E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(9): 794-799
Received: 28-07-2025
Accepted: 30-08-2025

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Influence of hydrogel and nutrient management on wheat (*Triticum aestivum* L.) growth and development under limited irrigation conditions

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DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i9k.3859

Abstract
A field experiment was conducted during the *Rabi* seasons of 2021-22 and 2022-23 at Department of Agronomy, R.B.S. College Bichpuri, Agra. The variable involved in this study were four levels of irrigation *viz.* I_0 (no irrigation), I_1 (a single irrigation at the CRI stage), I_2 (irrigation twice at the CRI and boot leaf stages), and I_3 (irrigation three times at the CRI, booting leaf, and milking stages) and six hydrogel and nutrient management levels *viz.* HNM_1 (75% NPK without hydrogel), HNM_2 (75% NPK with hydrogel @ 2.5 kg/ha), HNM_3 (75% NPK with hydrogel @ 5.0 kg/ha), HNM_4 (100% NPK without hydrogel), HNM_5 (100% NPK with hydrogel @ 2.5 kg/ha), and HNM_6 (100% NPK with hydrogel @ 5.0 kg/ha). Thus, in all 24 treatment combinations were compared in a "split plot design" having stage of irrigation in main plots and hydrogel and nutrient management levels in sub-plots with three replications. The results revealed that three irrigations I_3 (CRI, booting leaf, and milking stages) with treatment HNM_6 (100% NPK with hydrogel @ 5.0 kg/ha), significantly improved wheat growth and development under limited water conditions.

Keywords: Crop growth rate, irrigation, hydrogel, NPK, relative growth rate and wheat

Introduction
Wheat (*Triticum aestivum* L.) is the most important staple food crop of the world and emerged as the backbone of India's food security. It is grown all over the world for its wider adaptability and high nutritive value. (Singh *et al.*, (2025) [10]. Among food grains wheat is the richest source of protein and it stands at second place after pulses. In general wheat contains carbohydrate (70%), protein (12%), lipid (2%), vitamins & minerals (2% each) and crude (Archna *et al.*, 2023) [1]. In India, wheat is the second most important cereal crop after rice covering an area of 34.15 million hectares. Total annual production of wheat in India is 113.29 million tonnes with the productivity of 3.61 tonnes per hectare during 2023-24. India witnessed an all-time high wheat production during the year 2023-24. (Kumar *et al.*, 2025) [3, 6].
Wheat require appreciable amount of water on its different physiological stages of crop growth and development to expose higher potentials of yield of super quality. In wheat, irrigation scheduling is followed depending on the availability of water. Considerable area (86%) sown under wheat has an access to irrigation, however, crop sown in about 14-15 per cent of the area, which amounts approximately to 4 million hectares, depends on rain. (Kumar *et al.*, 2019) [2]. The limited availability of water resources in arid and semi-arid regions poses a significant challenge to sustainable agriculture. (Kumar *et al*., 2025) [3, 6]. Drought stress projected to cause up to a 30% reduction in global crop production by 2025. (Singh *et al*., 2024) [13, 14]. Studies suggest that six irrigations at CRI, tillering, jointing, booting, milking, and grain formation ensure better yield, while four irrigations at CRI, maximum tillering, boot, and milking stages promote taller plants, more tillers, higher dry matter accumulation, better leaf area index, and improved growth rates compared to fewer irrigations (Shivani *et al.*, 2003) [9]. Hydrogel are water-absorbing polymers that swell many times their size and act as water retention granules in agriculture. They improve soil water-holding capacity, enhance soil properties, and increase irrigation efficiency, especially in arid and semi-arid regions.

Their effectiveness depends on chemical properties like molecular weight. By providing better soil moisture and root growth conditions, hydrogels ultimately improve crop growth, water productivity, and yield.

Materials and Methods

The field experiment was carried out during *Rabi* season of 2021-22 and 2022-23 at Agricultural Research Farm, Department of Agronomy, R.B.S. College, Bichpuri, Agra (U.P.). The research farm is situated at about 11 km to the west of Agra on Agra-Bharatpur Road at latitude of 27º 02' N and longitude of 77º 09' E with an elevation of 163.4 m above the mean sea level. This region falls under south-western semi-arid zone of Uttar Pradesh. It was found that the total winter rainfall during the crop season amounted to 62.89 mm in 2021-22 and 108.3 mm in 2022-23. The variables involved in this study were four different irrigation levels as the primary plot treatments: I_0 (no irrigation), I_1 (a single irrigation at the CRI stage), I_2 (irrigation twice at the CRI and boot leaf stages), and I_3 (irrigation three times at the CRI, booting leaf, and milking stages) and six hydrogel and nutrient management levels were used as sub plot treatments *viz*. HNM_1 (75% NPK without hydrogel), HNM_2 (75% NPK with hydrogel @ 2.5 kg/ha), HNM_3 (75% NPK with hydrogel @ 5.0 kg/ha), HNM_4 (100% NPK without hydrogel), HNM_5 (100% NPK with hydrogel @ 2.5 kg/ha), and HNM_6 (100% NPK with hydrogel @ 5.0 kg/ha) thus, in all 24 treatment combinations were compared in a "split plot design" with three replications. Application of fertilizers, nitrogen, phosphorus, and potassium fertilizers were administered as urea, DAP, and muriate of potash at the rates of 150, 60, and 40 kg/ha, respectively. The entire amount of phosphorus and potassium, along with half of the nitrogen, was applied during sowing, while the remaining nitrogen was added after the first irrigation. In order to determine the effects of different treatments, following studies were conducted. Growth studies: Number of tillers/m row length, Plant height, Dry matter accumulation (g), Leaf area index (LAI), Crop growth rate (g/m2/day) and Relative growth rate (g/g/day).

Leaf area index (LAI)

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Ground area}}$$

Crop growth rate (g/m2/day)

$$\text{Crop growth rate (g/m2/day)} = \frac{W2 - W1}{t2 - t1}$$

Relative growth rate (g/g/day)

$$\text{Relative growth rate (g /g /day)} = \frac{(\log_e W2 - \log_e W1)}{t2 - t1}$$

Results and Discussion

Effect of irrigation levels on growth parameters.

The number of tillers per meter row length of wheat varied significantly under different irrigation levels during 2021-22, 2022-23, and pooled data (Table 1). During both the years (2021-22 and 2022-23), the maximum number of tillers was recorded four irrigations (I_3: 96.94 and 96.72, respectively), which remained statistically at par with three irrigations (I_2: 96.00 and 95.57, respectively). Both irrigation levels I_3 and I_2 were significantly superior to irrigation level I_1 (90.06 and 90.59) and the minimum tiller count recorded no irrigation I_0 (81.27 and 81.90). The pooled analysis further confirmed this finding, with the highest tiller density (96.83) obtained irrigation level I_3, which was statistically at par with irrigation level I_2 (95.78). The results revealed that the number of tillers per meter row length increased with successive irrigation levels and reached the maximum irrigation level I_3, which remained statistically at par with I_2, while both were significantly superior to irrigation levels I_1 and I_0. These findings corroborate the results of Kumar *et al*. (2019) [2] and Singh *et al.,* (2024) [13, 14],

During both the years (2021-22 and 2022-23), wheat plant height was maximum under four irrigations (I_3: 117.14 cm and 117.66 cm, respectively), which remained statistically at par with three irrigations (I_2: 116.88 cm and 117.36 cm, respectively). Both irrigation levels I_3 and I_2 were significantly superior to I_1 (112.81 cm and 113.10 cm), while the minimum plant height was recorded no irrigation I_0 (108.69 cm and 109.02 cm).The pooled data also confirmed this response, with irrigation level I_3 producing the maximum plant height (117.40 cm), statistically at par with I_2 (117.12 cm), while both were significantly superior to I_1 (112.96 cm). The minimum height was obtained irrigation level I_0 (108.86 cm). Thus, the increase in plant height irrigation level I_3 compared with no irrigation I_0 was about 8% in the pooled result, demonstrating the positive effect of irrigation on vegetative growth. This indicates that adequate water availability at critical stages of wheat growth ensured optimal cell elongation and vegetative development. Similar findings have also been reported by Kumar *et al.,* (2019) [2], Singh *et al.,* (2024) [13, 14] and Singh *et al.* (2024) [13, 14],

Dry matter accumulation per plant was significantly influenced by irrigation levels during both years as well as in the pooled mean. During both the years (2021-22 and 2022-23 and pooled), the maximum dry matter accumulation in wheat was recorded under four irrigations (I_3: 97.85 g/plant, 97.91 g/plant and 97.88 g/plant, respectively), which remained statistically at par with three irrigations (I_2: 97.18 g/plant, 97.41 g/plant and 97.88 g/plant). Both irrigation levels I_3 and I_2 were significantly superior to I_1 (93.10 g/plant and 93.28 g/plant), while the minimum dry matter was consistently observed no irrigation I_0 (88.14 g/plant and 88.26 g/plant). These two treatments were significantly superior to irrigation level I_1 (93.19 g/plant) and the lowest with no irrigation I_0 (88.20 g/plant). Adequate water availability in irrigation levels I_2 and I_3 ensured continuous photosynthetic activity, better assimilate partitioning, and enhanced vegetative and reproductive growth, thereby leading to higher dry matter accumulation. Similar findings were also reported by Kumar *et al.* (2019) [2], Lokendra *et al.,* (2024) [7] and Verma *et al., (*2025) [17].

Leaf area index (LAI) of wheat at harvest was significantly affected by irrigation levels during both years of study as well as in the pooled analysis (Table 1). In 2021-22, the maximum LAI (4.58) was recorded under four irrigations (I_3), which was statistically at par with three irrigations (I_2: 4.50). Both treatments were significantly superior to two irrigations (I_1: 4.27), while the lowest was observed no irrigation (I_0: 3.96). In 2022-23, a similar result was observed, with irrigation level I_3 the highest LAI (4.59), statistically at par with irrigation level I_2 (4.54). Both were significantly higher than irrigation level I_1 (4.34), whereas I_0 again produced the lowest LAI (4.01). The pooled data followed the, with the maximum LAI (4.59) irrigation levels I_3, statistically comparable with irrigation level

I_2 (4.52). Both these treatments were significantly superior to irrigation level I_1 (4.31), while the minimum LAI (3.98) was recorded irrigation levels I_0. The results demonstrate that higher irrigation levels supported greater leaf area development, which in turn enhanced photosynthetic surface area. Adequate moisture availability irrigation levels I_2 and I_3 ensured better leaf expansion and sustained canopy growth, resulting in higher LAI. These findings align with those reported by Singh *et al.,* (2023) [11], Singh *et al.,* (2024) [13, 14] and Kumar *et al.,* (2025) [3, 6].

Effect of Hydrogel + Nutrient Management on growth parameters.

The number of tillers per meter row length of wheat was significantly influenced by hydrogel in combination with nutrient management during both years of study as well as in the pooled analysis (Table 1). During both the years (2021-22 and 2022-23), the maximum number of tillers per meter row length (94.78 and 94.28) was recorded with treatment HNM_6, which remained statistically at par with HNM_5 (92.38 and 92.42, respectively) but significantly superior to HNM_4 (91.25 and 91.39), HNM_3 (90.89 and 91.00), and HNM_2 (89.72 and 89.96). The minimum tiller count was observed under treatment HNM_1 (87.38 and 87.62, respectively).The pooled data also confirmed this response, with the maximum tiller count (94.78) with treatment HNM_6, which was statistically at par with treatment HNM_5 (92.40). Both these treatments were significantly superior to treatments HNM_4 (91.32), HNM_3 (90.95), and HNM_2 (89.84), while the lowest number of tillers was recorded in HNM_1 (87.50). The improvement in tiller number treatment HNM_6 compared with HNM_1 was about 8% in the pooled data. The consistent superiority of treatments HNM_6 and HNM_5 indicates that higher levels of hydrogel application with balanced nutrient management ensured better soil moisture retention and nutrient supply, which promoted tiller initiation and survival.

Table 1: Different growth parameters of wheat at harvest stage as influenced by irrigation levels and hydrogel with nutrient management

Treatments	Number of tillers/m row length			Plant height (cm)			Dry matter accumulation (g/plant)			Leaf area index (%)		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Irrigation level												
I_0	81.27	81.90	81.58	108.69	109.02	108.86	88.14	88.26	88.20	3.96	4.01	3.98
I_1	90.06	90.59	90.33	112.81	113.10	112.96	93.10	93.28	93.19	4.27	4.34	4.31
I_2	96.00	95.57	95.78	116.88	117.36	117.12	97.18	97.41	97.30	4.50	4.54	4.52
I_3	96.94	96.72	96.83	117.14	117.66	117.40	97.85	97.91	97.88	4.58	4.59	4.59
SEm±	2.152	2.210	1.428	2.11	1.87	1.31	1.88	2.16	1.33	0.068	0.073	0.046
CD (P = 0.05)	7.447	7.647	4.400	7.31	6.47	4.03	6.52	7.47	4.09	0.234	0.254	0.142
Hydrogel+Nutrient management												
HNM_1	87.38	87.62	87.50	106.59	107.10	106.85	88.01	88.19	88.10	3.98	4.05	4.02
HNM_2	89.72	89.96	89.84	112.66	113.16	112.91	93.16	93.25	93.21	4.16	4.21	4.19
HNM_3	90.89	91.00	90.95	114.05	114.89	114.47	93.68	93.75	93.72	4.19	4.24	4.22
HNM_4	91.25	91.39	91.32	115.49	115.92	115.71	93.92	94.10	94.01	4.45	4.48	4.47
HNM_5	92.38	92.42	92.40	117.19	117.25	117.22	97.49	97.69	97.59	4.56	4.59	4.58
HNM_6	94.78	94.26	94.52	117.32	117.39	117.36	98.15	98.31	98.23	4.63	4.66	4.65
SEm±	1.787	1.769	1.455	1.70	2.07	1.49	1.40	1.50	1.23	0.080	0.080	0.061
CD (P = 0.05)	5.108	5.056	4.094	4.84	5.90	4.20	4.00	4.30	3.47	0.229	0.228	0.172

Plant height of wheat was significantly influenced by hydrogel with nutrient management during both years and in the pooled analysis. During both years 2021-22 and 2022-23, the maximum plant height at harvest stage (117.32 cm and 117.39 cm) was recorded in treatment HNM_6, which was statistically at par with HNM_5 (117.19 cm and 117.25 cm) but significantly superior to treatments HNM_4 (115.49 cm and 115.92 cm), HNM_3 (114.05 cm and 114.89 cm), and HNM_2 (112.66 cm and 113.16 cm). The minimum plant height was observed in treatment HNM_1 (106.59 cm and 107.10 cm). The pooled data followed the similar result, with maximum plant height (117.36 cm) with treatment HNM_6, statistically at par with treatment HNM_5 (117.22 cm). The improvement in plant height treatments HNM_6 over HNM_1 was about 10%. This shows that higher hydrogel and nutrient inputs ensured better water retention and nutrient uptake, resulting in taller plants, while lower inputs restricted vegetative growth.

Dry matter accumulation per plant was also significantly affected by hydrogel with nutrient management. During both the years 2021-22 and 2022-23, the highest dry matter (98.15 g/plant and 98.31 g/plant) was recorded in application of HNM_6, statistically at par with treatment HNM_5 (97.49 g/plant and 97.69 g/plant) but significantly greater than treatments HNM_4 (93.92 g/plant and 94.10 g/plant), HNM_3 (93.68 g/plant and 93.75 g/plant), and HNM_2 (93.16 g/plant and 93.25 g/plant). The lowest dry matter accumulation was in treatment HNM_1 (88.01 g/plant and 88.19 g/plant). The pooled results confirmed, with the maximum dry matter accumulation (98.23 g/plant) treatment HNM_6, which was statistically at par with treatment HNM_5 (97.59 g/plant). Both were significantly superior to treatments HNM_4 (94.01 g/plant), HNM_3 (93.72 g/plant), and HNM_2 (93.21 g/plant), while treatment HNM_1 (88.10 g/plant) remained the lowest dry matter. The increase dry matter with treatment HNM_6 compared to treatment HNM_1 was about 11%. Similar observations were made by Verma *et al.,* (2025) [17], who noted that integrated nutrient management combined with hydrogel application promoted higher dry matter production.

Leaf area index was significantly influenced by hydrogel and nutrient management across both years and in the pooled data (at harvest). During both the years 2021-22 and 2022-23, the highest Leaf area index (at harvest) 4.63 and 4.66 was observed in application HNM_6, statistically at par with application of HNM_5 (4.56 and 4.59) but significantly superior to HNM_4 (4.45 and 4.48), HNM_3 (4.19 and 4.22), and HNM_2 (4.16 and 4.19). The minimum LAI was recorded under HNM_1 (3.98 and 4.05). The pooled data also showed that the highest LAI (4.65) was obtained under HNM_6, statistically comparable with application of HNM_5 (4.58). Both these treatments were significantly higher than applications of HNM_4 (4.47), HNM_3 (4.22), and HNM_2 (4.19), while HNM_1 (4.02) recorded the minimum. The increase in LAI from application in HNM_1 to HNM_6 was about 16%, indicating that higher hydrogel application maintained leaf expansion and canopy growth, These findings align with those reported by Singh *et al.,* (2023) [11], Lokendra *et al.,* 2024 [7] and Singh *et al*. (2024) [13, 14]

Crop Growth Rate (CGR)

Effect of Irrigation levels

Table 2: Effect of Irrigation levels and hydrogel with nutrient management on crop growth rate (CGR) at 30- 60, 60-90, 90-120 DAS and 120 DAS to harvest stage of wheat

	Crop growth rate (g/m²/day)											
	30-60 DAS			60-90 DAS			90-120 DAS			120 DAS to harvest		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Irrigation levels												
I_0	0.43	0.44	0.43	0.97	0.98	0.97	1.23	1.24	1.23	0.137	0.129	0.133
I_1	0.47	0.47	0.47	1.07	1.07	1.07	1.25	1.26	1.26	0.132	0.122	0.127
I_2	0.50	0.50	0.50	1.14	1.15	1.15	1.28	1.28	1.28	0.126	0.130	0.128
I_3	0.50	0.51	0.51	1.18	1.19	1.18	1.25	1.24	1.24	0.139	0.134	0.136
SEm±	0.009	0.009	0.006	0.016	0.016	0.010	0.025	0.021	0.015	0.003	0.003	0.002
CD (P = 0.05)	0.030	0.032	0.018	0.054	0.054	0.031	0.086	0.074	0.047	0.010	0.010	0.006
Hydroge +Nutrient management												
HNM_1	0.44	0.45	0.44	0.97	0.98	0.97	1.23	1.24	1.23	0.130	0.123	0.127
HNM_2	0.46	0.47	0.46	1.08	1.08	1.08	1.25	1.26	1.26	0.135	0.119	0.127
HNM_3	0.46	0.47	0.47	1.09	1.08	1.09	1.25	1.25	1.25	0.134	0.131	0.133
HNM_4	0.46	0.47	0.47	1.10	1.09	1.10	1.25	1.24	1.25	0.134	0.135	0.134
HNM_5	0.51	0.51	0.51	1.14	1.15	1.14	1.28	1.28	1.28	0.134	0.130	0.132
HNM_6	0.51	0.52	0.52	1.17	1.18	1.18	1.26	1.25	1.25	0.133	0.134	0.134
SEm±	0.008	0.009	0.007	0.017	0.017	0.013	0.026	0.022	0.019	0.003	0.003	0.002
CD (P = 0.05)	0.024	0.026	0.019	0.048	0.049	0.037	0.075	0.063	0.053	0.009	0.009	0.007

The effect of irrigation levels on crop growth rate were significant effect was noticed at 30-60, 60-90, 90-120 DAS and 120 DAS-at harvest during both year. Among the irrigation levels maximum crop growth rate (0.50, 0.51 and 1.18, 1.19 and 1.25, 1.24 and 0.139, 0.134 g/m²/day at 30-60, 60-90, 90-120 DAS and 120 DAS-at harvest respectively were observed in I_3 (Three irrigations, CRI + BL+ M). At 30-60 DAS crop growth rate recorded under treatment I_3 as at par with I_2 (two irrigation at crown root initiation + boot leaf) and significantly higher than the remaining treatment over both years. At 60-90 DAS treatment I_3 was at par with I_2 during 2021-22 and 2022-23. At 90-120 DAS and at harvest I_3 being at par with I_2 over both years was significantly superior over the remaining treatment. Minimum crop growth rate (0.43, 0.44 and 0.97, 0.98 and 1.23, 1.24 and 0.137, 0.129 g/m2/day at 30-60, 60-90, 90-120 and 120 DAS-at harvest) were found in no irrigation (I_0) throughout till maturity. Wheat crop growth rate was highest with three irrigations (CRI + Boot Leaf + Milking) followed by two irrigations, while the lowest was in no irrigation. Thus, 2-3 irrigations at critical stages are essential for better crop growth and yield. The increase in the crop growth rate (CGR) can be linked to the abundant availability of moisture., which enhanced nutrient uptake, resulting in fully turgid leaves and a greater number of larger green leaves, thereby increasing the leaf area index (LAI). These findings align with the research of Saren *et al.* (2004) [8], Kumar *et al.* (2012) [4], Vishuddha *et al.* (2014) [18], and Kumar *et al.* (2015) [5], who also observed peak growth indices during their studies.

Hydrogel +Nutrient management

The data summarized in Table 2 revealed that the application of hydrogel with nutrient management on crop growth rate was significant effect was noticed at 30-60, 60-90, 90-120 DAS and 120 DAS-at harvest stage over both years. Among the hydrogel levels maximum crop growth rate were observed in HNM_6 (100% NPK with 5.0 kg ha^{-1} hydrogel). Which significant effect was noticed at 30-60, 60-90, 90-120 DAS and 120 DAS at harvest stage. Among the hydrogel levels maximum crop growth rate (0.51, 0.52 and 1.17, 118, 1.26, 1.25 and 0.133, 0.134 g/m²/day at 30-60, 60-90, 90-120 DAS and 120 DAS at harvest) were observed in HNM_6 (100% NPK with 5.0 kg ha^{-1} hydrogel), respectively. At 30-60 DAS crop growth rate recorded in treatment HNM_6 as at par with HNM_5 (100% NPK with 2.5 kg ha^{-1} hydrogel) and significantly higher than the remaining treatment over both years. At 60-90 DAS treatment HNM_6 was at par with HNM_5 during 2021-22 and 2022-23. At 120 DAS and 90-120 DAS and 120 DAS- at harvest, the treatment HNM6 being at par with HNM5 over both years, was significantly superior over the remaining treatment. Minimum crop growth rate (0.44, 0.45 and 0.97, 0.98 and 1.23, 1.24 and 0.130, 0.123 g/m2/day at 30-60, 60-90, 90-120 DAS and 120 DAS at harvest) were found in HNM_1 (75% NPK without hydrogel), respectively over both years of investigation. The use of 100% NPK combined with hydrogel @ 5.0 kg/ha. The use of 100% NPK along with 2.5 kg/ha of hydrogel notably boosted growth indices, especially CGR. Consequently, the enhanced photosynthetic activity per unit area and increased dry matter production contributed to the rise in growth indices like CGR. These findings align with the research of Saren *et al.* (2004) [8], Kumar *et al.* (2012) [4], Vishuddha *et al.* (2014) [18], and Kumar *et al.* (2015) [5], who also observed the highest growth indices during their experiments.

Relative Growth Rate (RGR)

Effect of Irrigation levels

The perusal of data (Table 3) revealed that the variation in relative growth rate at 30-60 DAS and 60-90 DAS, 90-120 DAS and 120 DAS and at harvest were not influenced significantly by irrigation levels over both years. Decline in relative growth rate higher in irrigation levels may be attributed to increased dry matter accumulation, which reduced relative growth rate when expressed per unit biomass. During the final phase, 120 DAS to harvest, Relative growth rate declined sharply across treatments. Similar result was observed in both experimental years, but differences among irrigation levels were not statistically significant. The results showed that while irrigation levels influenced the relative growth rate across growth stages, the differences were not statistically significant. Relative growth rate was higher irrigation levels I_2 and I_3 in the early stages (30-90 DAS), reflecting better moisture availability supporting active growth. In contrast, relative growth rate higher at later stages (90 DAS onwards) were noted under lower irrigation

levels, largely due to lower accumulated biomass in those treatments. Similar results were also reported by Singh, *et al.*, (2020) [15], Singh *et al*., (2022) [12] and Singh, *et al.*, (2025) [3, 6].

Table 3: Effect of Irrigation levels and hydrogel with nutrient management on relative growth rate (RGR) at 30-60, 60-90, 90-120 and 120 DAS and at harvest stage of wheat

	Relative growth rate (mg/g/day)											
	30-60 DAS			60-90 DAS			90-120 DAS			120 DAS to harvest		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Irrigation levels												
I_0	41.30	41.47	41.38	32.06	31.71	31.88	19.30	19.32	19.31	1.590	1.496	1.543
I_1	42.29	42.41	42.35	32.52	32.20	32.36	18.24	18.29	18.26	1.454	1.333	1.393
I_2	42.90	42.54	42.72	32.61	32.64	32.63	17.73	17.61	17.67	1.325	1.366	1.345
I_3	43.04	43.12	43.08	32.97	32.78	32.88	17.10	16.78	16.94	1.452	1.395	1.423
SEm±	0.750	0.715	0.480	0.682	0.720	0.459	0.347	0.382	0.239	0.024	0.024	0.016
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Hydrogel +Nutrient management												
HNM_1	42.57	42.43	42.50	31.88	31.84	31.86	19.29	19.30	19.30	1.514	1.430	1.472
HNM_2	42.15	42.02	42.09	32.74	32.58	32.66	18.24	18.33	18.28	1.489	1.299	1.394
HNM_3	41.95	42.27	42.11	32.84	32.40	32.62	18.12	18.06	18.09	1.469	1.433	1.451
HNM_4	41.06	41.39	41.22	32.89	32.44	32.66	18.05	17.88	17.96	1.458	1.468	1.463
HNM_5	43.24	42.96	43.10	32.21	32.23	32.22	17.66	17.52	17.59	1.411	1.360	1.385
HNM_6	43.30	43.24	43.27	32.69	32.52	32.60	17.19	16.91	17.05	1.390	1.393	1.392
SEm±	0.875	0.840	0.655	0.519	0.420	0.408	0.498	0.500	0.407	0.040	0.040	0.032
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Relative growth rate of wheat was not significantly influenced by hydrogel application with nutrient management at any of the observed stages during both years or in the pooled analysis, although differences were evident (Table 3). The higher relative growth rate application with HNM_1 and HNM_2 may be attributed to relatively lower dry matter accumulation compared with higher hydrogel treatments, which resulted in higher relative rates when expressed per unit biomass. At the final stage, 120 DAS to harvest, relative growth rate were very low across treatments, reflecting physiological maturity. The maximum pooled relative growth rate was observed application with HNM_1 (1.472 mg/g/day), followed by application of HNM_3 (1.451 mg/g/day) and HNM_4 (1.463 mg/g/day). Lower relative growth rate were recorded application with HNM_2 (1.394 mg/g/day), HNM_6 (1.392 mg/g/day), and HNM_5 (1.385 mg/g/day). Similar results were seen in both years, though differences remained non-significant. The results show that relative growth rate gradually declined with crop age across all treatments, irrespective of hydrogel application. While treatments with HNM_5 and HNM_6 to support higher relative growth rate during early stages (30-60 DAS), the later phases showed relatively higher values under lower hydrogel levels due to smaller biomass accumulation. Similar results were also reported by Singh, *et al.*, (2020) [15].

Conclusion

The results showed that three irrigations I_3 (CRI, booting leaf, and milking stages) with Hydrogel+Nutrient management (HNM_6: 100% NPK with hydrogel @ 5.0 kg/ha), significantly improved wheat growth and development under limited water conditions. This integrated approach enhanced tiller density, plant height, dry matter accumulation, and crop growth rate, making it the most effective practice for sustaining wheat yield in semi-arid regions.

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