



RESEARCH ARTICLE

Hydrogel-mediated effects on nutrient content and NPK uptake in barley (*Hordeum vulgare* L.) under varying fertiliser and irrigation regimes

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Abstract

A field experiment was carried out during the rabi seasons of 2023–24 and 2024–25 at the research farm, Mandawa, Jhunjhunu district, Rajasthan, to study the effect of irrigation levels and hydrogel application under different fertiliser doses on the nutrient uptake and protein content of barley (cv. RD-2035). The experiment was conducted in a split-plot design (SPD) with combinations of 9 treatments and 3 replications. The main plot consisted of 3 irrigation levels (1, 2 and 3 irrigations), while the subplots included 6 hydrogel nutrient treatments (100, 70 and 50 % nitrogen, phosphorous, potassium (NPK) with and without hydrogel at 2.5 kg ha⁻¹). Hydrogel was applied in seed rows at sowing to enhance soil moisture retention. Significant variations were observed in nitrogen (N), phosphorus (P), potassium (K) and protein content and their uptake in barley as influenced by irrigation levels and hydrogel-based fertiliser management. The application of 3 irrigations (I₃) resulted in the highest nutrient content and uptake in both grain and straw, while one irrigation treatment recorded the lowest values. Among moisture conservation practices, hydrogel at 2.5 kg ha⁻¹ combined with 100 % NPK consistently produced the maximum NPK content and uptake, along with superior protein content during both years. These results demonstrate that integrated use of hydrogel and balanced fertilisation under optimal irrigation markedly enhances nutrient availability, uptake efficiency and overall crop quality, suggesting its potential as a sustainable moisture-conservation and nutrient-management strategy for improving barley productivity under variable climatic conditions.

Keywords: barley; hydrogel; irrigation levels; NPK fertiliser; nutrients; protein content

Introduction

Barley (*Hordeum vulgare* L.) is one of the most important cereal crops worldwide, ranking after maize, wheat and rice in terms of both cultivated area and total production (1). Owing to its low input requirements and resilience to adverse agro-climatic conditions, barley is often referred to as a “poor man’s crop.” Its remarkable adaptability enables successful cultivation on marginal lands and problematic soils where other cereals fail to perform efficiently. Barley serves multiple purposes, including human food, animal feed and malting for the brewing industry. In addition to its economic importance, barley grains are rich in β-glucans, soluble dietary fibres known to reduce serum cholesterol levels and lower the risk of cardiovascular diseases, thereby enhancing its nutritional and health value (2).

Among cereal crops, barley exhibits the widest ecological amplitude and can thrive under diverse environments ranging from

high altitudes to extreme latitudes and longitudes. This wide adaptability has led to its recognition as one of the most cosmopolitan cereal crops globally. Its tolerance to drought, salinity, alkalinity and low fertility soils further strengthens its suitability for cultivation under resource-constrained and stress-prone environments (3). In India, barley is predominantly cultivated as a rabi season crop, with Rajasthan emerging as a major contributor. The crop occupies approximately 2.74 lakh ha in Rajasthan, accounting for 8.23 % of the total rabi cereal area of the state and contributing about 7.46 % to total rabi cereal production (4).

Barley grains possess considerable nutritional value. Per 100 g of grain, barley contains about 10.6 g protein, 2.1 g fat, 64.0 g carbohydrates, along with essential minerals and vitamins such as calcium (50.0 mg), iron (6.0 mg), vitamin B₁ (31.0 mg), vitamin B₂ (0.1 mg) and folate (50.0 μg), making it a valuable component of human and livestock diets (5). In India, barley is mainly grown in Rajasthan, Uttar Pradesh, Madhya Pradesh, Haryana, Punjab,

West Bengal and Bihar. Nationally, the crop is cultivated over an area of 0.62 million ha with a production of 1.91 million tonnes and an average productivity of 3030 kg ha⁻¹ (6). In Rajasthan alone, barley occupies about 0.27 million ha with a productivity of 3324 kg ha⁻¹, which is higher than the national average (6). Despite this, the existing productivity remains far below the attainable yield potential of 45–50 q ha⁻¹, primarily due to water scarcity and nutrient limitations (7).

Although the application of chemical fertilisers can enhance barley productivity, excessive and imbalanced fertiliser use has emerged as a major constraint by adversely affecting soil health (8). Soil degradation, characterised by declining organic matter and nutrient imbalance, poses a serious challenge to sustainable agriculture in India, particularly in low-responsive and marginal soils (9). Integrated nutrient management involving the combined use of organic manures and inorganic fertilisers has shown promising results in sustaining crop productivity, improving soil physical properties and enhancing nutrient use efficiency (10).

In recent years, polymeric hydrogel amendments have gained attention as a potential strategy to improve soil water retention and seedling establishment, especially under arid and semi-arid conditions. Hydrogels enhance soil moisture availability by absorbing and retaining large quantities of water, thereby regulating plant-available water supply during moisture stress periods (11). Studies have reported rapid water absorption by hydrogels, with maximum absorption occurring in distilled water, while increased salinity reduces their swelling capacity. The application of hydrogels has been shown to delay seedling wilting by 4–5 days compared to untreated soils, highlighting their role in improving plant survival under moisture stress (12). Consequently, the use of polymeric hydrogels has expanded, particularly in light-textured soils, to enhance water holding capacity and reduce irrigation frequency (13).

The present study investigates the influence of polymeric hydrogel on barley seed germination under conditions of low-quality irrigation water. For dual-purpose barley, the evaluation of suitable cultivars, optimum sowing time and appropriate harvesting stage is crucial to achieve both high-quality fodder and grain yield. While previous studies have reported the beneficial effects of hydrogels on crop growth, their specific role under low-quality irrigation conditions has not been adequately explored in barley (14). Moreover, hydrogel application has been reported to reduce irrigation frequency across cereals, pulses, vegetables and ornamental crops, thereby saving water, labour, time and irrigation costs and contributing to resource-efficient and sustainable crop production systems (15).

Therefore, in view of the above considerations, a field experiment was carried out during the rabi seasons of 2023–24 and 2024–25 at the research farm, Mandawa, Jhunjhunu district, Rajasthan, to evaluate the combined effects of different fertiliser regimes, irrigation levels and hydrogel application on nutrient content and NPK uptake in barley (*Hordeum vulgare* L.).

Materials and Methods

Experimental site

The field experiment was conducted during the rabi seasons of 2023–24 and 2024–25 at the research farm located at Mandawa in Jhunjhunu district, Rajasthan. Geographically, the experimental

site lies at 75°88'99" E longitude and 26°81'17" N latitude and falls under the Agro-climatic zone II A, designated as the 'Transitional Plains of Inland Drainage Zone of Rajasthan'.

Experimental details

The present investigation was conducted using a split-plot design (SPD) with 3 replications, comprising a total of 27 plots. The barley variety RD-2035 was sown at 22.5 cm row spacing with a seed rate of 100 kg ha⁻¹, using plots of 16 rows with a gross area of 18.0 m² and net area of 15.75 m². A total of 9 treatments were evaluated to assess the effects of different combinations of experimental factors (Table 1).

Table 1. Treatments details with their symbols

Treatment category	Treatment description	Symbol
Irrigation levels	One irrigation	I ₁
	Two irrigations	I ₂
	Three irrigations	I ₃
Hydrogel and nutrient levels	100 % NPK without hydrogel	H ₁
	100 % NPK with 2.5 kg ha ⁻¹ hydrogel	H ₂
	70 % NPK without hydrogel	H ₃
	70 % NPK with 2.5 kg ha ⁻¹ hydrogel	H ₄
	50 % NPK without hydrogel	H ₅
	50 % NPK with 2.5 kg ha ⁻¹ hydrogel	H ₆

Soil characteristics

The experimental soil was loamy sand in texture, comprising 84.3 % sand, 9.2 % silt and 6.5 % clay, with a bulk density of 1.52 mg m⁻³ and porosity of 41.76 %. Chemically, the soil was alkaline (pH 8.20) with low organic carbon (0.21 %), low available nitrogen (N) (132.73 kg ha⁻¹), medium phosphorus (P) (19.92 kg ha⁻¹), high potassium (K) (231.76 kg ha⁻¹) and low electrical conductivity (0.31 dS m⁻¹).

Characteristics of variety

RD-2035 is a high-yielding dual-purpose barley variety developed from the cross RD-103 × PL-101 and was released and notified in 1994. The variety is medium tall, attaining a plant height of about 85–90 cm and is characterised by pigmented awn tips and internodes. Its grains are dirty yellow in colour, medium bold in size and uniformly developed. RD-2035 is resistant to cereal cyst nematode and brown rust, contributing to its yield stability under biotic stress conditions. It is recommended for irrigated areas of the North-Western Plains Zone and is well suited to timely sown irrigated conditions. The variety matures within 120–125 days, produces grains with a test weight of 40–45 g and has an average yield potential of 50–55 q ha⁻¹.

Treatment application

Application of hydrogel

The hydrogel was thoroughly mixed with soil and applied at the time of sowing in a band along the seed rows, as per the respective treatments, at a rate of 2.5 kg ha⁻¹. Upon incorporation into the soil, the hydrogel absorbed and retained large quantities of water and gradually released the stored moisture, thereby improving soil moisture availability in the root zone.

Quality parameters

The grain and straw samples from the produce of each plot were collected and oven dried at 70 °C for 48 hr to obtain constant weight. The samples were grinded to pass through 40 mesh sieves. The sample was analysed for N, P and K content in grain and straw by following standard methods of analysis.

Protein content

Protein analysis of grain was calculated by (Eqn. 1) multiplying N content (%) by 6.25 (based on assumption that N content 16 % of protein) and protein yield from (Eqn. 2).

$$\text{Protein content (\%)} = \text{N content in \%} \times 6.25 \quad (\text{Eqn. 1})$$

Protein yield (kg ha⁻¹) =

$$\frac{\text{Protein content (\%)} \times \text{grain yield (kg/ha)}}{100} \quad (\text{Eqn. 2})$$

Chemical analysis

N content in grain and straw

N content in grain (Eqn. 3) and straw (Eqn. 4) was determined by micro-Kjeldahl method (16).

N uptake in grain (kg ha⁻¹) =

$$\frac{\text{N content in grain (\%)} \times \text{grain yield (kg/ha)}}{100} \quad (\text{Eqn. 3})$$

N uptake in straw (kg ha⁻¹) =

$$\frac{\text{N content in straw (\%)} \times \text{straw yield (kg/ha)}}{100} \quad (\text{Eqn. 4})$$

P content in grain and straw

P content in grain (Eqn. 5) and straw (Eqn. 6) was determined by Wet digestion (Diacid) Vanado-molybdo-phosphoric acid yellow colour method as standard procedure (17).

P uptake in grain (kg ha⁻¹) =

$$\frac{\text{P content in grain (\%)} \times \text{grain yield (kg/ha)}}{100} \quad (\text{Eqn. 5})$$

P uptake in straw (kg ha⁻¹) =

$$\frac{\text{P content in straw (\%)} \times \text{straw yield (kg/ha)}}{100} \quad (\text{Eqn. 6})$$

K content in grain and straw

K content in grain (Eqn. 7) and straw (Eqn. 8) was determined by flame photometry method (17).

K uptake in grain (kg ha⁻¹) =

$$\frac{\text{K content in grain (\%)} \times \text{grain yield (kg/ha)}}{100} \quad (\text{Eqn. 7})$$

K uptake in straw (kg ha⁻¹) =

$$\frac{\text{K content in straw (\%)} \times \text{straw yield (kg/ha)}}{100} \quad (\text{Eqn. 8})$$

Statistical analysis

To determine the significance of the various variables or the effects of the different treatments used in the experiment, the data were analysed using the Microsoft Excel and OPSTAT software at a 95 % level of significance (LSD ($p \leq 0.05$)).

Results

Protein content in grains

Protein content exhibited significantly with irrigation levels and hydrogel practices during both the years (Table 2, Fig. 1). Moreover, the interaction between irrigation level and moisture conservation practices was nonsignificant. Significantly maximum protein content was recorded with the application of 3 irrigations as compared with rest of the treatments. Moreover, 3 irrigations did also differ over 1 irrigation. The mean protein content in 3 irrigations was 11.72 and 11.18 % against 10.91 and 10.41 % under 1 irrigation during 2023–24 and 2024–25, respectively.

Table 2. Protein content of barley grains as influenced by hydrogel under different doses of fertiliser and irrigation practices

Treatment	Protein content (%)	
	2023–24	2024–25
Irrigation levels		
I ₁ (1 irrigation)	10.91	10.41
I ₂ (2 irrigations)	11.24	10.73
I ₃ (3 irrigations)	11.72	11.18
S Em ±	0.08	0.07
C.D. ($p \leq 0.05$)	0.27	0.26
Hydrogel and fertilisers		
H ₁ (100 % NPK without hydrogel)	11.72	11.18
H ₂ (100 % NPK with 2.5 kg/ha hydrogel)	12.35	12.78
H ₃ (70 % NPK without hydrogel)	10.2	9.74
H ₄ (70 % NPK with 2.5 kg/ha hydrogel)	10.9	10.4
H ₅ (50 % NPK without hydrogel)	9.15	9.61
H ₆ (50 % NPK with 2.5 kg/ha hydrogel)	9.92	9.90
S Em ±	0.06	0.05
C.D. ($p \leq 0.05$)	0.15	0.14

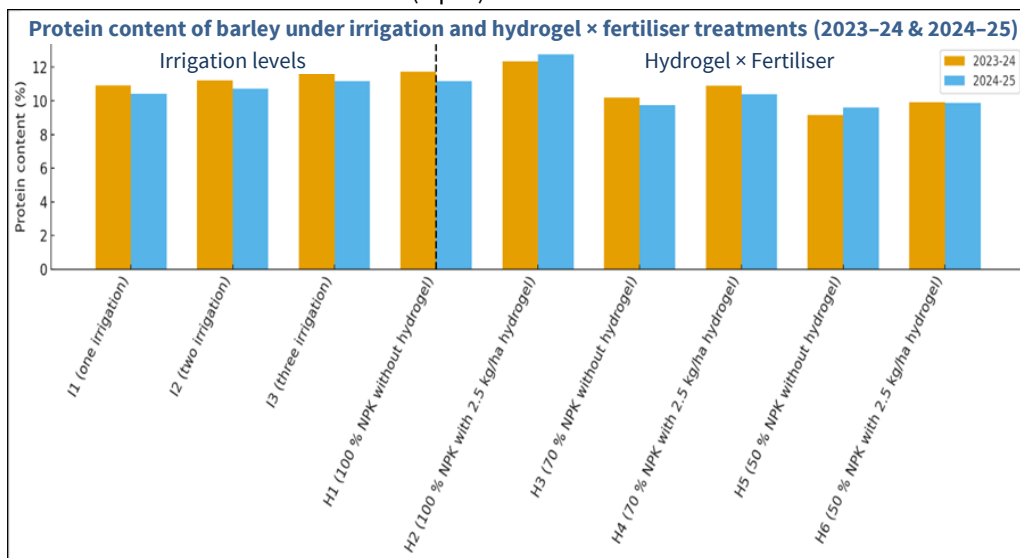


Fig. 1. Protein content of barley grains as influenced by hydrogel under different doses of fertiliser and irrigation practices.

Among the different doses of fertiliser conservation practice, combined application of hydrogel at 2.5 kg ha⁻¹ with 100 % NPK (H₂) recorded maximum protein content which was significantly differ over rest of the treatments, irrespective of the years.

Nitrogen content in grains and straw

Nitrogen content in grains and straw was significantly highest under the crop received 3 irrigation over 1 irrigation, followed by 2 irrigation during both the years (Table 3). Crop supply by 1 time irrigation was inferior over all other treatments. The mean percent of N in grains and straw under 1 irrigation was 1.60 and 0.36 % as against 1.72 and 0.45 %, respectively over 3 irrigation 2023–24 and 2024–25, respectively.

Control led to reduction in N content in grains and straw than rest of the treatments. Though, the effect was significant during both the years. Moreover, barley fertilised with hydrogel at 2.5 kg ha⁻¹ + 100 % NPK did obtain maximum N content in grains and straw followed by 70 and 50 % NPK.

Nitrogen uptake in grains and straw as well as their total uptake

Nitrogen uptake in grain and straw was significantly lowest under the application of 1 irrigation as against 3 and 2 irrigations during both the years (Table 3). Crop received 3-time irrigation was superior to other irrigation levels. Moreover, in total uptake, crop receiving 3 irrigation had removed 4.38 and 3.41 % more N over 2 irrigations, while 18.58 and 15.77 % over 1 irrigation during 2023–24 and 2024–25, respectively.

Crops grown under hydrogel at 2.5 kg ha⁻¹ along with 100 % NPK did showed significant increment in nitrogen uptake in grains and straw than rest of the treatments during both the years.

Phosphorous content in grains and straw

Application of 3 irrigations significantly resulted in maximum P content in grains (0.36 and 0.34 %) as against all other treatments during 2023–24 and 2024–25 respectively (Table 4).

Control did measure least P content in grain (0.31 and 0.29 %) and straw (0.17 and 0.16 %) during both the years. Moreover, barley fertilised with hydrogel at 2.5 kg ha⁻¹ with 100 % NPK obtained maximum P content in grain and straw followed by 70 and 50 % NPK.

Phosphorous uptake in grain and straw as well as their total uptake

Phosphorous uptake in grains and straw was significantly lowest under the application of 1 irrigation as against 3 irrigations and 2 irrigations during both the year (Table 4). Crops receiving 4 time irrigation was superior to other irrigation levels during both the years. Moreover, in total uptake, crop receiving 1 irrigation had removed 4.38 and 0.42 % lowest P over 3 irrigations, while 13.05 and 12.90 % over 3 irrigations during 2023–24 and 2024–25, respectively.

Integrated incorporation of hydrogel at 2.5 kg ha⁻¹ with 100 % NPK showed significant increment in P uptake in grains and straw than rest of the treatments during both the years. Application of hydrogel at 2.5 kg ha⁻¹ did record higher P uptake in grains and straw against control, whereas lowest over 50 % NPK after than 70 % NPK.

Table 3. Nitrogen content and uptake by barley as influenced by hydrogel under different doses of fertilisers and irrigation practices

Treatment	N content (%)				N uptake (kg ha ⁻¹)				Total	
	Grain		Straw		Grain		Straw		2023–24	2024–25
	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25		
Irrigation levels										
I ₁ (1 irrigation)	1.62	1.6	0.36	0.32	67.01	64.92	18.91	17.48	86.95	82.44
I ₂ (2 irrigations)	1.66	1.63	0.41	0.37	74.07	70.81	24.67	22.36	100.76	93.22
I ₃ (3 irrigations)	1.72	1.7	0.45	0.42	77.61	72.33	25.49	24.07	105.19	96.45
S Em ±	0.007	0.007	0.004	0.001	0.25	0.38	0.25	0.32	0.45	0.12
C.D. (p ≤ 0.05)	0.031	0.03	0.021	0.005	1.01	1.52	1.01	1.3	1.76	0.51
Hydrogel and fertilisers										
H ₁ (100 % NPK without hydrogel)	1.71	1.68	0.44	0.4	80.06	76.8	25.28	23.37	107.43	100.17
H ₂ (100 % NPK with 2.5 kg/ha hydrogel)	1.77	1.76	0.48	0.45	84.77	81.06	30.6	27.64	117.65	108.72
H ₃ (70 % NPK without hydrogel)	1.54	1.5	0.33	0.27	51.03	48.11	15.78	15.1	68.87	63.23
H ₄ (70 % NPK with 2.5 kg/ha hydrogel)	1.64	1.6	0.39	0.34	75.4	71.53	20.41	19.12	97.91	90.67
H ₅ (50 % NPK without hydrogel)	1.41	1.34	0.24	0.16	42.06	38.03	5.58	7.06	48.82	45.18
H ₆ (50 % NPK with 2.5 kg/ha hydrogel)	1.51	1.44	0.3	0.23	66.09	61.45	10.21	11.09	77.86	72.62
S Em ±	0.005	0.004	0.004	0.002	0.20	0.36	0.31	0.30	0.32	0.38
C.D. (p ≤ 0.05)	0.019	0.018	0.013	0.007	0.61	0.8	0.96	0.92	1.01	1.16

Table 4. Phosphorus content and uptake by barley as influenced by hydrogel under different doses of fertilisers and irrigation practices

Treatment	P content (%)				P uptake (kg ha ⁻¹)				Total	
	Grain		Straw		Grain		Straw		2023–24	2024–25
	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25		
Irrigation levels										
I ₁ (1 irrigation)	0.31	0.30	0.18	0.16	11.16	10.46	7.03	6.23	19.20	17.70
I ₂ (2 irrigations)	0.32	0.31	0.20	0.18	12.17	11.81	8.61	7.61	21.07	19.84
I ₃ (3 irrigations)	0.34	0.32	0.21	0.19	13.42	13.21	8.89	8.10	22.04	19.93
S Em ±	0.001	0.002	0.002	0.001	0.17	0.07	0.05	0.04	0.20	0.09
C.D. (p ≤ 0.05)	0.005	0.008	0.006	0.005	0.71	0.30	0.22	0.22	0.80	0.38
Hydrogel and fertilisers										
H ₁ (100 % NPK without hydrogel)	0.32	0.31	0.20	0.19	12.44	11.6	7.72	6.86	21.19	19.53
H ₂ (100 % NPK with 2.5 kg/ha hydrogel)	0.36	0.34	0.23	0.22	15.85	14.47	10.53	9.66	27.38	25.16
H ₃ (70 % NPK without hydrogel)	0.29	0.27	0.15	0.13	8.96	8.83	4.67	3.8	14.64	13.66
H ₄ (70 % NPK with 2.5 kg/ha hydrogel)	0.30	0.29	0.17	0.15	11.7	11.01	7.09	6.22	19.81	18.24
H ₅ (50 % NPK without hydrogel)	0.25	0.22	0.13	0.11	4.64	4.57	2.54	2.57	12.60	11.22
H ₆ (50 % NPK with 2.5 kg/ha hydrogel)	0.26	0.24	0.15	0.13	7.76	7.64	6.57	6.59	13.62	12.64
S Em ±	0.001	0.001	0.001	0.002	0.18	0.18	0.24	0.23	0.37	0.37
C.D. (p ≤ 0.05)	0.004	0.005	0.004	0.004	0.56	0.55	0.74	0.71	1.13	1.12

Potassium content in grains and straw

Potassium content in grains and straw was significantly highest under the crop received 4 irrigations over 1 irrigation, followed by 3 irrigations during both the year (Table 5). Crop supply by 1 time irrigation was inferior to all other treatments. The mean percent of K content in grains and straw under 3 irrigation was 0.44 and 1.70 % as against 0.38 and 1.40 %, respectively over 1 irrigation during both the year.

Control did lead to reduction in K content in grains and straw than rest of the treatments. Though, the effect was significant during both the years. Moreover, Crop fertilised with hydrogel at 2.5 kg ha⁻¹ with 100 % NPK obtained maximum K content in grains and straw followed by 50 % NPK after than 70 % NPK.

Potassium uptake in grains and straw as well as their total uptake

Potassium uptake in grains and straw was significantly lowest under the application of 1 irrigation as against 2 and 3 irrigations during both the year. Crop supply by 3-time irrigation was significantly recorded highest K uptake in grains and straw over other irrigation levels (Table 5). Moreover, in total uptake, crop receiving 2 irrigations had removed 5.02 and 5.26 % more K over 3 irrigations, while 8.38 and 8.24 % over 1 irrigation during 2023–24 and 2024–25, respectively.

Crops grown under hydrogel at 2.5 kg ha⁻¹ along with 100 % NPK showed significant increment in K uptake in grains and straw than rest of the treatments during both the years. Moreover, crops grown under unfertilised condition had recorded lowest K uptake in grains and straw.

Discussion

Nitrogen, phosphorus and potassium contents and their uptake by crop

Application of different irrigation levels significantly enhanced N, P and K content as well as their uptake by barley grain and straw over the control during both years of experimentation, with a few exceptions. Among the irrigation treatments, the application of three irrigations resulted in the highest NPK content and uptake. Compared to one irrigation level, three irrigation levels increased N, P and K content in grain by 6.30 and 5.17 %, 8.37 and 6.44 % and 15.01 and 15.75 %, respectively, during 2023–24 and 2024–25. Correspondingly, the increases in N, P and K content in straw were

22.07 and 27.56 %, 15.75 and 17.62 % and 16.72 and 16.88 % during the respective years.

The enhanced nutrient content under higher irrigation levels may be attributed to improved soil moisture availability, which facilitates nutrient solubilisation, diffusion and root uptake. Adequate moisture also promotes microbial activity, leading to sustained nutrient release and increased availability throughout the crop growth period. Similar findings were reported by earlier researchers who observed that organic sources exhibited longer-lasting nutrient release and greater efficiency compared to inorganic sources, thereby contributing to improved nutrient uptake and biomass accumulation (18).

Different irrigation treatments significantly increased the uptake of NPK by grain and straw, with 3 irrigation levels (I₃) recording the highest uptake and one irrigation level (I₁) the lowest. The uptake of nutrients was higher during 2023–24 than in 2024–25, which can be attributed to comparatively higher grain and straw yields recorded during the first year of experimentation. These findings align with the previous observations who reported enhanced N uptake under optimised irrigation regimes in regions with similar agro-climatic conditions (19).

Similarly, the application of different hydrogel treatments significantly improved N, P and K content and their uptake, as well as total nutrient uptake by barley grain and straw over the control during both years, with few exceptions (20, 21). Among the hydrogel treatments, application of hydrogel at 2.5 kg ha⁻¹ along with 100 % recommended NPK recorded the highest values for nutrient content and uptake. This treatment resulted in increases of 14.28 and 15.32 % in N, 27.65 and 29.56 % in P and 20.50 and 18.40 % in K content of grain during 2023–24 and 2024–25, respectively. Corresponding increases in straw were 40.65 and 53.84 % for N, 46.05 and 52.32 % for P and 20.41 and 19.85 % for K over the control.

The beneficial effect of hydrogel application, particularly when combined with balanced fertiliser doses, can be attributed to its ability to enhance soil water retention, reduce nutrient losses through leaching and improve nutrient availability in the root zone (22). These conditions promote better root growth and efficient nutrient uptake, ultimately leading to higher nutrient accumulation in both grain and straw (23). Similar improvements in nutrient content and uptake due to hydrogel application in combination with fertilisers have also been reported by earlier researchers (24, 25).

Table 5. Potassium content and uptake by barley as influenced by hydrogel under different doses of fertilisers and irrigation practices

Treatment	K content (%)				K uptake (kg ha ⁻¹)				Total	
	Grain		Straw		Grain		Straw		2023–24	2024–25
	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25		
Irrigation levels										
I ₁ (1 irrigation)	0.38	0.36	1.47	1.40	16.31	15.21	111.42	109.45	128.75	125.67
I ₂ (2 irrigation)	0.41	0.39	1.58	1.53	17.81	16.95	114.04	111.14	132.85	129.1
I ₃ (3 irrigation)	0.44	0.42	1.72	1.63	20.63	19.32	119.3	117.05	140.93	137.38
S Em ±	0.001	0.001	0.006	0.007	0.07	0.07	0.14	0.15	0.07	0.17
C.D. (p ≤ 0.05)	0.005	0.008	0.026	0.031	0.32	0.31	0.55	0.61	0.30	0.69
Hydrogel and fertilisers										
H ₁ (100 % NPK without hydrogel)	0.42	0.40	1.64	1.57	19.65	17.9	116.93	114.33	137.60	133.22
H ₂ (100 % NPK with 2.5 kg/ha hydrogel)	0.45	0.43	1.74	1.67	21.79	21.16	120.43	117.33	143.23	139.21
H ₃ (70 % NPK without hydrogel)	0.37	0.36	1.45	1.39	14.74	13.69	108.79	107.0	124.56	121.72
H ₄ (70 % NPK with 2.5 kg/ha hydrogel)	0.40	0.38	1.51	1.46	16.8	15.94	113.54	111.52	131.38	128.48
H ₅ (50 % NPK without hydrogel)	0.33	0.31	1.44	1.38	14.72	13.67	107.77	106.55	123.54	120.70
H ₆ (50 % NPK with 2.5 kg/ha hydrogel)	0.35	0.33	1.5	1.45	16.8	15.92	112.52	111.5	131.36	127.46
S Em ±	0.001	0.001	0.006	0.007	0.18	0.14	0.15	0.18	0.23	0.23
C.D. (p ≤ 0.05)	0.004	0.005	0.02	0.023	0.55	0.43	0.47	0.55	0.70	0.71

Conclusion

The application of hydrogel in combination with balanced fertiliser doses notably enhanced the N, P and K content and their uptake by barley grain and straw during both cropping years. The treatment of hydrogel at 2.5 kg ha⁻¹ with 100 % NPK consistently recorded the highest nutrient content and uptake, indicating its efficiency in improving nutrient retention and plant availability under varying moisture conditions. The substantial increases in NPK uptake over the control highlight hydrogel's role in improving soil-water-nutrient dynamics, leading to better crop performance and sustainable nutrient management. Hydrogel-based soil amendments hold great promise for optimising fertiliser use efficiency and enhancing resilience of cereal crops under limited irrigation or drought-prone regions. Further research should focus on long-term field evaluations and environmental implications of hydrogel application. Integrating hydrogel technology with precision irrigation, organic amendments and smart nutrient delivery systems could pave the way toward climate-resilient and resource-efficient barley production systems in sustainable agriculture.

Authors' contributions

N carried out the experiment, took observations and analysed the data. HS guided the research by formulating the research concept and approved the final manuscript, participated in the design of the study and performed the statistical analysis. All co-authors contributed by imposing the experiment and helped edit, summarise and revise the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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During the preparation of this work the authors used [ChatGPT 5.2] in order to check grammar and scientific language editing.

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