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Rice Productivity and Water Use Efficiency under Different Irrigation Management System in North-Western India

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ABSTRACT

Rice (*Oryza sativa* L.) is an important *kharif* cereal crop with huge irrigation water demand. Over the years, several water saving technologies have been developed, tested and disseminated among farming community for enhancing irrigation water productivity in rice. The present study, compared continuous flooding (T_1), alternate wetting and drying in which irrigation is done 2 days after seepage (AWD; T_2), soil matric potential (ψm; *tensiometer* guided) based irrigation scheduling at ψm=15kPa (T_3) and ψm=20kPa (T_4) using PAU tensiometer on basmati rice (*var*. Pusa Basamti-1121) productivity and water use efficiency (WUE). The results revealed significantly (p<0.05) higher rice grain yield (38.85 t ha^{-1}) under T_2, compared with the other irrigation scheduling methods. The AWD (T_2) method of irrigation scheduling resulted in saving of 27 per cent irrigation water, compared with T_1. The water productivity in basmati rice production was 0.285 kg m^{-3}, 0.446 kg m^{-3}, 0.414 kg m^{-3} and 0.528 kg m^{-3}, respectively in four compared irrigation scheduling methods. As in Punjab around 3.0 Mha area is under rice cultivation and if we adopt irrigation after 2-3 days of seepage it will save around 27 per cent water as compared to continuous flooding amounting about 9.6 billon m^3 of water.

INTRODUCTION

Rice (*Oryza sativa* L.), predominantly cultivated in rice-wheat cropping system is main cropping system in Indo Gangetic planes and also in Punjab (Gautam et al., 2021) which is a principal water guzzling cereal crop with significant impact on sustainability and national food security (Bhatt et al., 2019). Rice-wheat cropping system (RWCS) occupies ~4.1 Mha area in north-western states of India comprising Punjab, Haryana, Uttarakhand and western Uttar Pradesh (Singh et al., 2020). The rice based cropping systems are challenged due to decreased crop productivity, deteriorating soil health, emission of greenhouse gases and reduced carbon (C) sustainability (Singh et al., 2020). Among different agri-inputs, irrigation water has been the most lavishly used input by the farmers in north-western India, which enhanced the energy consumption in rice production (Singh et al., 2019). According to Timsina & Coonor (2001), the actual amount of water applied by farmers is much higher than the rice crop requirement in India.

World food demands are increasing consistently while the resources are declining. The reduced water supplies have created drought like conditions in many parts of the world (Wada et al., 2013). Use of water for diverse purposes, climatic changes and increased use in agriculture in response to high food demands may be the reasons for reduced water supplies throughout the world (Elliott et al., 2013). Achieving food security for India, with its rising population, is going to be a significant challenge, and water scarcity will make the goal tougher to attain. India will host >1.5 billion people by 2030 (Anonymous, 2019). It has been estimated that production of 1 kg dehusked rice, approximately 3702 liters (L) of water is required (Kumar & Jain, 2007), and India exports ~177.8 lakh metric ton of rice in different forms in 2020-21 (Anonymous, 2021). The north-western Indian state of Punjab

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produces more than 10 per cent of India's rice and utilizes groundwater for meeting 80 per cent of its crops' irrigation needs, therefore, depleting its own and the country's groundwater resources (Saranga et al., 2018; Sidhu et al., 2020).

Several water saving technologies have been developed and advocated for rice cultivation in north-western India including matric potential based irrigation scheduling, direct seeding of rice, cultivation on beds, laser land leveling, intermittent irrigation etc. (Singh et al., 2020a). Alternate wetting and drying (AWD), helps in scheduling irrigation after 2-3 days of seepage of previously applied irrigation water. Another approach is to schedule irrigation in rice based on soil matric potential (ψm) for which *tensiometer* have been developed (PAU tensiometer). Earlier research showed that AWD reduce the water inputs by ~23 per cent compared to continuously flooded rice systems (Bouman & Tuong, 2001). Additionally, AWD also has the potential of reducing greenhouse gas (GHGs) emissions (Singh & Benbi, 2020). There are studies that showed AWD decreased crop yields by ~5.4 per cent; however, under mild AWD (i.e., when soil water potential was ≥ –20 kPa or field water level did not drop below 15 cm from the soil surface), yields were not significantly reduced (Carrijo et al., 2017). Therefore, the present study was conducted to investigate the effect of different irrigation scheduling methods on basmati rice productivity and WUE to promote water efficient technologies in north-western India.

METHODOLOGY

The experiment was conducted at fields of KVK Sri Muktsar sahib in 2020 on Pusa Basmati 1121. The crop was sown on 9th July 2020 by transplanting the seedlings from the nursery sown on 15th June 2020 by broadcasting the seeds on well prepared seedbeds. There was total three rainfalls in the crop growing period. The 36 kg urea was applied and application is done in two equal splits. The first dose was applied three weeks after transplanting and second dose applied after six weeks after transplanting. In this experiment Pusa Basmati 1121 was grown under four irrigation practices which were 1) T_1: Continuous flooding; 2) T_2: Alternate wetting and drying (AWD) in which irrigation is done 2 days after seepage; 3) T_3: Soil matric potential (ψm; *tensiometer* guided) based irrigation scheduling at ψm=15 kPa using PAU tensiometer and 4) T_4: Soil matric potential (ψm; *tensiometer* guided) based irrigation scheduling at ψm = 20kPa using PAU tensiometer.

In continuous flooding system, the most commonly used method by the farmers; a water layer was maintained to keep rice flooded for maximum part of the crop growing season. In AWD system, rice was transplanted in a manner similar to the conventional systems but water was not standing continuously in the field. In treatment T_2 the irrigation is done after 2 days of seepage, in treatment T_3 the irrigation is done based on soil matric potential after it exceeds the value of 15kPa and in treatment T_4 the irrigation is done based on soil matric potential after it exceeds the value of 20 kPa. The design of plot consisted of three replications of all four irrigation practices and each plot size was of 25 m². The various parameters recorded included number and quantity of water applied to each plot, number of tillers/m at time of harvesting and yield of crop in each plot.

The parshall flume is an open channel flow metering device. The water applied to each treatment was recorded through the Parshall flume of size 3 inches installed in the field using the formula given by the manufacturers:

$$Q = 0.1771\ ha^{1.55}$$

Where, ha = height of water observed at upstream side of Parshall flume (cm)

Q = Discharge of open channel (Lps)

To measure average number of effective tillers for a particular treatment randomly five spots were selected. From each spot no of effective tillers bearing grains from 1 m length of field were counted and their average was calculated. Productivity is a ratio between a unit of output and a unit of input. In the domain of agriculture, it is expressed as the net consumptive use efficiency in terms of yield per unit depth of water consumed per unit area of cultivation. It is generally expressed in kg/m³. The concept of water productivity in agricultural production systems is focused on producing more food with the same water resources or producing the same amount of food with less water resources.

RESULTS AND DISCUSSION

The maximum yield was obtained under (T_2) alternate wetting and drying in which irrigation is done 2 days after seepage i.e. 15.54 qt/acre followed by field having (T_3) PAU tensiometer installed where soil matric potential (ψm; *tensiometer* guided) based irrigation scheduling at ψm=15kPa is done i.e. 15.12 qt/acre and lowest in

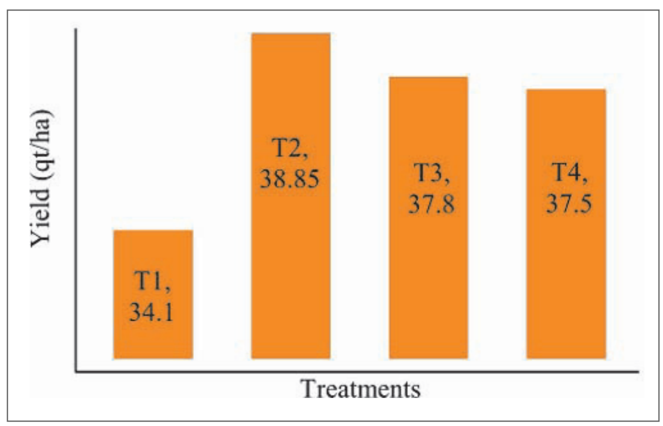

Figure 1. Yield of Pusa Basmati 1121 under different treatments

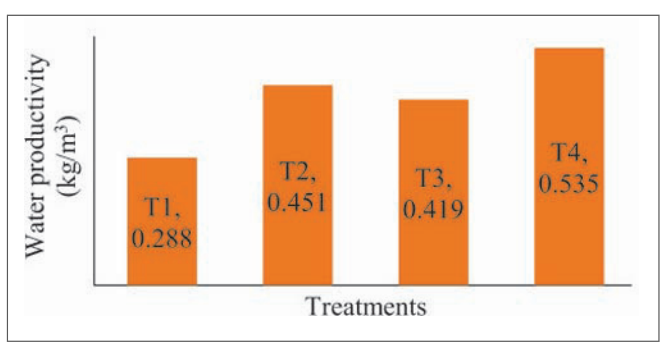

Figure 2. Water productivity of Pusa Basmati 1121 under different treatments

Table 1. Various parameters under different treatments of irrigation in Pusa Basmati 1121

Treatments	Yield (qt/ha)	No. of tillers/m	No of irrigations	Water used (m^3/ha)	Water productivity (kg/m^3)	Percentage of water saved	Percentage of increase in water productivity
T_1	34.10	54	27 + 3(rainfalls)	11827	0.288	-	-
T_2	38.85	61	19 + 3(rainfalls)	8619	0.451	27%	56.6%
T_3	37.80	58	20 + 3(rainfalls)	9020	0.419	23.7%	45.5%
T_4	37.50	59	15 + 3(rainfalls)	7015	0.535	40.7%	85.8%

(T_1) complete flooding condition i.e. 13.64 qt/acre. No of tillers per meter were maximum under irrigation after 2-3 days of seepage condition i.e. 61 and lowest under complete flooding condition i.e. 54 (Figure 1&2 and Table 1).

There was total 27 irrigation in complete flooding condition and lowest in field where (T_4) PAU tensiometer installed where soil matric potential based irrigation scheduling at ψm=20 kPa is done i.e. 15 irrigations. The maximum water productivity was observed in case of field where (T_4) PAU tensiometer installed where soil matric potential (ψm; *tensiometer* guided) based irrigation scheduling at ψm=20 kPa is done i.e. 0.535 kg/m^3 followed by field where water is applied 2-3 days after seepage i.e. 0.451 kg/m^3 and least was found in case of complete flooding situation i.e. 0.288 kg/m^3 (Table 2).

Table 2. Statistical parameters applied over yield and water productivity

Treatments	Yield (qt/ha)		Water productivity (kg/m^3)	
	Mean	Standard error	Mean	Standard error
T_1	34.10	1.129	0.288	0.01
T_2	38.85	0.787	0.451	0.009
T_3	37.80	1.913	0.419	0.021
T_4	37.50	2.002	0.535	0.029
C.D.	NS		0.046	
SE(m)	1.061		0.013	
SE(d)	1.501		0.019	
C.V.	4.959		5.382	

As per saving of water is concerned as compared to complete flooding maximum water is saved in case where (T_4) PAU tensiometer installed where soil matric potential based irrigation scheduling at ψm=20 kPa is done i.e. 40.7 per cent. In case where (T_2) irrigation was applied 2-3 days after seepage where we have gained maximum yield about 27 per cent water is saved as compared to complete flooding situation. Percentage of increase in water productivity over flood irrigation was about 56.6 per cent in case of irrigation after 2-3 days of seepage and 85.8 per cent in case of irrigation according to (T_4) PAU tensiometer installed soil matric potential based irrigation scheduling at ψm= 20 kPa is done.

As per statistics the variation in the yield of different treatments is non-significant while the water productivity of different treatments has critical difference of 0.046 at 5 per cent level of significance and has a coefficient of variation value of 5.382. Thus, different treatments of alternate wetting and drying have non-significant effect over the yield of Pusa Basmati 1121 while have significant effect over the water productivity. Numerous studies have shown that alternate wetting and drying (AWD) irrigation management can reduce water use which is valuable benefit in terms of achieving sustainable use of resources. However, it is also known that AWD can reduce rice yields if not implemented correctly. The growth behavior of rice under the recently developing water saving methods is importantly desired to be investigated. Owing to reduced water input, a negative influence of water-saving rice systems is presumed on the rice growth. However, the results of our study indicated that shifting from the flood irrigation to AWD systems had no negative effect on the growth and yield of rice. The results can be explained by the argument that a big portion of water applied to CFR is wasted in the form of percolation and evaporation, while a good rice growth can be attained even with the limited water supplied (Kukal & Aggarwal, 2002; Bouman et al., 2005; Tsubo et al., 2005). For example, the result of study conducted by Bouman et al., (2005) indicated that huge water losses were witnessed when rice was grown under conventionally flooded system compared with the water-saving rice system. The water losses of flood irrigation system included the ones which were recorded for land flooding and puddling (190 mm), evaporation (80 mm), percolation and seepage (250–300 mm), and transpiration (25 mm) (Bouman et al., 2005). Similarly, Bouman et al., (2007) concluded that a significant amount of water (200–900 mm) can be saved by growing rice by AWD instead of flood irrigation while not compromising the growth and productivity of the rice crop. The study undertaken by Tabbal et al., (2002) showed that the water input was reduced by 19 per cent when rice was grown by methods such as AWD, and the rice water-productivity was enhanced by 25–48 per cent. Our discussion concludes that improved rice growth is achievable by adding lower water inputs in rice-growing areas, meanwhile harnessing higher water-productivity.

CONCLUSION

As in Punjab around 3.0 Mha area is under rice cultivation and if we adopt irrigation after 2-3 days of seepage it will save around 27 per cent water as compared to continuous flooding amounting about 9.6 billon m^3 of water. The total water requirement for irrigation of Punjab has been estimated as 62.6 billion m^3 and the water saved makes about 15 per cent of the total irrigation water required which can be used for other domestic or industrial purposes. Hence, we can conclude that alternate wetting and drying saves a huge amount of water without compromising the yield.

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