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Research Paper

Water footprint of wheat under different irrigation practices at Faridkot, Punjab

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ABSTRACT

Field experiments were conducted during *Rabi* seasons at Punjab Agricultural University, Regional Research Station, Faridkot, Punjab for 13 years (2010-11 to 2022-23) to assess the water footprint (WF) of wheat crop irrigated through different methods such as conventional surface flood (SF) during 2010-11 to 2018-19, surface drip (SD) during 2019-20 to 2020-21, and subsurface drip (SSD) during 2021-22 to 2022-23. Results elucidated that quantity of the irrigation water applied to the wheat crop ranged between 209 and 375 mm in different years. Whereas, wheat yield ranged from 3450 kg ha^{-1} (2017-18) to 5471 kg ha^{-1} (2021-22). Wheat crop under SF irrigation recorded higher WF_{total} 0.98 to 1.57 m^3 kg^{-1}. The maximum rainfall 250.3 mm received in 2014-15 resulted highest WF_{green} (0.46 m^3 kg^{-1}) and lowest WF_{blue} (0.45 m^3 kg^{-1}). The wheat cultivation under SD and SSD reduced the WF_{grey} up to 35 % and WF_{blue} up to 35.0 – 42.8 % over SF. The higher crop yield and/or fewer water consumption both are associated with the lower WF. Therefore, for hydrological resource conservation and to ensure environmental sustainability, irrigation through SSD and SD should be promoted over the traditional SF method among the farming community.

Keywords: Irrigation, Surface drip, Sub-surface drip, Water footprint, Wheat.

Water is a basic natural resource for life, ecosystems, and human society. Climate and land surface variability result in variation in the hydrological cycles. Being an essential component for agricultural productivity, water significantly contributes to food security. Irrigated agriculture accounts for 20% of the total agriculture and 40% of the global food production. However, the irrigated agriculture production is almost twice compared to rainfed agriculture. In India during 2021, average annual per capita water availability was 1486 m^3, which may be around 1367 m^3 by the year 2031. The annual per capita water availability of less than 1700 m^3 is considered a water stressed condition, whereas a situation of annual per capita water availability less than 1000 m^3 is termed as severe water scarcity (Anonymous, 2019). In India, wheat (*Triticum aestivum* L.) is the second highest cultivated cereal crop after rice. In Punjab, during 2021-22, wheat production was 148.65 lakh tonnes with average yield of 42.16 q ha^{-1} (Anonymous, 2023). The total crop water requirement of wheat is 350-600 mm (Liu *et al.,* 2022).

The water footprint (WF) is a quantitative and qualitative indicator of direct and indirect water used in the production process. *Blue* WF (WF_{blue}) refers to the quantity of surface and groundwater used for irrigation, whereas *green* WF (WF_{green}) is the amount of consumed rainfall. According to current ambient water quality regulations, the *grey* WF (WF_{grey}) is the amount of freshwater needed to assimilate the pollutants from the polluted water which was contaminated during the production cycle. The sum of WF_{green}, WF_{blue}, and WF_{grey} is termed as *total* WF (WF_{total}) (Hoekstra *et al.,* 2011). Virtual water is freshwater used by a product or service at its original place of origin that moved to another place as embedded water along with the products or services through trade. Knowledge of how allocated water resources are consumed during the production process is extremely helpful to water resource managers and policymakers.

The drip irrigation system can increase both the water efficiency and the agricultural returns through uniform water distribution and lower evapotranspiration losses (Patel *et al.,* 2023). The SD and SSD potentially save a large quantity of water used in

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agriculture compared to SF irrigation (Singh *et al.,* 2018). Moreover, delivering water directly to the root zone in SSD increases the overall system efficiency by reducing evaporation, runoff and infiltration loss (Wolff *et al.,* 2017), increasing productivity and quality (Yan *et al.,* 2020), and improving nutrient utilisation (Singh *et al.,* 2022). The WF have been reported mostly for rice crop (Zhai *et al.,* 2019; Kashyap and Agarwal, 2021; Sidhu *et al.,* 2021; Hassan and Rana, 2024). Very limited work on WF of wheat are reported in India, hence, the present study was conducted to explore the comparative WF of long-term (2010-11 to 2022-23) experiments on wheat crop irrigated with SF, SD and SSD systems in Faridkot, Punjab, India.

MATERIALS AND METHODS

Description of experimental sites

Field experiments were conducted at Punjab Agricultural University (PAU), Regional Research Station (RRS) Faridkot (latitude 30°40'N, longitude 74°44'E, altitude of 200m above mean sea level). A popular wheat variety, HD 2967 was sown in the first week of November under Randomized block design during 2010-11 to 2022-23. As per recommendation of the Punjab Agricultural University, the rate of nitrogen to wheat crop under SF (125 kg ha^{-1}) was reduced by 20% (i.e., @100 kg ha^{-1}) under SD and SSD methods. The applied irrigation methods were SF during 2010-11 to 2018-19, SD during 2018-19 to 2020-21 and SSD during 2021-22 to 2022-23. The soil profiles have pH values between 8.2 and 8.4. The organic carbon at 0-15 cm and 15-30 cm soil depth were 0.44 and 0.25% whereas, available nitrogen contents were 210 and 248 kg ha^{-1}, respectively. The field capacity, wilting point and bulk density of soils for 0-15 and 15-30 cm depths were 29-32%, 9.87-10.60% and 1.54-1.55 g cm^{-3}, respectively.

Establishment of irrigation system

The Punjab Agricultural University has recommended 4-7 conventional SF irrigations each of 75 mm for wheat crop. In the present study, five irrigations applied to the wheat crop under accounted for irrigation water equal to 375 mm (5 x 75 mm). In the subsequent experiments, the irrigation was applied through SD (2019-20 to 2020-21) and SSD (2021-22 to 2022-23). The drip laterals having in-built emitters spacing of 20 cm were placed between two rows of the wheat crop on the surface for SD and at 20±2.5 cm below the soil for SSD systems. The drip lines of both the drip systems were established at 67.5 cm intervals thus, one lateral served for the 2 rows of wheat sown at 22.5 cm row to row spacing.

Estimation of effective rainfall

Effective rainfall is actual part of the precipitation which meet the CWR, after subtraction of the surface run-off or deep percolation losses from total rainfall. It was calculated using the formula proposed by the 'USDA Soil Conservation Service' as under:

$$\text{Effectiverainfall(ER)} = \begin{cases} \text{Rainfall} \times (125 - 0.2 \times P)/125, & \text{for Rainfall} \leq 250\,\text{mm} \\ 125 + 0.1 \times \text{Rainfall}, & \text{for Rainfall} \geq 250\,\text{mm} \end{cases}$$

Green water footprint

The WF_{green} was calculated using total effective rainfall of the whole crop season divided by the corresponding crop yield, using the following equation.

Green water footprint = (10 × Effective rainfall) / Yield

Blue water footprint

The consumption of surface and groundwater during the entire cultivation period is referred as the WF_{blue}, it was calculated using given formula:

Blue water footprint = (10 × Irrigation amount) / Yield

Grey water footprint

The *grey* component of the WF represents the total volume of fresh water contaminated during the crop production. It was calculated as below:

$$\text{Grey water footprint} = \frac{(1000 \times \alpha \times AR \times A)}{(Y\,(C_{max} - C_{nat}))}$$

Where, 10 = Conversion factor to change millimeter into cubic meter (m^3); α = Leaching factor (%); which is set at 10 %; AR = Area of nitrogen fertilizer usage (kg ha^{-1}); A = Planting area (ha); Y = Crop yield (kg ha^{-1}); C_{max} = Maximum concentration of nitrogen for a given water body (mg l^{-1}), which is set at 10 based on the Taiwan environmental protection agency (EPA) groundwater pollution control standards; C_{nat} = Natural background concentration of nitrogen (mg l^{-1}), which is set at 0.

Total water footprint

The summation of the green, blue, and grey footprints is considered as the WF_{total}. In other terms, the WF_{total} of wheat crop was calculated as:

$$WF_{total} = WF_{green} + WF_{blue} + WF_{grey.}$$

RESULTS AND DISCUSSION

Weather conditions at experimental site

The *Rabi* season is characterized by low temperatures and less rainfall. Heavy rainfall for extended periods, combined with prolonged humid conditions lead to massive outbreaks of diseases resulting in significant economic losses. During the study periods of 2010-11 to 2022-23, range of the average annual minimum and maximum temperatures was 9.9 to 11.8°C and 22.8 to 26.3 °C, respectively (Table 1). Likewise, the relative humidity ranged between 39% (2012-13) and 88% (2019-20). During the crop season, the lowest rainfall amounts of 15.0 and 27.2 mm have been recorded in the years 2011-12 and 2020-21, respectively. On the other hand, the years 2014-15, 2012-13 and 2013-14 recorded the highest rainfall values of 250.3, 113.0 and 104.9 mm, respectively. The mean effective rainfall values varied between 14.8 mm to 230.2 mm (Table 1).

Table 1: Weather conditions and effective rainfall during wheat growing season at Faridkot

Year	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	
	Maximum	Minimum	Maximum	Minimum	Total	Effective
Conventional flood irrigation						
2010-11	24.9	11.5	79	45	57.9	57.2
2011-12	24.2	10.8	74	49	15.0	14.8
2012-13	25.2	11.8	73	39	113.0	110.7
2013-14	24.2	10.9	80	53	104.9	103.0
2014-15	24.3	11.0	84	51	250.3	230.2
2015-16	25.8	11.5	84	43	104.0	100.7
2016-17	26.3	11.3	85	41	56.3	55.2
2017-18	25.8	10.9	86	42	41.6	41.2
2018-19	24.6	9.9	86	43	65.3	64.6
Mean	**25.0**	**11.1**	**81**	**45**	**89.8**	**86.4**
Surface drip irrigation						
2019-20	22.8	10.4	88	51	146.1	143.6
2020-21	25.2	10.5	84	42	27.4	27.2
Mean	**24.0**	**10.5**	**86**	**47**	**86.8**	**85.4**
Subsurface drip irrigation						
2021-22	26.2	10.9	84	43	125.0	118.3
2022-23	25.0	10.9	86	44	118.6	113.6
Mean	**25.6**	**10.9**	**85**	**44**	**121.8**	**115.9**

Irrigation water applied and wheat yield

The irrigation water requirement of wheat crop varied among the irrigation practices. Experiments under SF (2010-11 to 2018-19) were irrigated on the basis of total seasonal rainfall. Among 9 experiments under SF, a total of three irrigations (each of 75 mm) were provided during 2012-13 and 2014-15, four irrigations (each of 75 mm) during 2013-14, 2015-16 and 2018-19, and five irrigations (each of 75 mm) during 2010-11, 2011-12, 2016-17 and 2017-18. Similarly, amount of irrigation water applied through SD was 212 and 299 mm during 2019-20 and 2020-21, respectively, and for SSD it was 256 and 209 mm during 2021-22 to 2022-23, respectively (Table 2). Despite the benefits of water savings, SSD recorded higher wheat yields compared to SD and SF methods. Among different years, wheat yield ranged from 3450 kgha^{-1} (2017-18) to 5471 kg ha^{-1} (2021-22). The data presented in Table 2 clearly show that the average wheat yield under SF irrigation (4325 kgha^{-1}) was lower by 16.7% than SD (5189 kgha^{-1}) and 19.2% than SSD (5353 kgha^{-1}). A previous study conducted by Kamilov *et al.,* (2005) already reported that drip irrigation can save up to 22% of irrigation water and records 10-35% higher water productivity compared to furrow irrigation.

Temporal variation in water footprints (WF)

The WF components recorded considerable variation among the study period (2010-11 to 2022-23). Across the irrigation methods, the WF_{blue} remained high compared to WF_{green} and WF_{grey} because, groundwater fulfils the large proportion of the irrigation requirement of the winter wheat. Between the years 2010-11 and 2018-19, field experiments under SF recorded the higher values of WF_{total} between 0.98 m³ kg^{-1} (during 2012-13) and 1.57 m³ kg^{-1} (during 2017-18). The years 2011-12 and 2020-21 having lower effective rainfall amounts of 14.8 and 27.2 mm (Table 1), which exhibited lower values of WF_{green} to 0.03 and 0.05 m³ kg^{-1}, in the respective years. Thus, it has been noteworthy that with higher amount of rainfall the WF_{blue} decreases and the WF_{green} increases. Likewise, heavy consumption of rainfall (250.3 mm) in 2014-15 resulted the maximum WF_{green} (0.46 m³ kg^{-1}) leading to lower irrigation requirement (225 mm) as well as lesser WF_{blue} (0.45 m³ kg^{-1}). The maximum value of WF_{total} (1.57 m³ kg^{-1}) during 2017-18 has been contributed by 0.12 m³ kg^{-1} WF_{green}, 1.09 m³ kg^{-1} WF_{blue}, and 0.36 m³ kg^{-1} WF_{grey} (Table 2).

Obviously, variation in the rainfall driven crop water demand largely influence the WF of wheat. An inverse relationship has been noticed between the WF_{green} and the WF_{blue}. Whereas, the decreasing WF_{grey} was associated with higher WF_{green} and lower WF_{blue} especially under SF irrigation. The irrigation water requirement of SD experiments increased from 212 mm (in 2019-20) to 299 mm (in 2020-21) due to lower rainfall in later year. In SSD experiments, relatively higher rainfall during 2021-22 compared to 2022-23 correspondingly resulted lower irrigation requirement of 209 mm in the later year than 256 mm in the previous year. Overall, the WF_{total} of wheat under SSD (0.81 - 0.87 m³ kg^{-1}) and SD (0.88 - 0.88 m³ kg^{-1}) were lower than the wheat crop grown under SF irrigation (0.98 - 1.57 m³ kg^{-1}). These results enormously witnessed the superiority of drip irrigation methods over conventional SF irrigation. The findings of present investigation have been endorsed by Luan *et al.* (2018) who also reported the WF_{total} of 1.0 m³ ha^{-1} for the wheat crop in the Hetao irrigation district of China.

Table 2: Amount of irrigation, grain yield and water footprints of wheat during 2010-11 to 2022-23

Year	Amount of irrigation (mm)	Yield (kg ha^{-1})	WF_{green} (m^3 kg^{-1})	WF_{blue} (m^3 kg^{-1})	WF_{grey} (m^3 kg^{-1})	WF_{total} (m^3 kg^{-1})
Conventional flood irrigation						
2010-11	375	3619	0.16	1.04	0.35	1.54
2011-12	375	4279	0.03	0.88	0.29	1.20
2012-13	225	4678	0.24	0.48	0.27	0.98
2013-14	300	5039	0.20	0.60	0.25	1.05
2014-15	225	5046	0.46	0.45	0.25	1.15
2015-16	300	4517	0.22	0.66	0.28	1.16
2016-17	375	4797	0.12	0.78	0.26	1.16
2017-18	375	3450	0.12	1.09	0.36	1.57
2018-19	300	3496	0.18	0.86	0.36	1.40
Surface drip irrigation						
2019-20	212	5173	0.28	0.41	0.19	0.88
2020-21	299	5205	0.05	0.57	0.19	0.82
Subsurface drip irrigation						
2021-22	256	5471	0.22	0.47	0.18	0.87
2022-23	209	5234	0.22	0.40	0.19	0.81

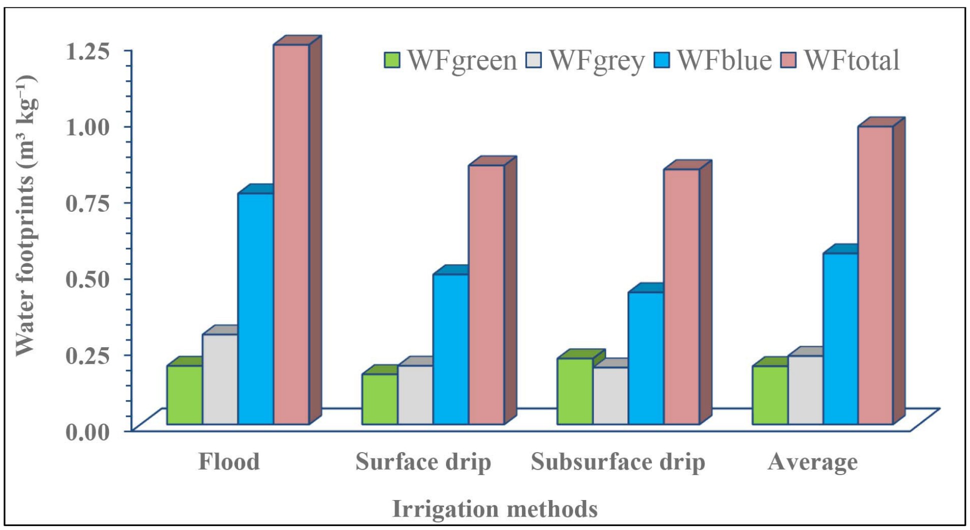

Fig. 1: Water footprint of wheat under different irrigation systems

Water footprints of different irrigation systems

The highest WF_{total} for wheat production was recorded under SF (1.37 m^3 kg^{-1}), which was attributed by 14.0% WF_{green}, 21.5% WF_{blue} and 64.5 % WF_{grey}. The WF_{total} of wheat in SD (0.90 m^3 kg^{-1}) and SSD (0.93 m^3 kg^{-1}) showed decreased WF by 32.2 to 34.6 % over the SF. The higher consumption of WF_{green} (0.22 m^3 kg^{-1}) by the wheat crop under SSD was a noteworthy, which remained lower under SF (0.19 m^3 kg^{-1}) and SD (0.16 m^3 kg^{-1}). On an average, the WF_{green} of wheat was 0.19, 0.16 and 0.22 m^3 kg^{-1} under, SF, SD and SSD, respectively. Similarly, the average WF_{blue} of wheat under SD (0.49 m^3 kg^{-1}) and SSD (0.43 m^3 kg^{-1}) has been declined by 35.0 and 42.8% compared to SF (0.76 m^3 kg^{-1}). Likewise, application of the SD and SSD was able to save the WF_{grey} of wheat by 35.0% over the SF irrigation (0.30 m^3 kg^{-1}). The higher proportion of WF_{grey} is an indicator of much leaching of the applied nitrogen fertilizer into the soil. Our results were supported by the findings of Bajpai and Kaushal (2021) who reported that the drip irrigated wheat not only accounts 5-7% higher grain yields but, it also enables water savings up to 36-76% than SF (Fig. 1). Overall average of different irrigation systems revealed that the mean WF_{total} of wheat production (0.98 m^3 kg^{-1}) has been attributed by 0.19 m^3 kg^{-1} WF_{green}, 0.56 m^3 kg^{-1} WF_{blue} and 0.22 m^3 kg^{-1} WF_{grey}. In other words, proportion of the WF_{green}, WF_{blue} and WF_{grey} to the average WF_{total} of wheat was 19.6 : 57.4 : 23.0.

CONCLUSION

The surface drip (SD) and subsurface drip (SSD) systems not only save irrigation water but also result in higher wheat yields compared to the surface flood (SF) system. The rainfall and number of rainy days reduced the irrigation requirement. The drip irrigation systems not only saved enormous quantity of irrigation water but also facilitated the crop to produce higher wheat yields than the SF system. Increased rainfall decreased the WF_{blue} but increased the WF_{green}. An inverse relationship was observed between the WF_{green}

and the WF_{blue}. Similarly, a lower WF_{grey} has been associated with higher WF_{green} and lower WF_{blue}. The WF_{total} of wheat (0.81 to 0.88 m^3 kg^{-1}) under drip irrigation was much lower than the wheat crop raised under the SF irrigation (0.98 to 1.57 m^3 kg^{-1}). This study concluded that the SD and SSD systems should be promoted over conventional SF method of irrigation to reduce agricultural WF and effective groundwater resource conservation.

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***Data availability*:** Data may be made available on request from the corresponding author.

***Author's contribution*:** **S Choudhary**: Field experiments, data collection, and writing; **SK Mishra**: Monitoring, Conceptualization, Field experiments, Analysis, Writing and review; **K Singh**: Conceptualization, Supervision, reviewing; **RK Pal:** Field experiments, data collection, analysis, writing; **P Kaur:** Conceptualization, review, and monitoring.

REFERENCES

Anonymous (2019). Central Water Commission. Reassessment of water availability in India using space inputs. Basin Planning and Management Organisation, Central Water Commission, New Delhi.

Anonymous (2023). Package of Practices for Rabi Crops. Pp 1. Punjab Agricultural University, Ludhiana. https://www.pau.edu/content/ccil/pf/pp_rabi.pdf.

Bajpai, A. and Kaushal, A. (2021). Drip Irrigation in Rice and Wheat Cropping System under Conservation Agriculture: Water Scarcity Solution. *Biol. Forum – An Int. J.,* 13(3b): 89-93.

Hassan, S. and Rana, A. (2024). Blue and green water footprint assessment of rice crop in high altitude temperate zone of Kashmir, India: *J. Agrometeorol.,* 26(2): 228-232. https://doi.org/10.54386/jam.v26i2.2569.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2011). The water footprint assessment manual-setting the global standard. Earthscan, London, UK. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1069&context=wffdocs.

Kamilov, B., Evett, S., Ibragimov, N., Bezborodov, G., Esanbekov, Y. and Lamers, J. (2005). Water use of winter wheat for two irrigation and scheduling methods in Uzbekistan. In ASA-CSSA-SSSA Proceedings.

Kashyap, D. and Agarwal, T. (2021). Carbon footprint and water footprint of rice and wheat production in Punjab, India. *Agril Syst.,* 186: 102959. https://doi.org/10.1016/j.agsy.2020.102959.

Liu, Y., Lin, Y., Huo, Z., Zhang, C., Wang, C., Xue, J. and Huang, G. (2022). Spatio-temporal variation of irrigation water requirements for wheat and maize in the Yellow River Basin, China, 1974–2017. *Agric Water Manag.,* 262: 107451.

Luan, X., Wu, P., Sun, S., Wang, Y. and Gao, X. (2018). Quantitative study of the crop production water footprint using the SWAT model. *Ecol Indic.,* 89 (1-10): https://doi.org/10.1016/j.ecolind.2018.01.046.

Patel, A., Kushwaha, N.L., Rajput, J. and Gautam, P.V. (2023). Advances in Micro-Irrigation Practices for Improving Water Use Efficiency in Dryland Agriculture. *In* Enhancing Resilience of Dryland Agriculture Under Changing Climate: Interdisciplinary and Convergence Approaches (pp. 157-76). Singapore: Springer Nature Singapore.

Sidhu, B.S., Sharda, R. and Singh, S. (2021). An assessment of water footprint for irrigated rice in Punjab. *J Agrometeorol.,* 23(1): 21-29. https://doi.org/10.54386/jam.v23i1.84.

Singh, K., Brar, A.S. and Singh, H.P. (2018). Drip fertigation improves water and nitrogen use efficiency of Bt cotton. *J Soil Water Conser.,* 73(5): 549-57.

Singh, K., Mishra, S.K., Singh, M., Singh, K. and Brar, A.S. (2022). Water footprint assessment of surface and subsurface drip fertigated cotton-wheat cropping system - A case study under semi-arid environments of Indian Punjab. *J. Clean Prod.,* 365: 132735.

Wolff, M.W., Hopmans, J. W., Stockert, C.M., Burger, M., Sanden, B.L. and Smart, D.R. (2017). Effects of drip fertigation frequency and N-source on soil N_2O production in almonds. *Agric Ecosyst Environ.,* 238: 67-77. doi: 10.1016/j.agee.08001.

Yan, S., Wu, Y., Fan, J., Zhang, F., Paw, U. and Zheng, K.T. (2020). A sustainable strategy of managing irrigation based on water productivity and residual soil nitrate in a no-tillage maize system. *J. Clean Prod.,* 262:121279. doi: 10.1016/j.jclepro.2020.121279.

Zhai, Y., Tan, X., Ma, X., An, M., Zhao, Q., Shen, X. and Hong, J. (2019). Water footprint analysis of wheat production. *Ecol Indic.,* 102: 95-102. https://doi.org/10.1016/j.ecolind.2019.02.036.