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Rainwater Harvesting and Supplemental Irrigation for Wheat in *Kandi* Region of Punjab

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ABSTRACT: Moisture stress coupled with variable weather conditions is common phenomena in lower Shivaliks of Northern India, which results in higher dependence on supplemental irrigation. The present study was conducted with wheat crop under rainfed conditions in Talwara block of Hoshiarpur district, Punjab with three treatments, *viz.,* T_1: No irrigation, T_2: Irrigation at crown root initiation (CRI) stage and T_3: Irrigation at CRI stage and at flowering stage. Significantly higher grain and straw yield (3485 kg ha^{-1} and 6029 kg ha^{-1}) was observed in T_3 in comparison to T_2 (3260 kg ha^{-1} and 5379 kg ha^{-1}) and T_1 (2820 kg ha^{-1} and 4484 kg ha^{-1}). Net return was Rs 34,610 ha^{-1}, Rs 27,208 ha^{-1} and Rs 17,826 ha^{-1}, whereas, B:C ratio was 2.63, 2.31 and 1.88 with respect to T_3, T_2 and T_1 treatments, respectively. Less heat use efficiency for water stress conditions was observed in T_1 (1.2 ha^{-1} °C days) as compared to T_3 (1.4 ha^{-1} °C days) and T_2 (1.3 ha^{-1} °C days). Hence, it can be concluded that supplemental irrigation improved the grain yield and economic returns of rainfed wheat sown under limited irrigation.

Key words: CRI stage, economic returns, rainfed, supplemental irrigation, wheat

Introduction

The importance of the rainfed agriculture can be determined from the fact that it contributes to 40% of the country's food production; accounts for much of the national area under coarse cereals (85%), pulses (83%), oilseeds (70%) and cotton (65%); and holds 60% of the total livestock populations (Suresh *et al*., 2014). Rainwater is the major source of soil moisture required for the crop growth and is most unpredictable with respect to onset, intensity and distribution of the rainfall especially in *Kandi* region of Punjab which covers about 7.8% of the state (Sharma *et al.,* 2017). India is the second largest producer of wheat (*Triticum aestivum* L.) after China. India's share is about 14.7% of world's wheat production (Verma *et al.,* 2019). In Punjab, maize-wheat is the predominant cropping system in the rainfed lower Shivalik (Khokhar *et al.* 2021). It is the most important winter crop grown in rainfed conditions of Punjab during *rabi* season (November to April). In arid and semi-arid conditions, moisture scarcity is the main limiting factor for crop productivity because all the plant growth processes are affected by water scarcity (Hussain *et al*., 2004). In rainfed areas, abiotic stress *i.e.,* drought affects different stages of plant growth and is mainly accountable for limiting crop production (Golbashy *et al.,* 2010). Efficient utilization of limited available water can play a major role in rainfed areas especially during the *rabi* season.

Based on various phenological stages *i.e.* crown root initiation (CRI), tillering, booting etc. irrigation is scheduled in wheat crop and it has been practical approach for the farmers as wheat respond to stress from stem elongation to booting stage, followed by anthesis and grain-filling stages (Zhang and Oweis 1999). In wheat, application of limited irrigation gives optimum yield and conserves water as compared to high irrigation levels (Khokhar *et al.,* 2010). During critical stages of crop growth, when limited available water is applied to improve yield is known as supplemental irrigation (Nangia and Oweis, 2016). Due to the close relationship between various plant growth stages and temperature, different agro-meteorological indices *i.e.* growing degree-days (GDD) and heat use efficiency (HUE) etc. are frequently used as indicators for crop development evaluation and are found beneficial in different crop growth studies (Ram *et al.,* 2012). Drought and heat stress are important environmental factors affecting the rate of plant growth and development (Dar *et al.,* 2018). Irrigation is one of the important factors for proper establishment of wheat and protects the crop from heat stress during the reproductive stage; it becomes imperative to generate knowledge of the interactive effect of heat and moisture on growth and yield of wheat. Therefore, a field experiment was conducted at farmer's field to evaluate the performance of wheat under limited irrigation conditions by using harvested water that might be applied during critical stages of crop.

Materials and Methods

Study area

The current experiment was conducted in the village Behdarya, near Kamahi Devi, block Talwara of district Hoshiarpur. The experimental site was located at latitude of 31°51'18" N with longitude 76°50'36" E, at an elevation of 231.6 m above mean sea level. The area has undulating topography with deep water table and there is lack of irrigation facilities. However, because of high surface runoff, there is high potential for water harvesting. Efficient utilization of this harvested water can play an important role in dryland areas especially during the *rabi* season. Harvested water can be applied to crop as supplemental irrigation (SI) during dry spells particularly during critical crop growth stages for maximizing the yield. The village lies in hilly terrain; due to sloppy lands and high surface runoff, there is high potential for water harvesting and its efficient utilization. During monsoon season *i.e.* from July-September, heavy rainfall occurs and the excess water could be harvested in the pond. During *rabi* season this harvested water can be applied to crop as supplemental irrigation. But this harvested water is not enough to provide 4-5 irrigations for wheat crop and therefore, it was necessary to decide at which stage irrigation should be applied to get maximum yield and returns by the farmers.

Treatment details

The experiment was conducted in wheat crop during 2017-18 and was laid out in randomized block design with three replications and with three treatments; T_1: No irrigation, T_2: One irrigation at crown root initiation (CRI) stage and T_3: Two irrigations, one at CRI stage and second at flowering stage. The irrigation depth of 50 mm was applied through sprinkler irrigation system.

Climate and crop management

The annual rainfall recorded at the experimental site for the year 2017-18 was 640.3 mm, which was 39% deficit over the mean normal rainfall (1055.6 mm). The total rainfall recorded at the research site for the period of May-September (506.6 mm) accounted 41% deficit over the normal rainfall (895.9 mm) and in case of *rabi* season (October-April) it was 133.7 mm, the rainfall was deficit by about 29% to that of normal rainfall (184.8 mm). Soil of the experimental site was silty loam, pH (7.1), organic carbon (0.32%), low available N (223 kg ha^{-1}), high in available P_2O_5 (25 kg ha^{-1}) and medium in available K_2O (213 kg ha^{-1}). Wheat variety PBW 677 was sown with seed rate of 100 kg ha^{-1} with row to row spacing of 25 cm at farmer's field near to the water harvesting structure of the village. The crop was sown on residual soil moisture on 27th October 2017 and was harvested on 28th April 2018. The recommended dose of 80 kg ha^{-1} N and 40 kg ha^{-1} of P was applied to the wheat crop. Half of nitrogen and full dose of P was applied at sowing, while rest of N was broadcasted with winter rains.

Grain yield and various yield attributes data were recorded at the harvest time. Plant height was recorded from randomly tagged plants (ten) inside net plot area of experimental unit. With the help of scale from one-meter row length the number of tillers per metre row and ear length (base to top of the ear) was calculated, respectively. For calculating the grains ear^{-1}, five ears were taken from each plot and grains were counted. One thousand grains were counted from each plot thereafter weighed and expressed in grams. Based on prevailing market prices of inputs cost of cultivation was calculated and gross returns were calculated according to the market price of the grain and straw. Water use efficiency was computed using the formula (Zhang *et al.,* 2018).

The agro-climatic indices, namely, growing degree-days and heat use efficiency were also calculated. Growing degree-days (GDD) were calculated as Nuttonson, (1955):

$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base}$$

where, T_{max} = Daily maximum temperature (°C); T_{min} = Daily minimum temperature (°C); T_{base} = Base temperature of 5° C for wheat (Slafer and Savin, 1991)

Heat use efficiency (HUE) for grain yield and biological yield was obtained as (Dar *et al.,* 2018):

$$HUE = \frac{\text{Seed yield/Total matter accumulated (kg ha}^{-1}\text{)}}{\text{Accumulated heat units (°C day)}}$$

Statistical analysis

The data obtained were subjected to analysis of variance (ANOVA) technique using SAS for windows 64.0 (SAS 9.4 Inc. Cary, North Carolina, U.S.A). The significant differences among treatments were tested at 5% ($P<0.05$) level of probability.

Results and Discussion

Yield attributes

Plant height of the wheat was determined at the time of harvest (Table 1) and it was reported that there was significant ($P<0.05$) increase in plant height when the supplemental irrigation was applied in comparison to rainfed wheat and this increase may be attributed to the moisture which contributed to highest yield attributes to increased photosynthesis activity of leaves, beside, translocation of photosynthates from source to sink, higher uptake of nutrients under irrigated condition (Naseri *et al.,* 2010). Number of tillers per meter row length varied from 71 tillers/ m (T_1) to 81 tillers/m (T_3). Significantly ($P<0.05$) highest number of tillers/ m were observed in treatment T_3 (Irrigation at CRI stage and at flowering stage) as compared to treatment T_2 (Irrigation at crown root initiation (CRI) stage) and T_1 (No irrigation). Similar results were observed by Kumar *et al.* (2016) who ascertained that number of tillers/ m increased significantly when irrigation was applied at CRI + tillering + flowering + milking stage in comparison to irrigation applied at single stage. Ear length and grains ear^{-1} increased significantly when the supplemental irrigation was applied at CRI and flowering stage from the harvested water in the pond (Table 1). Singh and Singh, (2001) also

Table 1: Effect of supplemental irrigation on yield attributes and WUE of rainfed wheat

Treatments	Plant height (cm)	No. of tillers/m	Ear length (cm)	Grains/ ear	1000-grain weight (g)	WUE (kg ha^{-1} mm^{-1})
T_1	79.8^c	71^c	8.3^c	46^c	33.5^c	21.1^a
T_2	87.6^b	78^b	9.2^b	52^b	38.6^b	15.6^b
T_3	91.3^a	81^a	9.8^a	58^a	43.6^a	12.3^c

Same letter within each column indicates no significant differences among the treatments ($P<0.05$).

pointed out that yield attributes were significantly lower in rainfed wheat. Significantly ($P<0.05$) highest 1000-grain weight (43.6 g) was obtained in treatment T_3 as compared to treatment T_2 (38.6 g) and T_1 (33.5 g). Paul *et al.* (2016) also observed that if irrigation was skipped at CRI stage there was significant decrease in 1000-grain weight of wheat crop. Water use efficiency reduced with increased number of supplemental irrigations (Table 1). Significantly, ($P<0.05$) highest WUE was observed in treatment T_1 (21.1 kg ha^{-1} mm^{-1}) in comparison to T_2 (15.6 kg ha^{-1} mm^{-1}) and T_3 (12.3 kg ha^{-1} mm^{-1}). Water use in wheat increased significantly with increase in supplemental irrigation in relation to rainfed wheat and was maximized in T_3 (Irrigation at CRI stage and at flowering stage). More proliferation of plant roots in the upper soil layer under higher moisture regimes in case of increased number of supplemental irrigation levels may be helpful in extracting more soil moisture (Kiani and Mirlatifi, 2012). Lowest WUE in T_3 treatment might be attributed to better moisture utilization by wheat crop at lower availability of soil moisture under various treatments (Li *et al.,* 2019).

Grain and straw yield

Grain yield was significantly influenced with supplemental irrigation and varied from 2820 kg ha^{-1} (T_1) to 3485 kg ha^{-1} (T_3). Significantly, highest grain yield (3485 kg ha^{-1}) was observed in treatment T_3 in comparison to treatment T_2 (3260 kg ha^{-1}) and T_1 (2820 kg ha^{-1}). Increase in plant water status due to stomatal conductance may have resulted into elevated rate of cell division and cell elongation more accumulation of photosynthates and their higher mobilization from various plants part have resulted into the increase in grain yield (Singh *et al.,* 2012). Significantly, highest straw yield (6029 kg ha^{-1}) was observed in treatment T_3 in comparison to treatment T_2 (5379 kg ha^{-1}) and T_1 (4484 kg ha^{-1}). The increase in yield attributes might have resulted into increase in grain yield with supplemental irrigation treatment as compared to rainfed wheat. Results revealed that CRI stage and flowering stage are the most critical stages for irrigation in wheat and omission of irrigation at these stages reduced the grain yield by 15.6 to 23.5%. Chauhan *et al.* (2008) also observed that application of supplemental irrigation significantly influences the yield of wheat.

Economic returns

Higher net return was recorded in treatment T_3 (Irrigations at CRI and flowering stage) *i.e.* Rs 34,610 ha^{-1} followed by T_2 (Irrigation at CRI stage) with net return of Rs 27,208 ha^{-1} and minimum net return of Rs 17,826 ha^{-1} in treatment T_1 (No irrigation). Similarly, highest B:C ratio was observed in treatment T_3 (2.63) followed by T_2 (2.31) and minimum B:C ratio of 1.88 in treatment T_1. The results are in conformity with the findings of Shah *et al.* (2016) which revealed that with the increase in irrigation levels there was increase in net returns and B:C ratio due to increase in grain yield as compared to less amount of water applied through irrigation.

Heat Use Efficiency (HUE)

Heat use efficiency was observed for different treatments of supplemental irrigation (Table 2). The heat use efficiency increased from treatment T_1 to treatment T_3. The highest HUE for grain yield (1.4 kg ha^{-1} °C days) as well as for biological yield (3.9 kg ha^{-1} °C days) was recorded when supplemental irrigation was applied at CRI + flowering stage and the minimum value of HUE was obtained in rainfed wheat for grain (1.2 kg ha^{-1} °C days) and biological (3.0 kg ha^{-1} °C days) yield. The less heat use efficiency for water stress conditions (T_1) may be ascribed by less yield as well as growing degree days as compared to supplemental irrigation at CRI + flowering (T_3) and at CRI stage (T_2). Dar *et al.* (2018) also reported the similar results. The higher HUE might be attributed to the proportionate increase in dry matter per each heat unit absorbed. The temperature was favourable throughout normal growing condition, it has utilized more heat efficiently and increased physiological activities that resulted in higher grain yield (Gill *et al.,* 2014).

Table 2: Effect of supplemental irrigation on yield and heat use efficiency (HUE) of rainfed wheat

Treatments	Grain Yield (kg ha^{-1})	Straw yield (kg ha^{-1})	HUE on grain yield basis (kg ha^{-1} °C day^{-1})	HUE on biological yield basis (kg ha^{-1} °C day^{-1})
T_1	2820^c	4484^c	1.2	3.0
T_2	3260^b	5379^b	1.3	3.6
T_3	3485^a	6029^a	1.4	3.9

Same letter within each column indicates no significant differences among the treatments ($P<0.05$).

Table 3: Effect of supplemental irrigation on economics of rainfed wheat

Treatments	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
T_1	20,264	38,090	17,826	1.88
T_2	20,808	48,017	27,208	2.31
T_3	21,260	55,871	34,610	2.63

Same letter within each column indicates no significant differences among the treatments ((P<0.05).

Table 4: Pearson's correlation among yield, yield attributing characteristics and WUE of rainfed wheat

	Grain yield	Straw yield	Plant height	Ear length	Grains/ ear	1000-grain weight	No. of tillers/m row length	WUE	HUE (GY)	HUE (BY)
Grain yield	1									
Straw yield	0.99	1								
Plant height	0.99*	0.99	1							
Ear length	0.99*	0.99*	0.99*	1						
Grains/ear	0.98	0.99*	0.98	0.99	1					
1000-grain weight	0.98	0.99	0.98	0.99	0.99*	1				
No. of tillers/m row length	0.99*	0.99	0.99*	0.99	0.98	0.97	1			
WUE	-0.99*	-0.99*	-0.99*	-0.99**	-0.99	-0.99	-0.99	1		
HUE (GY)	0.99**	0.99	0.99*	0.99*	0.98	0.98	0.99*	-0.99*	1	
HUE (BY)	0.99*	0.99*	0.99	0.99*	0.99	0.99	0.99	-0.99*	0.99*	1

* Significant at 0.05 probability level, ** Significant at 0.01 probability level

Correlation studies

Correlation analysis was done between yield (both grain and straw), yield attributes, WUE and HUE (Table 4). Results indicated that plant height, ear length, number of tillers/m were significantly (P<0.05) and positively correlated with grain as well as straw yield. Elhani *et al.* (2007) also observed positive correlation between yield and yield attributes in wheat crop. WUE showed negative relationship with biological yield (r= -0.99) and grain yield (r= -0.99). The HUE showed a positive relationship with grain yield (r= 0.99). Dar *et al.* (2018) also reported the positive correlation of GDD with grain yield and biological yield.

Conclusion

Wheat grown with supplemental irrigation resulted in higher grain yield as compared to rainfed wheat with no irrigation. If limited harvested water is available, we may apply single supplemental irrigation at CRI stage and if more amount of water is available then two supplemental irrigations may be applied, each at CRI and flowering stage, for maximizing yields. Positive and significant correlations were observed among yield and yield attributes. On the whole, it can be concluded that supplemental irrigation is desirable to augment grain yield and net returns.

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