Journal of Natural Resource Conservation and Management
Vol. 4, No. 1, pp 70-76, 2023
doi: 10.51396/ANRCM.4.1.2023.70-76

Irrigation water productivity trends in rice-wheat grown under partially reclaimed sodic soils

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Received : May 04, 2023
Revised : June 07, 2023
Accepted : June 08, 2023
Published : June 30, 2023

ABSTRACT

Productive use of water reflects better food and nutrition for families, more income, and productive employment. Targeting high water productivity can reduce the cost of cultivation of crops and lower energy requirements for water withdrawal. For several decades, researchers have made efforts to enhance water use efficiency. The primary objectives of these efforts were to conserve water rather than reflect the economic gains of water use. With the growing demand for water by sectors other than agriculture, the focus has changed, and the emphasis is more on the net economic return per unit of water used. This objective can be well addressed by assessing the water productivity of irrigation practices as the term water productivity is used to more accurately characterize the relationship between the output or income (such as biomass or yield) and the volume of water resource. At the same time, WUE measures the ratio or percentage of effective water demand to water consumption. Considering this concept, this paper presents the performances of different irrigation regimes in rice and wheat crops grown under a sodic environment regarding water productivity. The irrigation regimes are a combination of varying depths and varying irrigation schedules. In rice crops, ten combinations of irrigation regimes were developed by varying two irrigation depths (5 and 7 cm) and five scheduling techniques (2 DAD (days after the disappearance of ponded water), 3 DAD, 5 DAD, 7.5 kPa and 10 kPa in rice. Similarly, two irrigation depths (3 and 5 cm) and five scheduling techniques (30% SMD (Soil Moisture depletion), 50% SMD, 70% SMD, IW/CPE ratio – 0.8 and IW/CPE – ratio 1.0 in wheat crop. One control each in rice and wheat considering farmers' practices in the area was considered for comparison. The results reflect that the irrigation regime of applying 5 cm irrigation depth at 3 to 5 DAD in rice may result in higher irrigation water productivity (IWP). The observed values of water productivity in rice were 1.18 and 0.9 when 5 cm irrigation depth was scheduled at 5 DAD and 3 DAD respectively. In the wheat overall irrigation regime, applying 5 cm irrigation depth at the IW/CPE ratio 0.8 performed better. The irrigation water productivity value observed in this case was 2.27 kg/cubic m of water used. The results were further analyzed to decide the best-performing schedule for the RW cropping systems by combining the results under different irrigation regimes. Applying 5 cm irrigation depth at 5 DAD in rice and at an IW/CPE ratio of 0.8 may lead to optimum water utilization and higher crop yield, in the RW cropping system,.

Keywords: Irrigation, water productivity, rice-wheat cropping System

INTRODUCTION

Water is one of the most critical inputs for the production of crops. Excess or deficit water application at critical crop growth stages may adversely affect the yield. Quality, quantity, and time of water application directly impact crop yield

(Bhardwaj *et al*., 2008; Singh *et al*., 2016a; Singh *et al*., 2016b; Minhas *et al*., 2021) In India, the rice-wheat (RWCS) is the most widely adopted cropping system, covering an estimated area of around 12.3 million hectares (Bhatt. *et al*. 2016). Continuous adoption of this cropping system on the same fields has resulted in mining natural resources, most importantly soil and water. The soil and water conditions differ for rice and wheat, where rice requires overall wet conditions, while wheat requires pulverized soil with balanced moist conditions (Bhardwaj *et al*., 2020; Bhardwaj *et al*., 2021). However, the requirement of water at the right time to grow Rice and Wheat in the desired quantity is mandatory to avoid yield losses. Practically, the quantity and time of application of water vary with variation in factors like size, shape, and slope of the field, mode of irrigation, availability of water, soil and crop type, growth stages of crops, groundwater level in the area, farmer's socio-economic condition and their level of awareness about on-farm water management practices. The typical water requirement for rice ranges between 750 mm to 2500 mm, and for wheat, it is between 400 mm to 450 mm, depending on soil type and local conditions (Annonymous, 2010). This reflects that continuous cultivation of rice-wheat may require a sizable amount of water. This requires efficient and effective use of water resources in Rice-Wheat crop production. This concern has induced the concern of assessing the input productivity in agriculture, which indicates production per unit of input used. For example, in the mid-70s, the productivity of energy became popular due to the petroleum crisis or, later, due to the crisis of land and labour in the agriculture sector. The concept of land productivity and labour productivity was also introduced. With increased awareness, water is also now being considered a limiting resource, which has resulted in taking water productivity into account for its judicious use in agriculture. Water productivity in agriculture varies with location depending on cropping patterns, climatic conditions, irrigation methods, water management at the field level, infrastructure, and use of inputs such as labour, fertilizer, and machinery. Upadhyaya (2018) highlights that raising crop water productivity means raising crop yields per unit of water consumed, though, with declining crop yield globally, the attention has shifted to the potential offered by improved management of water resources. These concerns have forced researchers and practitioners to deviate from estimating crop yield merely to assessing crop productivity concerning inputs used. In this context, various researchers have estimated water and productivity in rice and wheat crops at different locations and under varying scenarios. Upadhya (2018) reviewed the water productivity of rice and wheat at different locations and under different scenarios. He mentioned that rice water productivity (kg/m^3) under continuous submergence, irrigation after one-day drainage, irrigation after 3-day drainage, and irrigation after 5 day drainage period at different locations and management practices varied between 0.31-0.669, 0.375-0.68, 0.372-0.851 and 0.462-1.153 respectively, whereas, wheat water productivity under different management practices and optimum schedule of irrigation was 0.715-1.511 and 0.585-2.25. Duttarganvi 2014 reports that rice (sown with the SRI technique) water productivity (kg/m^3) under varying irrigation regimes ranged between 0.23-0.62. The higher values were achieved when the irrigation schedule was based on AWD (alternate wetting and drying) at a 5-day interval. Singh *et al*. (2018) while evaluating different methods of irrigation report that the use of a LEWA (Low Energy Water Application) device and Sprinkler may double the irrigation water productivity in rice crops. The irrigation water productivity reported for a surface method of irrigation was 4.63 INR/m^{3,} whereas in the case of the Sprinkler and LEWA device, it was 7.28 and 7.38 INR/m3, respectively. Mallareddy *et al*. (2023) highlight that the water productivity of rice can be enhanced by adopting aerobic rice, as the water productivity of aerobic rice by different researchers from different locations has been reported to be between 0.7 to 1.13 kg/m^3. Tunio *et al*. (2020) in their study report that incorporating 1 t/hm^2 rice straw with 15 d of irrigation frequency may result in crop yield and crop water productivity of 7706.4 kg/hm^2 and 1.92 kg/m^{3,} respectively, in the case of wheat crop. Choudhury and Kumar (1980) and Singh and Malik (1983) showed large differences in the water productivity of wheat between wet and dry years. Tuong and Bouman (2002) reported that the water productivity of rice in India is in the range of 0.50-1.10 kg/m^3. Bhardwaj *et al*. (2021) deduced from their studies in rice-wheat system, that the availability of nitrogen in soil solution was maximum when the water application (rain+irrigation water) neared 3 mm, thus water application at this daily rate would enhance the N availability in wheat.

Sharma *et al*. (2018) reported that the average PWP (physical water productivity) of Punjab and Haryana in rice crops is around 0.57 kg/m^3 and 0.4 kg/$m^{3,}$ respectively. They also report that IWP (Irrigation water productivity) in these states is found to be relatively low at 0.22 kg/m^3, indicating the inefficient irrigation water use, whereas, in the case of wheat, the PWP for Punjab and Haryana was 1.88, and 1.57 kg/m^3 respectively) and irrigation water productivity 1.23 and 1.05 kg/m^3 respectively. The same was reported in the case of Uttarakhand, which was 1.27 kg/m^3 (PWP) and 1.04 kg/m^3 (IWP). These findings indicate the importance of water productivity as it varies with varying conditions and management practices. Water productivity directly relates to crop production; hence it also has an economic importance. Considering these factors, an experiment was planned to evaluate the performance of different irrigation regimes on productivity patterns of rice and wheat grown under sodic soils. This paper analyses the impact of different irrigation regimes on the water productivity pattern of rice and wheat and, on that basis also attempts to analyze the water productivity of the Rice-Wheat cropping system.

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 average pH of 0-15 cm was 8.54, and at 15-30 cm soil depth, the pH analyzed was 9.19. The average ECe was 1.04 and 0.72 at 0-15 cm and 15-30 cm soil depth, respectively. The average value of organic carbon level at 0-15 cm was 0.36% and 0.33% at 15-30 cm depth. Experiments were carried out from 2014 to 2017. Two irrigation depths, i.e. 5 cm and 7 cm, were fixed for different irrigation schedules for rice crops, and 7.5 cm irrigation depth in the control plots. Irrigation was scheduled at 2,3, and 5-day intervals after the disappearance of ponded water and based on the soil moisture potential monitored by tensiometers at 7.5 and 10 kPa, whereas, in control plots, the irrigation was applied considering farmers' practices in the area. Irrigation in wheat was applied with two different depths i.e. 3 cm and 5 cm for different irrigation schedules and 6 cm for control plots. Irrigation was scheduled a) at soil moisture depletion i.e. 30%, 50%, and 70%, and b) IW/CPE ratio of 0.8 and 1.0 whereas, irrigation in the control plot was applied at 30-day intervals after sowing. Overall, there were a total of eleven different irrigation strategies, which were field evaluated for both crops. Each rice plot measured 7 m x 21 m (147 m^2), and the wheat plot measured 7 m × 10 m, replicated thrice in a randomized block design (RBD). Salt-tolerant rice varieties CSR 36 and KRL 210 for wheat (recommended for a sodic environment) were used. The crop management practices were common to all treatments. Recommended fertilizer doses of N:P: K was applied. Standard agronomic practices were followed during the crop-growing season.

RESULTS AND DISCUSSION

Water and Yield Trends

The water used to provide irrigation and the yield of Rice and Wheat are presented in Tables 1 and 2. It is observed that the highest irrigation water was used in rice crops when 7 cm of irrigation depth was applied at 2 DAD followed by in control plots. The lowest use of irrigation water was observed when irrigation of 5 cm was applied at 5 DAD. Similarly, the highest use of wheat was observed when a 5 cm irrigation depth was applied at 30% and 50% SMD (Soil Moisture Depletion). This indicates that a higher irrigation depth at a shorter frequency results in higher use of irrigation water.

Observing the impact of different depths and frequencies of irrigation on rice and wheat yield reflects that irrigation schemes resulting in higher water use do not result in higher yields either. The yield trends reflect that the highest yielding irrigation scheme in the case of rice was the application of 7 cm irrigation depth at 3 DAD followed by 5 cm irrigation depth at 3 and 5 DAD. In the case of wheat, the irrigation scheme applying a 5 cm irrigation depth at an IW/CPE ratio of 0.8 resulted in the highest yield. This indicates that the highest-yielding irrigation scheme uses approximately 27 per cent less irrigation water in comparison to the irrigation scheme using the highest irrigation water in the case of rice. Meanwhile, irrigation schemes of 5 cm irrigation depth at 3 and 5 DAD, which is second best in yield trends, resulting in the use of

Table 1. Water used for applying irrigation in Rice and Yield trends

Irrigation Depth	Irrigation Schedule	Vol of water (m^3) (irrigation)	Vol of water (m^3) (Rain+irrigation)	Rice Yield (t/ha)
5	2 DAD	80.85	147.9	4.0
7	2 DAD	113.19	180.3	3.8
5	3 DAD	66.15	133.2	4.1
7	3 DAD	82.32	149.4	4.5
5	5 DAD	51.45	118.5	4.1
7	5 DAD	61.74	128.8	3.7
5	7.5 kPA	66.15	133.2	3.7
7	7.5 kPA	82.32	149.4	3.5
5	10 kPA	66.15	133.2	3.7
7	10 kPA	82.32	149.4	3.8
7.5	Control	88.20	155.3	3.5

Table 2. Water used for applying irrigation in Wheat and Yield trends

Irrigation Depth	Irrigation Schedule	Vol of water (m^3) (irrigation)	Vol of water (m^3) (Rain+irrigation)	Wheat Yield (t/ha)
3	30% of SMD	11.90	15.36	2.1
3	50% of SMD	11.90	15.36	2.7
3	70% of SMD	9.80	13.26	2.6
5	30% of SMD	17.50	20.96	2.5
5	50% of SMD	17.50	20.96	2.6
5	70% of SMD	12.83	16.30	2.9
3	IW/CPE - 0.8	8.40	11.86	2.8
5	IW/CPE - 0.8	9.33	12.80	3.0
3	IW/CPE - 1.0	10.50	13.96	2.9
5	IW/CPE - 1.0	10.50	13.96	2.8
6	Control	16.80	20.26	2.5

around 40 to 50 per cent less irrigation water, concerning irrigation schemes using the highest irrigation water. The scenario in the case of wheat reflects that the highest yielding irrigation scheme of 5 cm irrigation depth at an IW/CPE ratio of 0.8 results in about 40 per cent less use of irrigation water concerning the irrigation scheme using the highest use of irrigation water.

Water Productivity Trends of Rice and Wheat

The water productivity trends of rice and wheat under different irrigation regimes are depicted in Tables 3 and 4. It is observed that the irrigation water productivity (IWP) of rice ranged between 0.49 to 1.18 whereas under varying irrigation regimes when rain water is also combined with irrigation

Table 3. Productivity trends in rice under varying irrigation regimes

Irrigation Depth	Irrigation Schedule	Water Productivity (kg/cubic m of irrigation water used)	Total Water Productivity (kg/cubic m of all water used)
5	2 DAD	0.73	0.40
7	2 DAD	0.49	0.31
5	3 DAD	0.90	0.45
7	3 DAD	0.81	0.45
5	5 DAD	1.18	0.51
7	5 DAD	0.89	0.42
5	7.5 kPA	0.81	0.40
7	7.5 kPA	0.63	0.34
5	10 kPA	0.81	0.40
7	10 kPA	0.68	0.37
7.5	Control	0.57	0.32

Table 4. Productivity trends in wheat under varying irrigation regimes

Irrigation Depth	Irrigation Schedule	Water Productivity (kg/cubic m of irrigation water used)	Total Water Productivity (kg/cubic m of all water used)
3	30% of SMD	1.25	0.96
3	50% of SMD	1.64	1.27
3	70% of SMD	1.86	1.37
5	30% of SMD	0.99	0.83
5	50% of SMD	1.05	0.88
5	70% of SMD	1.59	1.25
3	IW/CPE - 0.8	2.33	1.65
5	IW/CPE - 0.8	2.27	1.65
3	IW/CPE - 1.0	1.96	1.47
5	IW/CPE - 1.0	1.90	1.43
6	Control	1.03	0.85

water the total water productivity (TWP) of rice ranged between 0.32 to 0.51 Kg/cubic m of water used. The highest IWP and TWP values of 1.18 and 0.51 kg/cubic m of water used were observed when a 5 cm irrigation depth was applied at 5 DAD followed by an irrigation scheme of 5 cm irrigation depth at 3 DAD. This suggests that the application of 5 cm irrigation depth at 3 to 5 DAD in rice may not only result in optimum use of water but also facilitate the achievement of maximum economic yield in sodic soils. The trends in wheat crops reflect that IWP ranged between 0.99 and 2.33 and TWP ranged between 0.83 and 1.65. The highest IWP values of 2.33 were observed when a 3 cm irrigation depth was applied at an IW/CPE ratio of 0.8 followed by an IWP value of 2.27 in the case of the highest yielding irrigation regime of 5 cm irrigation depth, applied at an IW/CPE ratio of 0.8. In addition to rainwater, the TWP value of 1.65 was observed when a 3 cm irrigation depth was applied at an IW/CPE ratio of 0.8 as well as when a 5 cm irrigation depth was applied at an IW/CPE ratio of 0.8. This suggests that an irrigation scheme of 5 cm irrigation depth at an IW/CPE ratio of 0.8 will result in the optimum use of irrigation water as well as provide a higher yield. Secondly, applying a 5 cm irrigation depth is practically feasible at farmers' fields in large plots compared to an irrigation depth of 3 cm.

Water Productivity Trend of best performing irrigation regime in RW system

The best-performing irrigation regimes in the case of rice, i.e. applying a 5 cm irrigation depth at 3 to 5 DAD is combined with the best-performing irrigation regime in the case of wheat, i.e. applying a 5 cm irrigation depth at IW/CPE ratio of 0.8 is analyzed for water productivity trends for Rice-Wheat cropping system and depicted in Table 5. The water productivity was obtained by adding irrigation and total water used by rice and wheat crop and their yield. The wheat yield was converted to rice equivalent yield. Table 5 reflects that by adopting the best irrigation regimes, the IWP ranged between 1.05 to 1.32, and TWP ranged between 0.54 to 0.61. The irrigation depth of 5 cm when applied at 3 DAD in rice and IW/CPE ratio of 0.8 in wheat. The RW system IWP results in 1.05 kg/cubic m of water used, whereas the corresponding TWP values are 0.54 kg/cubic m of water used when rainwater is also added with irrigation water. In comparison to this, the irrigation regime of applying 5 cm irrigation depth at 5 DAD in rice and at an IW/CPE ratio of 0.8 in wheat results in an IWP of 1.32 kg/cubic m of water used, and the corresponding TWP value of 0.61 kg/cubic m of water used is observed when rainwater is added with irrigation water. This suggests that an irrigation

Table 5. Productivity trends of Rice-Wheat under varying irrigation regimes

Depth of Irrigation (cm)	Irrigation Schedule	Water Productivity (kg/cubic m of water used)	Total Water Productivity (kg/cubic m of all water used)
5	3 DAD +IW/CPE-0.8	1.05	0.54
5	5 DAD +IW/CPE-0.8	1.32	0.61

regime of 5 cm at 5 DAD in rice and at an IW/CPE ratio of 0.8 may be considered for the optimum water use and obtaining the best economic yield in the RW cropping system.

CONCLUSION

The study reflects that higher use of water in Rice and Wheat may not result in higher yield in sodic soils. There is a need to optimize the depth of irrigation to be applied and its application interval. To achieve this, water productivity can be one means that can provide a fair idea for deciding on a suitable irrigation strategy. This study observed that applying 5 cm irrigation depth at 3 to 5 DAD in rice and at an IW/CPE ratio of 0.8 in wheat may result in saving water and obtaining higher crop yield.

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