

30 November, and 10 December, respectively (Table 5). However, maximum grain yield in both the wheat cultivars was recorded under irrigation regime IW/CPE=1.0 (KRL-210: 6.76 t/ha and KRL-213: 6.88 t/ha) when sowing was done on 20 November, which was numerically higher than 10 November sowing. This reduction in grain yield with delayed sowing may be due to terminal heat stress which reduces the grain filling period. Similar, decrease in grain yield with delayed sowing of wheat after 15 November was reported by Kaur *et al.* (2010). Among two wheat varieties, grain yield did not differ significantly while, spike length and 1000-grain weight were significantly higher in KRL-210.

Irrigation water (IW), irrigation water productivity (IWP), and total water productivity (TWP): Based on pooled data of three years, mean irrigation water used in rice varied between 765 to 1134 mm across different irrigation schedules and 822 to 1204 mm across different dates of transplanting (Fig 4). Among irrigation schedules, irrigation water used in 5 and 3 DAD was 369 (32.5%) and 224 mm (19.7%) lower compared to complete submergence. The water saving in 5 and 3 DAD was due to less frequency of application which saved considerable irrigation water. The results obtained are in close agreement with Gill (2008) and Mahajan *et al.* (2012).

In rice crop, IW used was maximum when transplanting was done on 21 June (1204 mm) and decreased markedly with transplanting on 1 July (39.9%) and thereafter, it remains nearly same with later date of transplanting (Fig 4). The IW saving was 361, 382, and 328 mm when transplanting was done on 1 July, 11 July, and 21 July, respectively, compared to 21 June. Higher water consumption with sowing on 21 June than 1 July, may be due to longer crop period (~11 days), higher evaporation losses, thereby more amount of irrigation water applied.

In rice crop, irrigation water productivity (IWP) varied between 0.438 to 0.522 kg/m^3 for different irrigation schedules and 0.353 to 0.556 kg/m^3 for different dates of transplanting (Fig 4). The highest IWP in 5 DAD (0.522 kg/m^3) was due to comparatively lesser amount of irrigation water applied (765 mm) than CS/FP and 3 DAD (1134

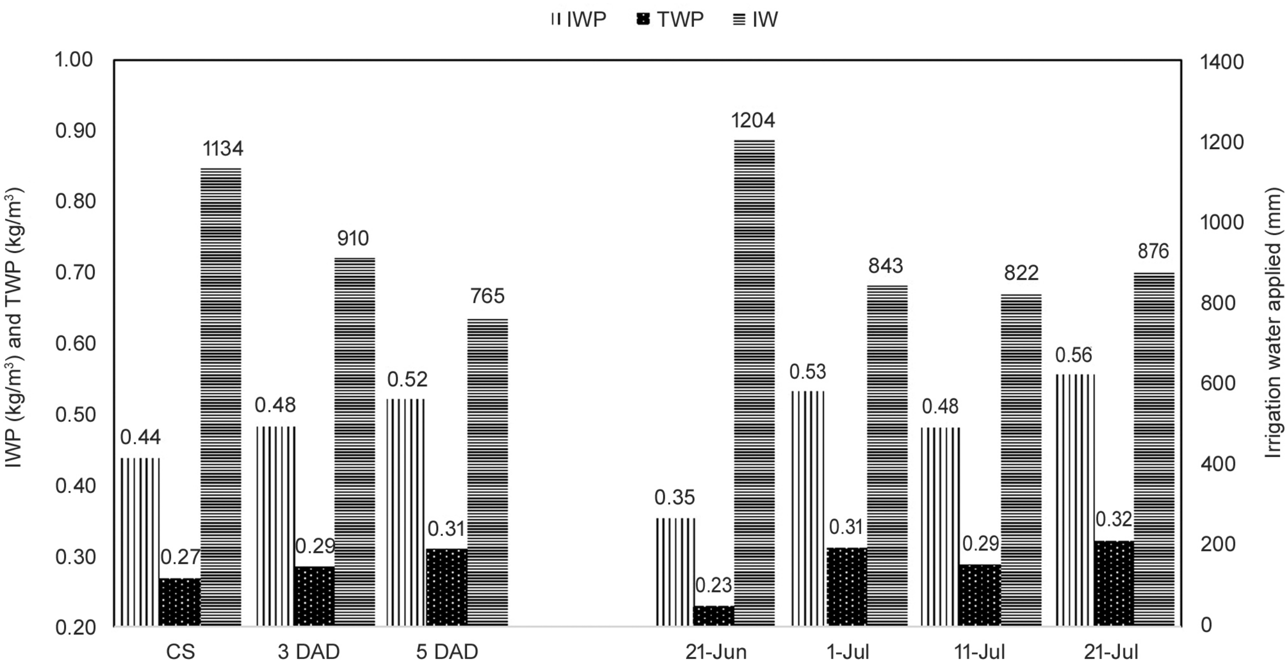

Fig 4 Irrigation water productivity (IWP), total water productivity (TWP), and irrigation water applied (IW) under different irrigation scheduling and transplanting date of rice (Pooled over 3 years).

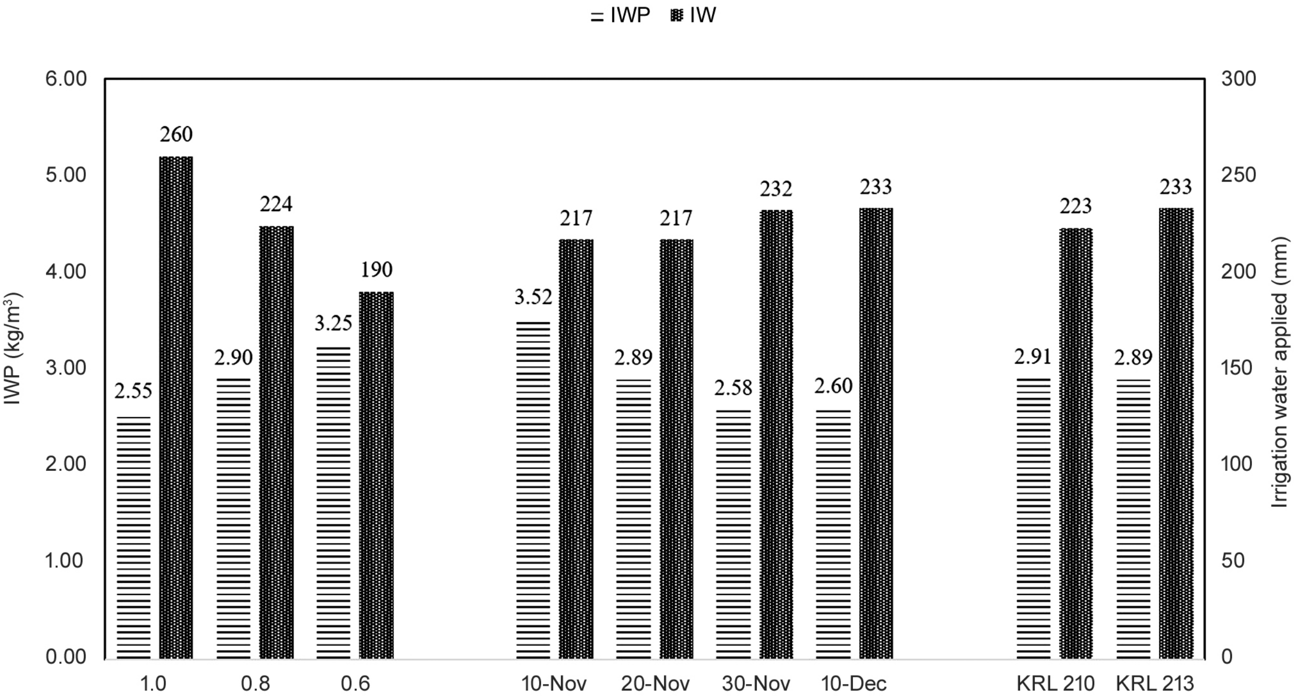

Fig 5 Irrigation water productivity (IWP) and irrigation water applied (IW) in different treatments to wheat crop (Pooled over 3 years).

and 910 mm, respectively) without significant loss in grain yield. Similar findings were reported by Mahajan *et al.* (2012). Higher IWP was observed when transplanting was done after 1 July, i.e. 0.533, 0.482, and 0.556 kg/m^3 with transplanting at 1 July, 11 July and 21 July, respectively than 0.353 kg/m^3 with transplanting on 21 June. This may be due proportionate saving of irrigation water with sowing after 1 July was more than relative decrease in grain yield than sowing on 21 July.

The total water productivity (TWP) also followed the same pattern as that of IWP. It varied from 0.268-0.310 kg/m^3 among different irrigation schedules and 0.230-0.322 kg/m^3 among dates of transplanting (Fig 4). The mean TWP was higher under 3 and 5 DAD (0.285 and 0.310 kg/m^3, respectively) than 0.268 kg/m^3 under CS/FP. Higher TWP was recorded with transplanting done after 1 July, i.e. 0.312, 0.288, and 0.322 kg/m^3 with transplanting at 1 July, 11 July and 21 July, respectively than 0.230 kg/m^3 with transplanting on 21 June.

In wheat crop, mean irrigation water applied varied between 190 to 260 mm with different irrigation schedules, 217 to 233 mm with different dates of sowing, and 223 to 233 for two wheat varieties (Fig 5). Among irrigation schedules, IW used in IW/CPE=0.8 and 0.6 was 36 (~14%) and 70 mm (~27%) lower compared to complete IW/CPE=1.0. The water saving in IW/CPE 0.8 and 0.6 was due to less frequency of irrigation which saved considerable irrigation water. The results obtained are in close accordance with Rajanna and Dhindwal (2019). Higher amount of IW was used when sowing of wheat was done after 20 November. The irrigation water used with sowing on 10 and 20 November was 217 mm, slightly lower than used with sowing done on 30 November and 10 December. The irrigation water applied in two wheat varieties was almost similar.

As expected IWP in wheat increased with decreased irrigation frequency, IW/CPE = 1.0 (2.55 kg/m^3) to 0.8 (2.90 kg/m^3) and 0.6 (3.25 kg/m^3) (Fig 5). However, IWP decreased linearly with delay in sowing of wheat from 10 November to 30 November (3.52-2.58 kg/m^3), and remains almost constant with wheat sown on 10 December (2.60 kg/m^3). This may be due to significant loss in grain yield with delayed sowing after 20 November. These findings are in accordance with Kaur *et al*. (2010). IWP was slightly higher in KRL-210 (2.91 kg/m^3) than KRL-213 (2.89 kg/m^3).

On the basis of three-year study, it could be concluded that salt tolerant rice variety Basmati CSR 30 may be transplanted ~1^{st} July to realize higher yield (3.63 t/ha) and irrigation water productivity (0.522 kg/m^3) by following 5 days absent after 1 month of transplanting. This simple agronomical intervention can save 32.5% irrigation water than farmers practice. Further, salt tolerant wheat varieties can be sown ~ 20 November with irrigation schedule of IW/CPE=1.0 (KRL-210: 6.76 t/ha and KRL-213: 6.88 t/ha) to realize maximum yield.

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