



Wheat (*Triticum aestivum*) response under soil moisture and crop water stress based irrigation scheduling at variable nitrogen regimes

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ABSTRACT

The field experiment was conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at research farm of ICAR-Indian Agricultural Research Institute, New Delhi to examine the water productivity and crop response under soil moisture and crop water stress based irrigation scheduling at variable nitrogen regimes in wheat (*Triticum aestivum* L.). Experiment was conducted in a split-plot design (SPD) design comprised of 3 irrigation regimes in main plots and 5 graded nitrogen (N) levels in sub-plots, replicated thrice. Irrigation scheduling regimes included I₁ (50% available soil moisture depletion-ASMD); I₂ (CWSI i.e. crop water stress index based); and I₃ (Conventional crop growth stage based). The 5 graded N levels included 0 (N₀); 50 (N₁); 100 (N₂); 150 (N₃); and 200 (N₄) kg N/ha. Results showed that 50% DASM based irrigation significantly increased grain yield (11.28 and 6.30%), straw yield (5.33 and 5.70%), dry matter accumulation (5.65 and 5.44%), water productivity (11.37 and 6.19%), root length (15.89 and 44.48%), root weight (11.63 and 12.77%) and grain N uptake (20.88 and 14.52%) compared to conventional crop stage based irrigation during 2021–22 and 2022–23, respectively. Among the graded N application, maximum grain yield (4.78 and 4.82 t/ha) and crop water productivity (13.91 and 15.09 kg/ha-mm) were recorded with treatment N₄ (200 kg N/ha), but remained statistically at par with N₃ (150 kg N/ha) due to the marginal increment beyond 150 kg N/ha. Overall, soil moisture based irrigation at 50% MAD with 150 kg/ha N application proved to be the most effective and economical approach to enhance dry-matter accumulation, yield and water productivity with saving from harmful environmental effects ascending from excessive nitrogen use.

Keywords: CWSI, Graded N, Soil moisture based irrigation, Water productivity, Wheat, Yield

Wheat (*Triticum aestivum* L.) is the important staple food crop. For obtaining higher productivity of wheat effective irrigation scheduling is crucial. The purpose of scheduling irrigation is to supply water to crop at optimal time and amount for enhanced yield and crop water productivity. Irrigation in wheat can be scheduled by considering the soil moisture content in the root zone, water lost as evapotranspiration (ET) and water stress response to the plant. Most of the initiatives for scheduling irrigation till date have been centered on approaches based on ET or soil water balance (Pramanik *et al.* 2022). Wheat yield is primarily influenced by water and nutrient interaction, which is essential for its continued enhanced productivity without compromising soil and ecological health. In nutrients, nitrogen stands out as a major essential element, exerting a profound influence on wheat yield and its quality (Fazily and Hunshal 2019). Nitrogen and water act synergistically

to improve crop productivity. To achieve higher wheat yields, the crop must meet the high N requirements, which typically leads to proportional increase in N fertilizer usage. Moreover, crop yield doesn't increase significantly by excess N fertilization. It is sufficient to apply 120–240 kg N/ha to sustain high winter wheat yields (Sui *et al.* 2015). This is further aggravated by under and over irrigation in conventional stage based irrigation method. In order to lower the cost of resources, it is crucial to use water and N fertilizer in an appropriate manner. However, to optimize water use in production and WUE, there is a need for water stress detection in crop in real time (Han *et al.* 2018). Hence, soil moisture detection and infrared thermometry proves valuable in accurate supervision of irrigation water by constant monitoring of soil and plant stress, respectively. This will incorporate climate conditions and soil water status. Moreover, infrared thermometry is less labour-intensive and conducted on extended temporal or spatial scales. Infrared thermometers gauge canopy temperature, a parameter that has garnered significant attention to identify crop water stress. This method is non-destructive, continuous and

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scalable, applicable from individual plants to entire fields (Gonzalez-Dugo *et al.* 2020). Therefore, present study was planned to examine the water productivity and crop response under soil moisture and crop water stress based irrigation scheduling at variable nitrogen regimes in wheat.

MATERIALS AND METHODS

The field experiment was conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at Research farm of ICAR-Indian Agricultural Research Institute, New Delhi (28° 38' 15" N; 77° 09' 28" E; average altitude of 243 m amsl). This region has subtropical climate with cold winter and dry with hot summer with average maximum and minimum temperature of 17.37–40.44°C and 5.50–27.34°C. The cumulative average annual rainfall for past 30 years was around 710 mm. In the years 2021–22 and 2022–23 the rainfall was around 1863.60 mm and 1116.18 mm, respectively. The test variety of wheat i.e. HD 2967 is popular among the farmers in present time was used for research experiment. The texture of 0–60 cm soil depth was sandy loam. The top soil (0–15 cm) contain available N, P₂O₅, K₂O and organic carbon as 223.09, 60.97, 526.43 kg/ha and 0.64%, respectively. The water retention at field capacity (FC) and permanent wilting point (PWP) was 19.75% and 13.34%, respectively with 0.65 cm/h hydraulic conductivity.

Experimental design and field management: Field experiment involved 3 irrigation regimes (main plots) and 5 graded nitrogen levels (sub-plots) with 3 replications under split-plot design (SPD). The 3 irrigation scheduling regimes included I₁ (50% available soil moisture depletion-ASMD); I₂ (CWSI i.e. crop water stress index based); and I₃ (Conventional crop growth stage based). The 5 graded N levels included 0 (N₀); 50 (N₁); 100 (N₂); 150 (N₃); and 200 (N₄) kg/ha N. Phosphorus and potassium were uniformly applied as 60:40 kg/ha of P₂O₅ and K₂O. At the time of sowing, 1/3_{rd} N and full doses of P and K were applied and remaining nitrogen was administered through top-dressing at CRI (Crown root initiation) stage and tillering stage in two equal portions. The research area was segmented into 45 plots, delineated by earthen bunds of height 0.20 and width of 1.0 m. Standard package of practices were followed for recording observations from main plots (65 m × 7.2 m) and sub plots (13 m × 7.2 m). Ten plants in each scenario were selected randomly for recording plant height. The dry matter accumulation (g/m²) by crop plants was recorded from four randomly selected places using 0.25 m² area by oven drying samples at 60±2°C. The root length was captured using the root skeleton's scanning and image analysis (WINRHIZO system, Regent Instruments Inc., Canada). The crop was harvested manually at maturity during both the years when spikes turns brownish and grains become hard. Harvesting and threshing was done manually from 5 m × 5 m for crop yield (t/ha) estimation. Multi-crop plot thresher was used for threshing of wheat samples in both the years.

Irrigation scheduling, discharge measurement and water productivity: Soil moisture status was analyzed from 60 cm soil depth at 15 days interval through thermo-

gravimetric method at 105°C under soil moisture based irrigation scheduling. Irrigation was applied whenever available soil moisture reaches 50% of available water content (AWC). Under CWSI based irrigation scheduling the canopy temperature measurements were recorded by a non-contact, handheld infrared thermometer named Everest Inter-Science AGRI-THERM II (Model 6110.4ZL). The canopy temperature was taken between 12:00–14:00 pm through infrared thermometer on sunny day at 10-days interval during different growth stages. To cover the maximum canopy area, images were captured in sunlight directions between 30–45° angles from the top of the canopy. Irrigation was given when CWSI value reaches 0.5. Under conventional crop growth stage irrigation scheduling irrigation water was applied as per farmers' practices. Starflow meter a 12-V battery mounted sensor-based device mounted at channel/stream bottom equipped with mechanical components used for measurement of water discharge, velocity, depth and cumulative volume at 15–600 s scan interval. Finally, total flow and flow rate was calculated. Water productivity shows the association between amount of water used as irrigation water applied or actual evapotranspiration (ET_c) and crop produced in terms of yield (kg).

Nutrient uptake: NPK uptake in grain and straw was calculated by multiplying the corresponding biomass of grain and straw by the corresponding nutrient concentration. The sum of the nutrients absorbed in grain and straw was used to calculate the total NPK uptake in the plant.

RESULTS AND DISCUSSION

Plant height and dry matter accumulation at flowering stage: Different irrigation regimes had no significant effect on plant height at flowering stages during any studied years (2021–22 and 2022–23). However, application of graded N levels at different growth stages results in significant increase in height in both the years (Table 1). Maximum height at flowering was witnessed in soil moisture based irrigation (75.0 cm and 72.5 cm) in both the years, respectively. It might be due to expansion of cells under optimum soil moisture availability at 50% DASM. Also, the increased number of irrigations than conventional irrigation results in enhanced nutrient availability consequently promoting plant growth by augmenting the size and quantity of cells within internodes. These results are consistent with the findings of Moursi *et al.* (2019) and Zafar *et al.* (2020). However, application of 200 kg N/ha documented significantly higher height at flowering (75.2 cm and 76.1 cm), compared to other treatments in both years, respectively. Plant height increased with increased application of N fertilizer because of positive impact of N on nitrogen metabolism, protein synthesis and photosynthesis (Anas *et al.* 2020). We found limited impact on increase in plant height beyond 150 kg/ha of N application. Findings are similar with the studies documented by Kumar *et al.* (2023). However, the interaction effects between different irrigation and graded N application regimes studied were not significant in both the years at different growth stages.

Significant difference in dry matter accumulation at flowering stage was observed with different irrigation and N application regimes during 2021–22 and 2022–23 (Table 1). Similarly, the interaction between different irrigation and graded N application regimes were significant in two years at different stages. Significantly higher accumulation of dry matter at flowering was observed in soil moisture based irrigation (542.6 g/m² and 523.3 g/m²) in both the years, respectively. Increase might result from progressively increase in growth parameters with the decrease in depletion levels and increase in frequency of water applied at 50% DASM compared to conventional irrigation regime. Similar findings were reported by Meena *et al.* (2015). Application of 200 kg N/ha noted significantly greater dry matter accumulation at flowering (561.4 g/m² and 540.8 g/m²), compared to other treatments. N application leads to more tillers with tallest plants and the highest biological output. Similar results were documented by Kumar *et al.* (2023).

Root length and root weight at jointing: Significant effect was observed on root length and root weight with different irrigation and graded N regimes in both the years (Table 1). The interaction effects of different treatments on root length were significant in both years. However, the interaction effect on root weight was found significant in 2021–22 and insignificant in 2022–23 (Table 2). With irrigation regimes, significantly larger root length was observed with soil moisture based irrigation (96.3 cm and 94.2 cm), while the smallest was found with conventional growth stage based irrigation (83.1 cm and 65.2 cm) in both

years, respectively. Root weight also follows the similar trend with maximum value in soil moisture based irrigation (0.48 g and 0.53 g), while the minimum value was found in conventional growth stage based irrigation (0.43 g and 0.47 g) in both the years, respectively. Application of 200 kg N/ha documented significantly larger root length (95.9 cm and 91.0 cm) and root weight (0.50 gm and 0.55 gm) compared to 0 kg N/ha (81.6 cm and 69.7 cm) (0.41 gm and 0.42 gm) in both the years, respectively. Irrigation at 50% DASM resulted in enhanced rates of translocation and photosynthesis with reduced respiration thereby augmented pool of available assimilates for higher root activity. N is directly involved in metabolic activities of plant thereby enhancing plant growth attributes. These results are in accordance with the findings of Moursi *et al.* (2019) and Zafar *et al.* (2020).

Grain yield and straw yield: Significant effect of different irrigation and graded N regimes was observed on grain and straw yield in both years (Table 1). The interaction between irrigation and graded N application studied were significant in both years (Fig. 1 and 2). With irrigation regimes, significantly higher grain yield was observed with soil moisture based irrigation (4.44 t/ha and 4.39 t/ha), while the lowest was found in conventional growth stage based irrigation (3.99 t/ha and 4.13 t/ha) in both years, respectively. Irrigation at 50% DASM resulted in enhanced rates of translocation and photosynthesis with reduced respiration thereby augmented pool of available assimilates for higher grain yield. The results are in accordance with the findings

Table 1 Effect of different irrigation and N regimes on plant height, dry matter accumulation, grain yield, straw yield, root length and root weight of wheat during 2021–22 and 2022–23

Treatment	Plant height at flowering (cm)		Dry matter accumulation at flowering (g/m ²)		Grain yield (t/ha)		Straw yield (t/ha)		Root length at jointing (cm)		Root weight at jointing (g)		Water productivity (kg/ha-mm)	
Year	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23
Irrigation regimes (I)														
I ₁	75.0	72.5	542.6	523.3	4.44	4.39	7.11	7.05	96.3	94.2	0.48	0.53	12.93	13.73
I ₂	72.5	72.3	523.0	505.0	4.11	4.27	6.83	6.88	88.7	88.2	0.44	0.48	11.98	13.38
I ₃	71.5	71.3	513.6	496.3	3.99	4.13	6.75	6.67	83.1	65.2	0.43	0.47	11.61	12.93
SEm (±)	1.45	1.26	0.24	0.22	0.00	0.00	0.02	0.03	0.78	2.04	0.01	0.01	0.01	0.01
CD (P=0.05)	NS	NS	0.94	0.87	0.01	0.01	0.08	0.10	3.05	8.02	0.02	0.04	0.04	0.03
Graded nitrogen levels (N)														
N ₀	70.4	66.0	488.6	473.0	3.30	3.48	5.55	5.50	81.6	69.7	0.41	0.42	9.62	10.89
N ₁	71.7	70.7	504.5	487.9	3.78	3.77	6.12	6.08	84.7	76.6	0.42	0.47	11.01	11.81
N ₂	72.9	72.3	528.1	509.8	4.31	4.48	6.89	6.98	91.3	87.3	0.45	0.48	12.56	14.01
N ₃	74.7	75.1	549.3	529.5	4.73	4.77	7.51	7.38	93.5	88.1	0.47	0.54	13.76	14.92
N ₄	75.2	76.1	561.4	540.8	4.78	4.82	8.43	8.39	95.9	91.0	0.50	0.55	13.91	15.09
SEm (±)	1.17	1.92	0.29	0.27	0.01	0.01	0.04	0.05	1.12	2.69	0.00	0.01	0.02	0.02
CD (P=0.05)	3.42	5.60	0.85	0.79	0.02	0.02	0.11	0.14	3.27	7.87	0.01	0.04	0.05	0.05
I (I X N)	**	**	*	*	*	*	*	*	*	*	*	**	*	*

*, Significant; **, Not significant. Treatment details are given under Materials and Methods.

Table 2 Interaction effects of different irrigation and N regimes on dry matter accumulation, water productivity, root length and root weight of wheat during 2021–22 and 2022–23

Treatment	Dry matter accumulation at flowering (g/m ²)		Root length at jointing (cm)		Root weight at jointing (g)		Water productivity (kg/ha-mm)	
Year	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23
I ₁ N ₀	499.0	482.8	90.7	92.6	0.46	0.49	9.92	11.14
I ₁ N ₁	510.5	493.4	85.4	78.2	0.43	0.48	12.70	12.10
I ₁ N ₂	547.4	527.7	97.8	91.7	0.47	0.53	13.38	14.43
I ₁ N ₃	572.0	550.6	101.1	111.7	0.50	0.57	14.25	15.41
I ₁ N ₄	584.2	561.9	106.5	96.8	0.52	0.58	14.38	15.58
I ₂ N ₀	486.7	471.3	76.8	63.8	0.44	0.41	9.38	11.08
I ₂ N ₁	497.4	481.2	83.5	81.8	0.39	0.50	10.55	11.94
I ₂ N ₂	529.0	510.6	93.4	107.3	0.44	0.45	12.32	13.91
I ₂ N ₃	548.7	528.9	92.7	84.4	0.47	0.52	13.76	14.90
I ₂ N ₄	553.0	533.0	97.3	103.8	0.49	0.53	13.88	15.07
I ₃ N ₀	480.0	465.1	77.2	52.7	0.33	0.36	9.56	10.46
I ₃ N ₁	505.7	489.0	85.1	69.7	0.45	0.43	9.78	11.37
I ₃ N ₂	507.9	491.0	82.7	63.1	0.44	0.46	11.99	13.70
I ₃ N ₃	527.3	509.1	86.7	68.2	0.45	0.52	13.28	14.46
I ₃ N ₄	547.1	527.5	83.9	72.2	0.48	0.56	13.46	14.63
SEm(±)	0.50	0.47	1.94	4.67	0.00	0.02	0.03	0.03
CD (P=0.05)	1.47	1.37	5.66	13.62	0.02	NS	0.09	0.09

Treatment details are given under Materials and Methods.

of Moursi *et al.* (2019) and Zafar *et al.* (2020). Significantly more grain yield was obtained with 50% DASM over the 4 irrigations at most sensitive critical crop growth stages (conventional irrigation practices), which is still practiced by majority of wheat growers in India as reported by Meena *et al.* (2015). Application of 200 kg N/ha documented significantly greater grain yield (4.78 t/ha and 4.82 t/ha), compared to 0 kg N/ha (3.30 t/ha and 3.48 t/ha) in both the years, respectively. N is directly involved in metabolic activities of plant thereby enhancing yield. Kumar *et al.* (2023) reported similar results of enhanced yield up to 150 kg/ha of N application, thereafter higher N application leads to minimal increase in yield.

With irrigation regimes significantly higher straw yield was observed in soil moisture based irrigation (7.11 t/ha and 7.05 t/ha), while the lowest was found in conventional growth stage based irrigation (6.75 t/ha and 6.67 t/ha) in both the years, respectively. It may be attributed to augmentation of irrigation water, thereby enhancing growth attributes and components of

yield like tiller numbers. Similar findings were reported by Moursi *et al.* (2019). Application of 200 kg N/ha recorded significantly higher straw yield (8.43 t/ha and 8.39 t/ha), compared to 0 kg N/ha (5.55 t/ha and 5.50 t/ha) in both the years, respectively. Straw yield and other indicator found highest at 150 kg N/ha as also reported by Kumar *et al.* (2023) and Gawdiya *et al.* (2023).

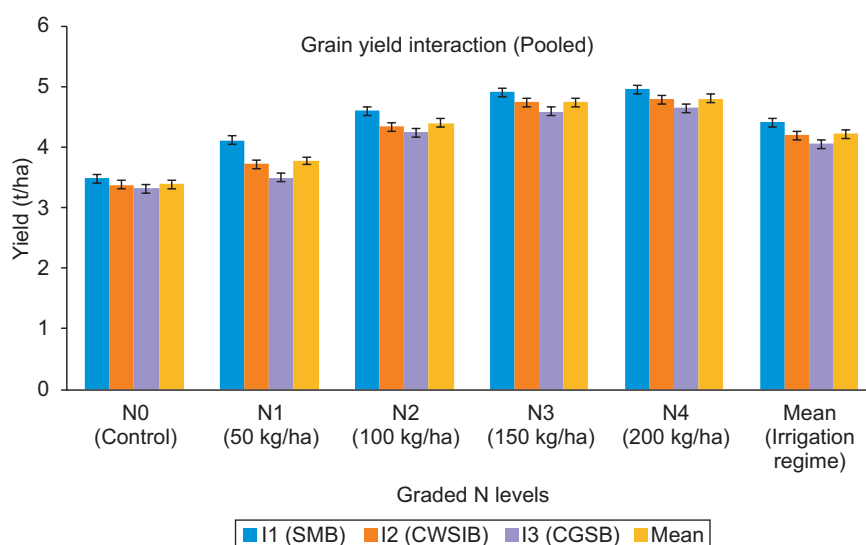


Fig. 1 Interaction effects of different irrigation and N regimes on grain yield of wheat during 2021–22 and 2022–23.

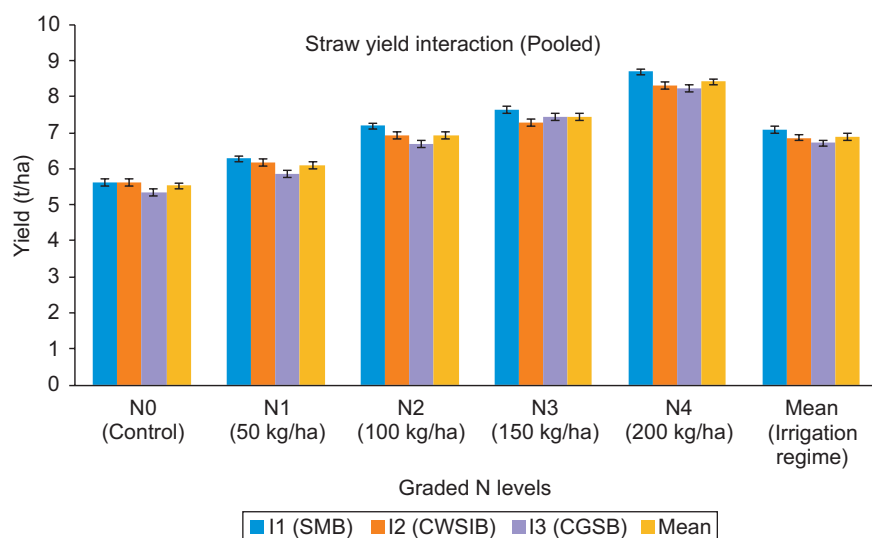


Fig. 2 Interaction effects of different irrigation and N regimes on straw yield of wheat during 2021–22 and 2022–23.

Water productivity: Significant difference in water productivity was observed with different irrigation and graded N application regimes during both the years (Table 1). The interaction effect between irrigation regimes and graded N application studied were significant in both the years (Table 2). Significantly higher water productivity was observed with soil moisture based irrigation (12.93 kg/ha-mm and 13.73 kg/ha-mm), while lowest was found in conventional growth stage based irrigation

(11.61 kg/ha-mm and 12.93 kg/ha-mm) in both the years, respectively. Generally, higher water productivity in soil moisture based irrigation compared to conventional stage/time based irrigation was due to optimum amount of water consumptive use and reduction of water losses at 50% maximum allowable depletion (MAD). Application of 200 kg N/ha recorded significantly higher water productivity (13.91 kg/ha-mm and 15.09 kg/ha-mm), compared to 0 kg N/ha (9.62 kg/ha-mm and 10.89 kg/ha-mm) in both the years, respectively. The average water productivity (14.50 kg/ha-mm), also follows the similar trend. These results are consistent with the findings of Moursi *et al.* (2019) and Zafar *et al.* (2020).

Nutrient uptake: The data on NPK uptake by wheat grain and straw as affected by different irrigation and graded N application regimes was estimated (Table 3). During both the study years, significantly higher grain N uptake was observed with soil moisture based irrigation (79.28–81.64 kg/ha) with application of 200 kg N/ha (91.72–93.08 kg/ha). Significantly higher grain P and K uptake was observed with higher N application of 150 and 200 kg N/ha. Higher N application of 200 kg N/ha results in

Table 3 Effect of different irrigation and N regimes on grain and straw NPK uptake at harvest in wheat during 2021–22 and 2022–23

Treatment	Grain NPK uptake (kg/ha)						Straw NPK uptake (kg/ha)					
	N		P		K		N		P		K	
Year	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23
Irrigation regimes (I)												
I ₁	81.64	79.28	13.75	12.93	15.31	13.62	33.18	33.91	1.88	1.92	111.40	111.10
I ₂	72.60	74.40	12.91	12.73	14.44	13.42	33.01	33.21	1.85	1.75	90.08	91.33
I ₃	67.54	69.23	13.14	12.74	14.65	13.59	30.87	30.54	1.72	1.72	94.00	93.61
SEm(±)	1.40	1.74	0.31	0.28	0.33	0.38	1.36	1.71	0.25	0.23	3.41	2.99
CD (P=0.05)	5.48	6.84	NS	NS	NS	NS	NS	NS	NS	NS	13.40	11.75
Graded nitrogen levels (N)												
N ₀	51.89	54.06	10.29	10.68	11.61	10.99	19.96	19.46	1.34	1.38	80.93	82.57
N ₁	62.11	62.28	12.41	11.45	13.35	12.13	25.38	25.52	1.81	1.77	86.37	86.98
N ₂	74.96	76.93	14.00	13.87	15.22	14.36	31.96	32.56	2.07	1.98	95.10	94.50
N ₃	87.58	86.52	15.46	13.76	16.93	15.21	40.64	39.73	1.84	1.79	103.43	103.05
N ₄	93.08	91.72	14.18	14.24	16.89	15.03	43.83	45.48	2.03	2.06	126.64	126.29
SEm(±)	0.84	1.18	0.51	0.34	0.27	0.36	0.71	0.74	0.20	0.19	4.98	5.08
CD (P=0.05)	2.46	3.43	1.49	1.00	0.79	1.05	2.07	2.16	NS	NS	14.53	14.83
I (I × N)	**	**	**	**	**	**	**	**	**	**	**	**

**, Not significant. Treatment details are given under Materials and Methods.

enhanced uptake of N by wheat straw (43.83–45.48 kg/ha). Significantly higher straw K uptake was observed in soil moisture based irrigation (111.10–111.40 kg/ha) with application of 200 kg N/ha. Higher water availability in root zone increased the nutrient solubility which helped roots to absorb it and translocate to the plants. Increased application of N leads to increase N absorption. This could be because of ample amount N available to boost N mobilization to the grain during the grain-filling stage as reported by Kumar *et al.* (2023) and Gawdiya *et al.* (2023). However, the interaction effects between irrigation regimes and graded N application studied were not significant during both the years.

Based on the 2-years study it can be concluded that 50% DASM based irrigation significantly increased grain yield (11.28 and 6.30%), straw yield (5.33 and 5.70%), dry matter accumulation (5.65 and 5.44%), water productivity (11.37 and 6.19%), root length (15.89 and 44.48 %), root weight (11.63 and 12.77%) and grain N uptake (20.88 and 14.52%) compared to conventional crop stage based irrigation during 2021–22 and 2022–23, respectively. Among the graded N application, maximum grain yield (4.78 and 4.82 t/ha) and crop water productivity (13.91 and 15.09 kg/ha-mm) were recorded with treatment N₄ (200 kg N/ha), but remained statistically at par with N₃ (150 kg N/ha) due to the marginal increment beyond 150 kg N/ha. It can be concluded that soil moisture based irrigation at 50% DASM with 150 kg/ha N application proved to be most effective and economical approach to enhance water productivity, yield and dry matter accumulation with saving from harmful environmental effects arising from excessive nitrogen use.

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