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Varying water regime in the rice-wheat system and its impact on yield and water saving under a sodic environment

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ABSTRACT

In agriculture under sodic soil conditions, water application is key to keeping away the salts from the root zone and maintaining a healthy root zone environment for crop growth. The reason is, under-irrigation may result in salt accumulation in the root zone and over-irrigation may increase ground water level facilitating upward movement of salts. Hence, the depth of irrigation and irrigation interval should not only meet the crop water demand but also facilitate keeping salts down without excessive surface runoff or deep percolation. To achieve this light irrigation is advocated for crop production in sodic soils. The dominant crop rotation in the area is Rice in Kharif and wheat in Rabi. Rice is considered to be a sodic tolerant and reclamative crop whereas wheat is considered to be moderately tolerant. Keeping in view these aspects a study was initiated to apply a low depth of irrigation at varying intervals to save irrigation water and pumping energy to facilitate a favourable soil moisture regime to achieve optimum production of rice (CSR 36) in kharif and wheat (KRL 210) in rabi under partially reclaimed sodic soils. The method of irrigation adopted was surface with different irrigation schedules during *kharif* and *rabi* seasons. During *kharif* two depths of irrigation i.e. 5 cm and 7 cm were applied at 2, 3, and 5 days after the disappearance of water, and when soil moisture tension reached 7.5 kPa and 10 kPa besides one schedule as control where 7.5 cm of water was applied when cracking in top layer starts. During rabi season two irrigation depths i.e. 3 cm and 5 cm were applied at 30%, 50%, and 70% depletion of soil moisture from field capacity and at IW/CPE ratio of 0.8 and 1.0 besides one schedule as control where irrigation was applied at different crop stages in wheat. The effect of three years of imposition of different irrigation treatments in rice during *kharif* and wheat during *rabi*, it was observed that 6 to 11 irrigations were applied in rice under different treatments resulting in irrigation depth in the range of 30 cm to 77 cm. Similarly, in the case of wheat 3 to 6 irrigations were applied resulting in an irrigation depth of 12 cm to 25 cm under different treatments. The effect of varying irrigation regimes was finally evaluated for overall water saving, yield enhancement over control, and B:C ratio. It was observed that in the case of rice, the irrigation schedule of 5 DAD (applying 5 cm depth of irrigation) overall performed better by resulting in 50 percent saving of irrigation water as well as 17.3 percent yield enhancement over control. This resulted in a B:C ratio of 1.72 in the case of 5 DAD (applying 5 cm depth of irrigation), which was the highest among all treatments. The results observed in the case of wheat reflect that the irrigation schedule of IW/CPE ratio 0.8 (applying 5 cm depth of irrigation) was found most suitable as it resulted in 30 to 40 percent water saving along with 18 percent yield enhancement over control. This resulted in a B:C ratio of 1.39 which was the highest in comparison to most of the other irrigation regimes under experimentation.

Keywords: Rice, wheat, yield, water saving, sodic

INTRODUCTION

The Rice Wheat Cropping System (RWCS) is India's most widely adopted cropping system practiced on an estimated area of around 12.3 million hectares in India (Bhatt et al., 2016). The RWCS is prevalent in Indo-Gangetic plains (IGP) and is predominant in Uttar Pradesh, Punjab, Haryana, Bihar, West Bengal, Madhya Pradesh etc. The soil requirement for rice and wheat differs as rice requires overall wet conditions whereas, wheat requires well-pulverized soil balanced with moisture, air, and thermal regime. The continuous cultivation of rice and wheat over a prolonged period has resulted in the degradation of natural resources (groundwater, soil) to a great extent due to the over-mining of vital nutrients from soil and water resources. Bajpai and Kaushal 2021 highlight the RCWS consumes about 11,650 m^3 ha^{-1} water. Out of this rice consumes about 7650 m^3 ha^{-1} alone. As it is evident that irrigated rice requires effective water management during the entire crop cycle as it is very sensitive to water stress. Reduction in optimum water requirement may affect plant growth and a further reduction in rice yield. Generally, the conventional method of transplanting is practiced as a way of crop establishment technique to get the assured rice yield by a majority of the farmers. This requires a large amount of water as compared to other cereal crops. It is being reported that continuous flooding is preferred mostly at the farmers' level for increased growth and yield of transplanted rice Marimuthu et al. (2010). Whereas excessive and injudicious use of water in rice may result in greater chances of high surface runoff, seepage, and percolation and also loss of nutrients from rice fields. As various studies have reported much lower WUE in rice by practicing continuous flooding and conventional practices. Hence, precise application of irrigation water which fulfills the consumptive use demand of rice is required which will not only improve the water use efficiency but may also minimize nutrient losses from rice fields leading the favourable condition for rice plant growth in rice fields. In this endeavour, it is advocated to maintain moisture at saturation level in rice fields to achieve optimum yield instead of ponding techniques. To achieve this situation, the technique lies with an increase in yield per unit transpiration, reducing the various irrigation losses, use of effective rainfall, and application irrigation water based on visible observation after the disappearance of saturation. In this concept, irrigation water is applied to bring the saturation and afterward, irrigation is provided after the development of hair crack in the field. Several water management scientists revealed the maximization of WUE through the application of deficit irrigation (Chowdhury et al., 2014; Reddy and Bandopadhyay, 2015; Kumar et al., 2015 and Diproshan et al., 2015). Sudhakara et al. (2017) & Duvvada et al. (2020) in their study have reported the beneficial effect of saturation in improving plant growth and rice yield. Anning et al. (2018) in their study recommend AWD (alternate wetting and drying) over continuous flooding for saving irrigation water without comprising the rice yield. Son and Ha (2021) reported higher WUE and NUE under AWD over continuous flooding. They also reported better crop growth parameters and yield enhancement under AWD irrigation practice in rice. Tyagi et. al. (2022) in their studies adopted three irrigation regimes i.e. continuous submergence (5 cm), irregular submergence after 2 days (5 cm), and irregular submergence after 5 days (5 cm) in rice fields. They reported that irregular submergence irrigation regimes resulted in significantly better yield contributing parameters in comparison to continuous submergence. Results from northwestern India have consistently shown substantial irrigation water savings (24–40% or up to 650 mm) with no or small yield loss in changing from continuous submergence to irrigating 1–3 days after the flood water has disappeared (Sandhu et al. 1980; Chaudhary 1997; Sharma 1989). On the other hand, several studies also focussed on the efficient use of water in wheat crop. Parihar et al., 1978a and Parihar et al., 1978b concluded that wheat should be irrigated at around 60% and 70% depletion of plant available soil water storage to avoid yield loss, with the lower value for the lighter soil, compared with a deficit of 50% determined by (Singh and Malik 1983) on a sandy loam in Haryana. The recommended practice involves one irrigation prior to soil preparation, irrigation (70 mm) at the crown (nodal) root initiation stage, 3-4 weeks after sowing, then a 70 mm irrigation whenever cumulative pan evaporation minus rain reaches 93 mm (an "IW/Pan" ratio of 0.75), with the last irrigation no later than mid-March for crops "sown on time". This method saved up to 160 mm of irrigation water compared with applying 70 mm at each of the 5 key stages. (Narang and Gulati 1995) suggested that there was scope to reduce wheat irrigation further by publicizing data from evaporation and rainfall and training farmers to keep their own evaporation-rain budgets. Sharma

D.K. (1994) reported the optimum schedule of irrigation for wheat and its response to irrigation based on the ratio of irrigation water and cumulative pan evaporation (IW/CPE). It was reported that maximum water use efficiency was observed when irrigation was scheduled at a 1.0 IW/CPE ratio.

Most of these studies represent findings under normal environments where soils are not problematic. Whereas, in the case of a sodic environment the irrigation strategies need to be different, as it is evident, that, alkali or sodic soils in Indo-Gangetic plains are generally light to medium textured, sandy loam in the surface and clay loam in lower depths with $CaCO_3$ concentration resulting into existence of hardpan of both indurated Kankar and clay (Singh et al., 2016a). Sodic soils are characterized by relatively, low ECe (<4 dS m^{-1}), but a high amount of Na^+ occupying exchange sites (ESP>15%), often resulting in the soil having a pH at or above 8.5. This suggests that under a sodic environment, generally, root growth is hampered; the capacity to store water decreases and transmission characteristics deteriorate. Thus, the application of higher depths of irrigation is likely to cause damage to standing crops. In light of these facts, the study was designed to assess water use patterns for rice and wheat by employing varying schedules of irrigation, to optimize water use for rice-wheat production systems under a sodic environment.

MATERIAL AND METHODS

The experiments were conducted at Shivri experimental farm of ICAR-Central Soil Salinity Research Institute, Regional Research Station, Lucknow, Uttar Pradesh, India which extends 26° 47′45″ N to 26°48′13″ N on latitude and 80°46′7″ E to 80°46′32″ E on longitude at 120 m above mean sea level. The annual mean precipitation based on data recorded from 2000 to 2012 at the Shivri experimental farm was 829 mm (Singh et al., 2016b). The initial analysis of soil reflects that the average pH of 0-15 cm is around 8.54 and at 15-30 cm soil depth the pH analyzed was 9.19. The average ECe found was 1.04 and 0.72 at 0-15 cm and 15-30 cm soil depth. The average Na and K were found to be 10.42 and 0.18 respectively in 0-15 cm soil depth and 10.05 and 0.22 in 15-30 cm soil depth. The organic carbon level at 0-15 cm was higher with an average value of 0.36% and lower at 15-30 cm depth having an average value of 0.33%. Field experiments were carried out from 2014 to 2017 and the results presented comprised of data recorded for three crop seasons (2014-15, 2015-16, and 2016-17). Two depths of irrigation i.e. 5 cm and 7 cm were fixed for different irrigation schedules for rice crop and a 7.5 cm irrigation depth in the case of the control plot. Two approaches were followed to schedule the irrigation in rice crop a.) Based on days after the disappearance of ponded water (DAD) i.e. 2-DAD, 3-DAD, and 5- DAD and b.) based on soil moisture potential monitored by tensiometers at 7.5 and 10 kPa. In the case of wheat two depth of irrigation was applied i.e. 3 cm and 5 cm for different irrigation schedules and 6 cm for control plots. Irrigation was scheduled by employing two irrigation approaches a) Irrigation schedule based on soil moisture depletion i.e. 30%, 50%, and 70%, and b) irrigation schedule based on IW/CPE ratio i.e. at 0.8 and 1.0. Overall, there were a total of eleven different irrigation strategies, which were field evaluated for both crops. Each rice plot measured 7m × 21m (147 m^2) and the wheat plot measured 7m × 10m which was replicated thrice in a randomized block design (RBD). An outlet was provided upstream of plots, for each replication to apply irrigation water from where the irrigation water was conveyed to each plot with the help of flexible plastic pipes. The nursery of salt-tolerant rice variety CSR 36 (recommended for the sodic environment) was raised and transplanted in the main field during the 2nd week of July, whereas, KRL 210 a salt-tolerant variety was sown between the last week of November and to the first week of December. The crop management practices were common to all treatments. Recommended fertilizer doses of N: P: K was applied. Standard agronomic practices (manual weeding etc.) were followed during the crop-growing season. Based on the outlet discharge and the irrigated area the time to irrigate was also fixed and the same was monitored and recorded while practicing irrigation. The crop yield and plant growth parameters of rice and wheat were recorded in each replication and averaged.

RESULTS AND DISCUSSIONS

Irrigation Water use pattern

The average number of irrigation practiced and depth of irrigation applied under different irrigation treatments in rice and wheat crops are depicted in Fig. 1 and Fig. 2, respectively. The irrigation events

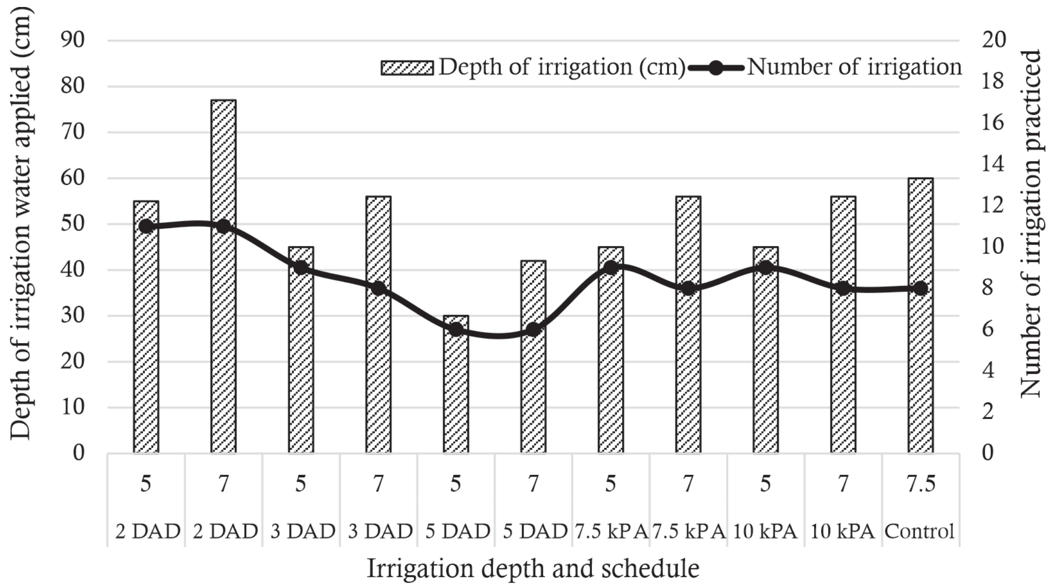

Fig. 1. Water use pattern in rice crop under different irrigation depths and schedules

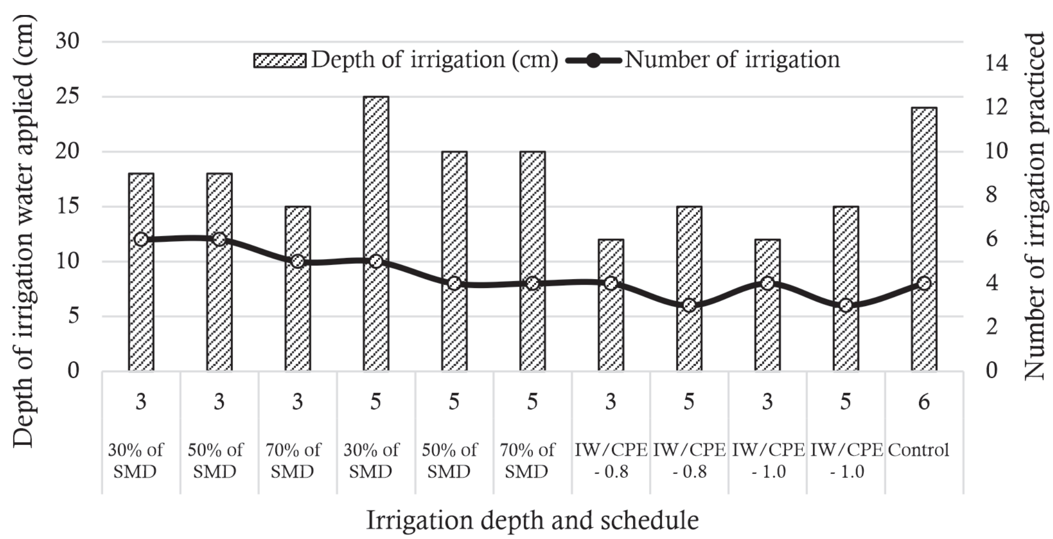

Fig. 2. Water use pattern in wheat crop under different irrigation depths and schedules

varied with variations in irrigation depth and irrigation interval. The irrigation schedule of 2 DAD (7 cm irrigation depth) resulted in the highest irrigation depth of 77 cm through 11 irrigations, whereas, the irrigation schedule at 5 DAD (5 cm depth of irrigation) resulted in the application of the lowest depth of irrigation water amounting to 30 cm by practicing 6 number of irrigation in rice crop. The average seasonal rainfall recorded for 3 years was 45.63 cm during the rice crop. Similarly in the case of wheat crop irrigation schedule of 30% SMD (5 cm irrigation depth) resulted in the highest application of irrigation depth amounting to 25 cm through 5 numbers of irrigation, whereas, the irrigation schedule at IW/CPE 0.8 and 1.0 (3 cm depth of irrigation) resulted in the application of lowest depth of irrigation water amounting to 12 cm by practicing 4 number of irrigation in wheat crop. The average seasonal rainfall recorded for 3 years was 4.95 cm during the wheat crop. The trend indicated that shorter irrigation interval and higher irrigation depths resulted in the application of higher depth of irrigation water and vice versa. These trends were further analyzed for their impact on water saving and rice yield under different irrigation regimes and presented further.

Effect of Irrigation Regime on Rice and Wheat Yield and Water Saving

The effects of varying irrigation regime on plant height, the number of tillers, thousand-grain weight, and yield trends of rice and wheat at harvesting during three years of experimentation was averaged and depicted in Table 1 and Table 2 respectively. It was observed that the plant height of rice ranged between 102.4 cm to 111.8 cm, the number of tillers per square meter was noted to be between 302 to 333, 1000-grain weight ranged between 24.8 gm to 26.1 gm, biological yield between 8.4 t/ha to 9.9 t/ ha, and paddy grain yield ranged between 3.5 t/ha to 4.1 t/ha. Considering the grain yield it is observed that the highest grain yield of 4.1 t ha^{-1} was recorded when irrigation was scheduled at 3-DAD and 5 DAD (applying 5 cm depth of irrigation). Similarly, in the case of the wheat crop, the plant height ranged between 72.8 cm to 82.6 cm, the number of tillers per square meter observed between 63 to 71, the 1000-grain weight ranged between 27.7 gm to 30.8 gm, the biological yield between 4.4 t/ha to 5.7 t/ha and paddy grain yield ranged between 2.1 t ha^{-1} to 3.0 t ha^{-1}. Considering the grain yield it is observed that the highest grain yield of 3.0 t ha^{-1} was recorded in the wheat crop when irrigation was scheduled at an IW/CPE ratio of 0.8 (applying a 5 cm depth of irrigation). Based on the irrigation water used and yield obtained saving of irrigation water and its impact on rice and wheat yield were analyzed and are presented through Table 3 and Table 4. The benefit-cost ratio was also estimated in the case of rice and wheat by taking into account the cost of cultivation and the cost of applying irrigation as input and rice and wheat yield as output. The rate of rice and wheat per Kg was considered as Rs. 14.00 per Kg considering MSP and local market price for estimating B:C ratio.

The trends in the case of rice reflect that most of the irrigation regimes register water saving (%) in the range of 6.7 to 50 in rice, except 2 DAD (applying 5 cm irrigation depth) over control. In the case of 2

Table 1. Plant height, numbers of tillers at harvesting, and rice yield under different irrigation depths and schedules.

Irrigation Depth (cm)	Irrigation Schedule	Plant ht. (cm)	Tillers per sq. m	1000 grain wt (g)	Biological Yield (t/ha)	Grain Yield (t/ha)
5	2 DAD	108.0	315	26.1	8.7	4.0
7	2 DAD	107.6	333	26.0	8.6	3.8
5	3 DAD	109.1	305	25.5	8.7	4.1
7	3 DAD	108.1	315	25.4	9.9	4.5
5	5 DAD	109.9	329	26.1	9.2	4.1
7	5 DAD	109.3	306	25.3	8.7	3.7
5	7.5 kPa	108.0	312	25.5	8.2	3.7
7	7.5 kPa	110.8	305	24.8	7.9	3.5
5	10 kPa	109.8	311	25.6	8.8	3.7
7	10 kPa	111.8	302	25.8	8.4	3.8
7.5	Control	102.4	323	25.3	8.8	3.5
CD 5%	NS	3.89	NS	0.99	0.56	

Table 2. Plant height, numbers of tillers at harvesting, and wheat yield.

Irrigation depth (cm)	Irrigation schedule	Plant ht. per running m	Nos. of tillers wt. (g)	1000 Grain	Biological Yield	Grain Yield
3	30% of SMD	74.4	71	26.9	5.5	2.1
3	50% of SMD	82.6	68	27.7	4.9	2.7
3	70% of SMD	81.3	71	28.5	5.1	2.6
5	30% of SMD	79.3	70	28.2	4.8	2.5
5	50% of SMD	72.8	68	28.9	4.8	2.6
5	70% of SMD	81.7	71	30.8	5.2	2.9
3	IW/CPE - 0.8	81.5	63	32.6	5.4	2.8
5	IW/CPE - 0.8	80.0	61	29.4	5.7	3.0
3	IW/CPE - 1.0	81.6	67	29.5	5.4	2.9
5	IW/CPE - 1.0	73.1	70	28.6	5.1	2.8
6	28 - 30 days interval	80.0	67	27.7	4.4	2.5
CD 5%	NS	6.94	3.25	NS	1.12	

Table 3. Saving of irrigation water and impact on rice yield trends

Irrigation depth (cm)	Irrigation Schedule	% saving of Water over control	% Yield increase over control	B:C ratio
5	2 DAD	8.3	15.2	1.24
7	2 DAD	-28.3	10.0	0.95
5	3 DAD	25.0	15.7	1.39
7	3 DAD	6.7	24.3	1.37
5	5 DAD	50.0	17.3	1.72
7	5 DAD	30.0	8.0	1.32
5	7.5 kPA	25.0	6.3	1.25
7	7.5 kPA	6.7	2.2	1.06
5	10 kPA	25.0	6.5	1.26
7	10 kPA	6.7	9.8	1.15
7.5	Control	0.0	0.0	1.00

Table 4. Saving of irrigation water and impact on wheat yield trends

Irrigation Schedule	Irrigation depth (cm)	% saving of Water over Control	% Yield increase over control	B:C ratio
3	30% of SMD	25.0	-16.1	0.91
3	50% of SMD	25.0	8.6	1.15
3	70% of SMD	37.5	4.9	1.17
5	30% of SMD	-4.2	0.4	0.91
5	50% of SMD	16.7	5.7	1.01
5	70% of SMD	16.7	15.1	1.20
3	IW/CPE - 0.8	50.0	11.6	1.31
5	IW/CPE - 0.8	37.5	18.1	1.39
3	IW/CPE - 1.0	50.0	15.6	1.39
5	IW/CPE - 1.0	37.5	13.2	1.27
6	Control	0.0	0.0	0.91

DAD (applying 5 cm irrigation depth) excess irrigation water was used compared to control. Similarly, yield enhancement (%) over control ranged between 2.2 to 24.3, and B:C ratio ranged between 0.95 to 1.72 for different irrigation regimes. Comparing overall performance, it is observed that an irrigation schedule of 5 DAD (applying 5 cm depth of irrigation) resulted in a higher water saving of 50 percent along with the highest B:C ratio of 1.72, whereas, an yield enhancement of 17.3% over control was registered which was next to the highest yield enhancement (24.3%) obtained under the irrigation regime of 3 DAD (applying 7 cm irrigation depth). Similarly, the trends in the case of wheat reflect that most of the irrigation regimes register water saving (%) in the range of 16.7 to 50 except 30% SMD (applying 5 cm irrigation depth) over control, which reflects excess water use. The yield enhancement (%) over control ranged between 2.2 to 24.3 and B:C ratio ranged between 0.95 to 1.72 for different irrigation regimes. Comparing overall performance, it is observed that the irrigation schedule of IW/CPE – 0.8 (applying 5 cm depth of irrigation) resulted in a higher yield enhancement of 18.6 percent along with the highest B:C ratio of 1.39, whereas, percent saving of water over control was registered to be 37.5 percent which was second best. The above narrations indicated that in the case of rice and wheat application of a lower depth of water (5 cm) under a sodic environment is more beneficial at an interval of 5 days of disappearance of ponded water from the field to maximize the benefit of irrigation water in rice and at IW/CPE – 0.8 in case of wheat.

CONCLUSION

The study highlights the importance of a suitable irrigation strategy for rice and wheat grown under a sodic environment for economizing water use. It was observed that the irrigation schedule of 3 DAD (applying 7 cm depth of irrigation) in rice resulted in the highest yield whereas the irrigation schedule of 5 DAD (applying 5 cm depth of irrigation) resulted in the highest saving of irrigation water along with 17% yield increase over control. In the case of wheat irrigation schedule of IW/CPE – 0.8 (applying 5 cm depth of irrigation) resulted in the highest yield and water saving of around 37%. Considering overall performance taking into consideration the percent saving of water, percent yield enhancement, and B:C ratio the study recommends scheduling irrigation at 5 DAD (applying 5 cm depth of irrigation) in rice and IW/CPE – 0.8 (5cm depth of irrigation) for wheat to maximize the saving of irrigation water as well as overall benefit.

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