Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 26 (3) : 290-294 (September - 2024)
https://doi.org/10.54386/jam.v26i3.2608
https://journal.agrimetassociation.org/index.php/jam

Research Paper

Plant stress index (PSI) based irrigation scheduling of wheat in Punjab, India

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ABSTRACT

A field experiment was caried out over a period of two years (2022-23 and 2023-24) at Lovely Professional University, Phagwara, Punjab with eight irrigation treatments (based on PSI, soil moisture depletion & critical growth stages) and four replications in RBD Design. The different irrigation levels had an impact on plant growth, parameters contributing to yield, grain and straw production, as well as irrigation water use efficiency (IWUE). Among all the PSI based irrigation treatments, schedule irrigation at 0.50 PSI was found the best irrigation level for growing wheat with significant grain yield (5.67 t ha^{-1}), IWUE (0.092 t ha^{-1} cm) and gave 11.16% water saving over $I_{50\%\ FC}$ (irrigation as per farmer practices). To schedule irrigation as per the soil moisture depletion approach, irrigation levels $I_{50\%\ FC}$ and $I_{75\%\ FC}$ result in maximum grain yield over PSI & critical growth stage-based irrigation treatments, but this practice does not support sustainable wheat production in water-scarce regions. Therefore, irrigation can be tailored for wheat crops based on 0.5 PSI in water-scarce and water-abundant regions of Punjab.

Keywords: Critical growth stages, Canopy temperature, Soil moisture, Water stress, Irrigation scheduling, Water use efficiency

Wheat is a crucial staple in the global food supply, accounting for approximately 29% of total food grain output ensuring the nutritional well-being of over 35% of the population worldwide. About 80% of the India's wheat production is produced in the three central wheat-growing states of Uttar Pradesh, Punjab, and Haryana. Punjab is India's primary agricultural region, encompassing 3.52 million hectares dedicated to wheat cultivation, yielding a production and productivity of 14.82 million tonnes and 4.206 tonnes per hectare, respectively (Government of India, 2022). The crop demonstrates sensitivity to fluctuations in environmental factors to optimize its germination, growth, and flowering (Dabre *et al.,* 1993). It is also at significant risk of heat stress during its reproductive phases (Kalra *et al.,* 2008). The significant factors contributing to the comprehension of water requirements in agriculture include climatic conditions, crop types, and soil patterns (Sharma *et al.,* 2021; Singh *et al.,* 2021). Canal water serves as the primary means of irrigation in Punjab; however, the distribution of canal water to farmers' fields is constrained by the extent of their irrigated land (Garg *et al*., 2022; Changade *et al.,* 2023). Groundwater resources in Punjab are depleting rapidly at a rate of 0.54 meters per year because of excessive exploitation and imprudent irrigation water management strategies (Aggarwal *et al*., 2020). Farmers use groundwater for traditional irrigation practices, which maximises crop yield but fails to ensure water savings. This can be attributed to significant seepage loss, unequal distribution, and irregular supply. Thus, such irrigation techniques are not conducive to sustainable agricultural practices (Garg *et al.,* 2022). Hence, it is imperative to address the declining groundwater level trend by diminishing the water volume used for irrigation, all while avoiding any negative impact on crop yield. This indicates the necessity to enhance irrigation scheduling from abundant to restricted irrigation while assessing innovative, precise irrigation techniques. Various conventional methods are considered, which depend on the soil water balance, plant growth stages, and meteorological conditions for irrigation scheduling. Additionally, plant-based schedules have been explored to determine suitable measures for irrigation scheduling purposes. This plant phenomenon can be harnessed to detect plant stress and enhance the accuracy of stress detection in plants. Scheduling irrigation can also be done based on canopy temperature (Kaur *et al.,* 2023). Thus, crop water stress index (CWSI) is widely utilized as the predominant approach for assessing crop water stress by analysing canopy surface temperature across various crops

Article info - DOI: https://doi.org/10.54386/jam.v26i3.2608
Received: 20 May 2024; Accepted: 10 June 2024 ; Published online : 01 September 2024

and climatic environments. The Crop Water Stress Index (CWSI) serves as a valuable metric for assessing the water stress levels in crops like wheat, maize, soybean, sugarcane, watermelon, and vegetables at a given moment, with reference to both the upper and lower thresholds (Irmak *et al*., 2000; Alderfasi *et al*., 2001; Orta *et al*., 2003; Erdem *et al*., 2005). But the CWSI, an index that uses a variable base point or a reference point; instead of baselines that must be developed using a different strategy, has several drawbacks. To overcome this, a new water stress index was introduced as Plant Stress Index (PSI) by Pramanik *et al*., (2017) which is based on observed, minimum and maximum canopy temperatures. PSI value lies between 0 and 1, where zero represents the non-stress and one indicates the maximum stress condition of the crop.

Therefore, the current research was undertaken to identify a proficient, dependable, and cost-effective method of irrigation timing to cultivate wheat in the trans-Gangetic region of Punjab, aiming to enhance water resource management.

MATERIAL AND METHODS

Experiment details

A field experiment was conducted during *rabi* season (November to April) for two consecutive years (2022-23 and 2023-24) at the research farm of Lovely Professional University, Phagwara, Punjab which is situated at 31°13′N and 75°46′E. While winter is mostly dry with little breezes and minimum temperatures that frequently drop below freezing throughout December and January, summer is hot and dry between May and June. The wheat variety, Unnat PBW-343 was selected for this experiment. The nine treatments were arranged in randomized block design with four replications. The treatment details are given below.

1. I_R: Rainfed irrigation (control)
2. $I_{CRI\ \&\ Flowr.}$: Irrigation at CRI (C) and flowering growth stages
3. $I_{25\%\ FC}$: Irrigation scheduled at 25% depletion of field capacity
4. $I_{30\%\ FC}$: Irrigation scheduled at 30% depletion of field capacity
5. $I_{50\%\ FC}$: Irrigation scheduled at 50% depletion of field capacity
6. $I_{75\%\ FC}$: Irrigation scheduled at 75% depletion of field capacity
7. $I_{0.25\ PSI}$: Irrigation at 0.25 plant stress index (PSI)
8. $I_{0.50\ PSI}$: Irrigation at 0.50 plant stress index (PSI)
9. $I_{0.75\ PSI}$: Irrigation at 0.75 plant stress index (PSI)

In treatments 3-6, the irrigation water was supplied as per the change in soil moisture content in the effective root zone which was continuously checked by the gravimetric method. A barrier measuring 1 m was built around each plot to lessen the impact of irrigation water seeping to the nearby plots. To schedule irrigation in treatments 7-9, the plant stress index (PSI) value was calculated by dividing the difference between observed and minimum canopy temperature to the difference between maximum and minimum canopy temperature as described by Pramanik *et al*., (2017).

$$\mathrm{PSI} = \frac{(\mathrm{Tc} - \mathrm{Tcmin})}{\mathrm{Tcmax} - \mathrm{Tcmin}}$$

Where, T_c, T_{cmax} and T_{cmin} and are the observed, maximum and minimum canopy temperature respectively. PSI range lies between 0 and 1, where zero represents the non-stress and one indicates the maximum stress condition of the crop. The treatment $I_{50\%\ FC}$ and I_R were used to ascertain the minimum canopy temperature (Tc min) and maximum canopy temperature (Tc max), respectively. The full irrigation amount was administered in $I_{50\%\ FC}$ in the absence of any stress conditions, while I_R experienced rainfed conditions or no irrigation at all (no water was provided through irrigation, solely relying on rainfall) to induce severe water stress conditions on the crop. The effective rainfall (ER) was determined monthly using the following equation, which was based on the USDA S.C.S method:

$$ER = P_t \left[\frac{125 - 0.2 \times P_t}{125}\right] \text{ for } P_t < 250 \text{ mm}$$

Where, P_t – total rainfall (mm)

The mean weekly weather data recorded during two crop season (2022-23 & 2023-24) are presented in Fig. 1. Total rainfall of 91.5 was recorded during the crop growing season.

Crop observations

The plant height (cm), effective tillers (m^{-2}), dry matter accumulation (m^{-2}) and grain yield ($t\ ha^{-1}$) were taken at the time of harvest of the crop during both years. The irrigation water requirement and water use efficiency were calculated.

RESULTS AND DISCUSSION

Effect on growth, yield and yield attributes of wheat

The effect of different methods of scheduling irrigation on growth, yield and yield attributes of wheat is presented in Table 1. It is evident that all the parameters viz. plant height, dry matter accumulation, number of effective tillers, grain and straw yield were notably influences by irrigation schedules.

The plant height was significantly higher (105.9 cm) in treatment $I_{50\%\ FC}$ and was at par with treatments $I_{25\%\ FC}$ and $I_{30\%\ FC}$, while the lowest plant height (82.4 cm) was recorded under rainfed treatment (I_R). Maximum dry matter accumulation of 854

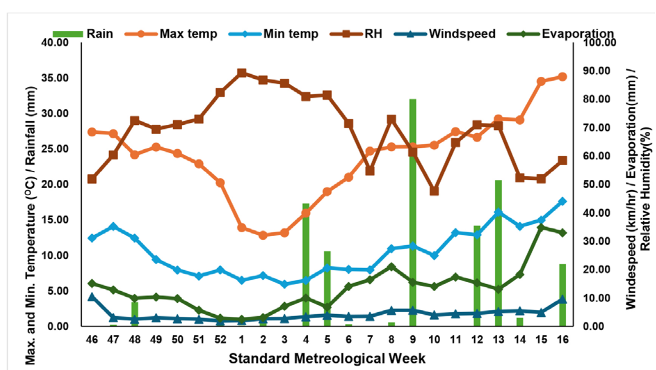

Fig. 1: Weekly metrological pooled data recorded for crop season (2022-23 and 2023-24)

Table 1: Growth, yield and yield attributes of wheat crop under various irrigation scheduling treatments (2 years pooled data at harvest)

Treatments	Plant height (cm)	Dry matter accumulation ($g\ m^{-2}$)	Number of effective tillers (m^{-2})	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)
I_R	82.4	727.6	309.8	3.0	4.9
$I_{CRI\ \&\ Flowr.}$	95.2	816.1	355.1	4.8	6.5
$I_{25\%\ FC}$	100.5	831.4	379.6	5.6	7.2
$I_{30\%\ FC}$	102.9	846.9	393.6	5.8	7.4
$I_{50\%\ FC}$	105.9	854.0	406.5	6.0	7.6
$I_{75\%\ FC}$	88.7	754.1	328.7	3.2	5.2
$I_{0.25\ PSI}$	97.5	830.2	368.7	5.3	6.9
$I_{0.50\ PSI}$	96.7	821.6	363.5	5.7	7.3
$I_{0.75\ PSI}$	89.6	770.6	337.5	3.9	5.6
C.D @ 5%	7.7	40.5	38.2	0.4	0.6

$g\ m^{-2}$ under $I_{50\%\ FC}$ and minimum of 727.6 $g\ m^{-2}$ under I_R. Among all the treatments based on PSI, maximum plant height and dry matter accumulation was observed with $I_{0.25\ PSI}$ (97.5 cm and 830.2 $g\ m^{-2}$) and was found to be significantly at par with $I_{0.50\ PSI}$ (96.7 and 821.6 $g\ m^{-2}$). The adequate soil moisture provided by the $I_{50\%\ FC}$ irrigation treatments likely contributed to the increased plant height and maximal dry matter accumulation. The profound effect of water availability on dry matter content may be attributed to improved nutrient absorption under optimal moisture levels as opposed to the stress induced by limited irrigation, as supported by prior studies (Liu *et al*., 2018; Si *et al*., 2020). The diminished plant height and dry matter accumulation under rainfed conditions can be linked to insufficient irrigation leading to moisture stress, which in turn hinders various growth aspects such as tillering and biomass production through photosynthesis inhibition (Asif *et al*., 2010; Ram *et al*., 2013; Dar 2017).

A significant impact of irrigation schedules was observed on the number of effective tillers. In comparison with other irrigation treatments, $I_{50\%\ FC}$ (406.5) had the most effective tillers, indicating a substantial difference (Table 1). Conversely, the lowest number was noted in I_R (309.8). The presence of a greater number of effective tillers in frequently irrigated plots can be attributed to the consistent moisture availability throughout the growing season, particularly when irrigation is provided during crucial growth stages. Studies by Asif *et al*., (2010) have also revealed a decline in effective tillers with increasing water deficit. Among the various treatment groups, the highest grain (6.0 $t\ ha^{-1}$) and straw yield (7.6 $t\ ha^{-1}$) were achieved in $I_{50\%\ FC}$ (full recommended irrigation), followed by $I_{30\%\ FC}$ (5.8 $t\ ha^{-1}$ and 7.4 $t\ ha^{-1}$), $I_{25\%\ FC}$ (5.6 $t\ ha^{-1}$ and 7.2 $t\ ha^{-1}$), and $I_{0.50\ PSI}$ (5.7 $t\ ha^{-1}$ and 7.3 $t\ ha^{-1}$). In contrast, the lowest yields were observed in I_R (rainfed or no irrigation). It is possible to attribute the lower grain and straw (3.2 $t\ ha^{-1}$and 5.2 $t\ ha^{-1}$) yields in $I_{75\%\ FC}$ to infrequent watering, which causes physiological limitations such early senescence of leaf, a shorter growth phase, and diminished grain formation (Asch *et al*., 2005; Farooq *et al*., 2009). The substantial influence of water availability on straw yield may be attributed to enhanced nutrient uptake under optimal moisture levels compared to conditions of water scarcity or no irrigation (Liu *et al.*, 2018; Si *et al*., 2020).

Crop water requirement and water use efficiency

According to the aggregated data, the effective rainfall (ER) was documented as 91.5 mm, which was utilized in the computation of the overall crop water demand. The data compilation displayed in Table 2 indicates that the total volume of water for irrigation provided peaked at 796 mm in $I_{0.25\ PSI}$ and hit a low of 467.3 mm in $I_{CRI\ \&\ Flowr.}$ (irrigation during CRI and flowering phases). The analysis revealed that the highest reduction in irrigation water usage compared to the standard full irrigation practice ($I_{50\%\ FC}$) was noted for I_{CF}, followed by $I_{0.75\ PSI}$ but the grain yield was found to be relatively low compared with other irrigation levels. In the context of total water use efficiency in irrigation (TWUE), the most optimal TWUE was observed in the case of I_R (0.327 $t\ ha^{-1}$ cm), which was subsequently followed by $I_{CRI\ \&\ Flowr.}$ (0.084 $t\ ha^{-1}$ cm) and $I_{0.50\ PSI}$ (0.080 $t\ ha^{-1}$ cm). Among the various levels of soil moisture depletion, $I_{50\%\ FC}$ exhibited the highest TWUE (0.076 $t\ ha^{-1}$ cm). Since no irrigation water was used, the highest TWUE in I_R was seen; nevertheless, given the yield, this approach is not economically feasible for farmers growing wheat in irrigated areas. Whereas the optimum irrigation water use efficiency (IWUE) was observed to be highest under $I_{CRI\ \&\ Flowr.}$ (0.100), followed by $I_{0.50\ PSI}$ and $I_{50\%\ FC}$ with IWUE of 0.092 and 0.086 $t\ ha^{-1}$ cm. Thus, in regions where enough water is accessible for irrigation purposes, wheat crop can be irrigated as per recommended irrigation practice (irrigation scheduled at every 50% depletion in FC of soil) because it results in maximum grain yield in conjunction with significant irrigation water use efficiency (IWUE). Among all the soil moisture depletion-based irrigation treatments, grain yield under $I_{25\%\ FC}$ and $I_{30\%\ FC}$ was noted at par with $I_{50\%\ FC}$ but these treatments showed no water saving (-10.21 % and -5.99%) over $I_{50\%\ FC}$ which can be a possible reason for giving low irrigation water use efficiency under these treatments. Conversely, treatment $I_{75\%\ FC}$ (irrigation at 75% depletion of field capacity) demonstrated a water saving of up to 10.20%. Nonetheless, this treatment resulted in a decreased grain yield of 3.2 $t\ ha^{-1}$ cm and IWUE of 0.050 $t\ ha^{-1}$ cm, indicating its ineffectiveness.

Therefore, it can be concluded that recommending soil moisture depletion irrigation strategies may not align with sustainable agricultural practices. In PSI based irrigation levels water saving was found to be highest for $I_{0.75\ PSI}$ (20.86 %). However,

Table 2: Irrigation water requirement and irrigation water saving under different treatments (2-years pooled data)

Treatments	Total irrigation water applied (mm)	Effective rainfall (mm)	Crop water requirement (mm)	Irrigation water saving (%) over $I_{50\% FC}$	Irrigation water use efficiency (t ha^{-1} cm)	Total Irrigation water use efficiency (t ha^{-1} cm)
I_R	----	91.5	91.5	---	----	0.327
$I_{CRI\ \&\ Flowr.}$	467.3	91.5	558.8	33.29	0.100	0.084
$I_{25\% FC}$	759.7	91.5	851.2	-10.21	0.076	0.065
$I_{30\% FC}$	737.2	91.5	828.7	-5.99	0.075	0.070
$I_{50\% FC}$	694.6	91.5	786.2	---	0.086	0.076
$I_{75\% FC}$	616.8	91.5	708.3	10.20	0.050	0.045
$I_{0.25 PSI}$	796.0	91.5	887.5	-14.58	0.066	0.059
$I_{0.50 PSI}$	617.5	91.5	709.0	11.16	0.092	0.080
$I_{0.75 PSI}$	549.4	91.5	641.0	20.86	0.071	0.061

this irrigation level does not support wheat production where water availability is sufficient. As per results, among all the PSI and soil moisture depletion-based irrigation treatments, the treatment $I_{0.50 PSI}$ gives maximum IWUE (0.092) with significant grain yield (5.7 t ha^{-1}) and up to 11.16 % irrigation water saving over recommended irrigation practice ($I_{50\% FC}$). When there is limited water available, canopy temperature can be used to anticipate crop water requirements (Ninanya *et al*., 2021). Higher canopy temperature demonstrates a greater inclination towards uneven assimilate distribution across spikes than cooler canopy temperatures (Thakur *et al*., 2022). Thus, higher yield in $I_{0.50 PSI}$ can be attributed to cooler canopy temperatures, facilitating better grain assimilation distribution. These results were also obtained by Pramanik *et al*., (2017), in which higher grain yield, crop water use efficiency and field water use efficiency were found when irrigation with 0.5 PSI, up to which yield did not differ. Therefore, scheduling irrigation for wheat crop at 0.5 PSI could be the best irrigation level in water scarce region of the Gangetic Plains of Punjab.

CONCLUSION

The current investigation was conducted to evaluate the different irrigation scheduling approaches and levels for watering wheat crops in the regions of Punjab. Adhering to the complete set of recommended irrigation practices (i.e. irrigation at 50% depletion in field capacity of soil) can result in increased development, production, and irrigation water use efficiency (IWUE) in the selected study area but for different water-scarce regions of Punjab (where freshwater resources are limited and groundwater quality is poor), irrigating wheat at 0.5 PSI may prove to be a more efficient approach of irrigation scheduling. As per results, among all the PSI and soil moisture depletion-based irrigation treatments, the treatment $I_{0.50 PSI}$ gives maximum IWUE (0.092) in conjunction with significant grain yield (5.7 t ha^{-1}) and up to 11.16 % irrigation water saving over recommended irrigation practice ($I_{50\% FC}$). Therefore, this methodology of scheduling irrigation can be appropriately applied to assess the fluctuating water requirements of wheat cultivation, consequently aiding farmers and policymakers in the preservation of freshwater resources and enhancement of water productivity. The results of this study can also be extrapolated to water-deficient areas in Punjab with similar climate and management circumstances.

ACKNOWLEDGEMENT

The authors thank the Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, Punjab for extending their guidance and technical assistance in conducting this research work.

Conflict of Interests: The authors declare that there is no conflict of interest related to this article.

Funding: No funding agency was involved.

***Data availability*:** To be provided on request.

Authors Contribution: **Gurleen Kaur**: Investigating, Formal analysis, and Writing draft; **Sreethu S**: Reviewing and editing; **Vikas Sharma**: Conceptualization, Methodology, editing; **Vandna Chhabra**: Methodology, Visualization and Supervision.

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