Effect of Hydrogel on Soil Moisture Dynamics and Crop Growth Inside a Polyhouse in Hill Agro Ecosystem

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ABSTRACT

The hilly terrain in Northeast India, despite experiencing substantial rainfall, faces water scarcity due to insufficient storage, high runoff, and limited infiltration. This causes water scarcity during the dormant period which poses as a threat to agriculture. To address this, a field experiment was carried out to evaluate the effect of hydrogel on the production of bean crop (*Phaseolus vulgaris* L.) inside a polyhouse with drip irrigation system at the hilly terrain of Department of Agricultural Engineering, Assam University, Silchar. The experiment was conducted with four irrigation treatments T-1 (Treatment-1) 50% Field Capacity (FC), T-2 60% FC, T-3 80% FC and T-4 100% FC with and without hydrogel system. It was found that the highest irrigation amount was required in 100% of FC in the condition without hydrogel, totalling 21.5 litres during the 90-day span. The lowest irrigation amount was required in the treatment with 50% of FC with hydrogel application, totalling 2.6 litres. It was also revealed that use of hydrogel significantly ($p < 0.05$) affected the growth parameters (plant height, leaves, flowers, pods) and water use efficiency in comparison with the system with no hydrogel. This study highlights that the combination of a drip irrigation system with hydrogel improves water use efficiency significantly, reduces total irrigation amount while maintaining agricultural production. These findings could be useful to optimize the consumption of water resources in bean cultivation in the hilly region of North Eastern India.

Keywords: *Beans, Drip irrigation, Field Capacity, Hydrogel, Poly house.*

Introduction

Phaseolus vulgaris L., often known as the common bean, is a crucial legume from the *Leguminosae* family and is native to Central and South America. (Sahana *et al.,* 2018). It serves as a vital source of nutritional fibre, calories, proteins, minerals, and vitamins for millions of people globally, making it the primary legume for direct human consumption on an international scale. (Nowwar *et al.,* 2023). The scarcity of water, inconsistent irrigation methods, and increasing temperatures in recent years have adversely affected the production of green beans. (Tahiri *et al.,* 2024).

Despite experiencing heavy orographic rainfall, the northeastern states of India face shortage of water due to geographical factors such as steep slopes and rocky impermeable surfaces that prevent infiltration for groundwater storage or well construction (Islam, 2012). With the current global development of irrigated land and the scarcity of water for irrigation, it is vital to maximize water use efficiency (WUE) in order to boost crop yields especially in situations where there is a frequent irrigation deficit (Lotha *et al.,* 2024).

Thus, taking into consideration the climatic and topographic scenario of North eastern India precise technology for efficient use of irrigation water is necessary. In this study drip irrigation, which have high water use efficiency (Zhang *et al.,* 2022) in alongside extremely absorbent polymers that can absorb and hold 400 times its dry weight in water, ensuring soil moisture for plant roots (Hazrati *et al.,* 2017, Doklega *et al.,* 2024) was used for cultivation of French bean under protected cultivation. Protected cultivation technology enhances crop productivity and quality, conserves soil and water, and shields against rain or wind erosion. (Pachiyappan *et al.,* 2022).

Drip irrigation is a type of micro irrigation that provides water to plants close to their roots, resulting in increased crop output and balanced soil moisture in the active root zone with minimal water loss (Sandhu *et al.,* 2019, Swain *et al.,* 2019, Wu *et al.,* 2022).

Using water-saving polymers like superabsorbent hydrogels is one of the modern agricultural techniques to reduce water loss and increase irrigation efficiency (Salimi *et al.,* 2023). Hydrogels are polymer networks with a three-dimensional structure that are both hydrophilic and have the ability to hold a significant quantity of water (Tariq *et al.,* 2023). Hydrogel serves as a reservoir, storing and releasing water and other vital nutrients gradually to maintain a steady supply for plant growth (Rajanna *et al.,* 2022).

Few studies have explored the role of hydrogel acting as reservoir on French bean crop. Pouresmaeil *et al.,* (2012), studied that the utilization of super absorbent polymer preserved the soil's ability to retain water, consequently, the relative water content (RWC) in leaves, as well as bean plant growth and yield, experienced an increase even under water scarcity. Ahmed *et al.,* (2015) found that after undergoing drought stress, the application of hydrogel improved growth and productivity measures on snap bean plants. Satriani *et al.,* (2017) demonstrated the efficacy of employing hydrogel for water conservation in irrigation, which enables the maintenance of production levels while simultaneously reducing the quantity of irrigation water required.

Nonetheless, the replication of these studies within the North East region of the Indian Himalayas is hindered by differences in soil composition, climatic conditions, and agricultural management approaches. There is a noticeable gap in research regarding the impact of hydrogel on crop growth and yield under different field capacities within a polyhouse environment in this region. Therefore, this research work is performed to study the influence of hydrogel in combination with drip irrigation and polyhouse in deficit irrigation conditions.

MATERIALS AND METHODS

Experiment details

The experiment was carried out in the experimental farm at Assam University, Silchar. The soil type within the experimental plot was clay loam. The pH of the soil was between 4.7 and 5.3, which is ideal for the growth of crops including tomatoes, okra, beans, and capsicum. The study site experiences a humid subtropical climate, with an average annual rainfall ranging from 2,500 to 3,300 mm. The majority of this precipitation, about 80–85%, occurs between April-May and September-October. Field experiments were conducted to study the effect of hydrogel on French bean production over a 90-day crop duration. A drip irrigation system was installed prior to sowing, with one dripper placed per plant along each row. Syngenta bean seeds, sourced from the local market, were used for the experiment.

The soil physico-chemical characteristics such as soil moisture content, bulk density, soil texture, moisture content, soil pH, electrical conductivity was determined to procure the irrigation and nutrient requirement. Moisture content of soil was calculated by oven drying method (Reynolds, 1970). Bulk density of soil was estimated by soil corer method (Blake and Hartege, 1986) using soil core with a known diameter (d) and height (h). Hydrometer method is used to determine the particle size of soil and soil texture was found out with the help of the USDA textural classification triangle (Bouyoucos, 1962). Soil pH and electrical conductivity (EC) are measured with pH meter and EC meter respectively.

The experiment was laid out in Randomized Block Design with four treatments and three replications. Each treatment has three replications and each replication had two plants, two plants. The irrigation practices for the plants inside the polyhouse with hydrogel (WH) and without hydrogel (WOH) consist of four treatments with various levels of water based on the field capacity (Table I).

- T1 (Treatment-1) —50% of Field Capacity (FC)
- T2—60% of Field Capacity
- T3—80% of Field Capacity
- T4—100% of Field Capacity

Table I. Experimental details of the field layout

Treatment	Field Capacity (%)	Treatment size (m^2)	Plant to Plant Distance (cm)	Row to Row Distance (cm)	No. of plants per replication	With Hydrogel (WH)/ Without Hydrogel (WOH)	No. of Replications
T1	50 %	10.5	75	50	4	2H, 2NH	3
T2	60 %	10.5	75	50	4	2H, 2NH	3
T3	80 %	10.5	75	50	4	2H, 2NH	3
T4	100 %	10.5	75	50	4	2H, 2NH	3

Estimation of the irrigation requirement:

The net irrigation requirement was calculated using equation (1), (Topp *et al.,* 2008) Net irrigation (mm^3) = Moisture Content (Depth) – Available Moisture Content (mm) --------(1)

Irrigation water use efficiency index (IWUE) was calculated as crop yield divided by applied water during the whole growing time (Jensen, 1983).

Statistical Analysis:

The collected data were statistically examined, and the analysis of variance (ANOVA) in Microsoft Excel (Analysis Tool Pak) was utilized to analyze the differences in crop growth characteristics, crop yield, and irrigation amount applied in various treatments. Five percent was the probability level at which significance was to be determined.

Economics of Production

The economics of production of bean cultivation includes the following elements:

- Gross Returns (Rupees(₹)/ha(hectare)): It is calculated as the average yield of crop in quintal (q)/ha multiplied by the average price received from market in ₹ /q.
- Net Returns per unit area (₹/ha): It is the difference between the gross returns (₹/ha) to the cost of cultivation (₹/ha).
- Net Profit per unit production (₹/ha): It is the difference between the average price received (₹/ha) to the average cost of production (₹/ha).

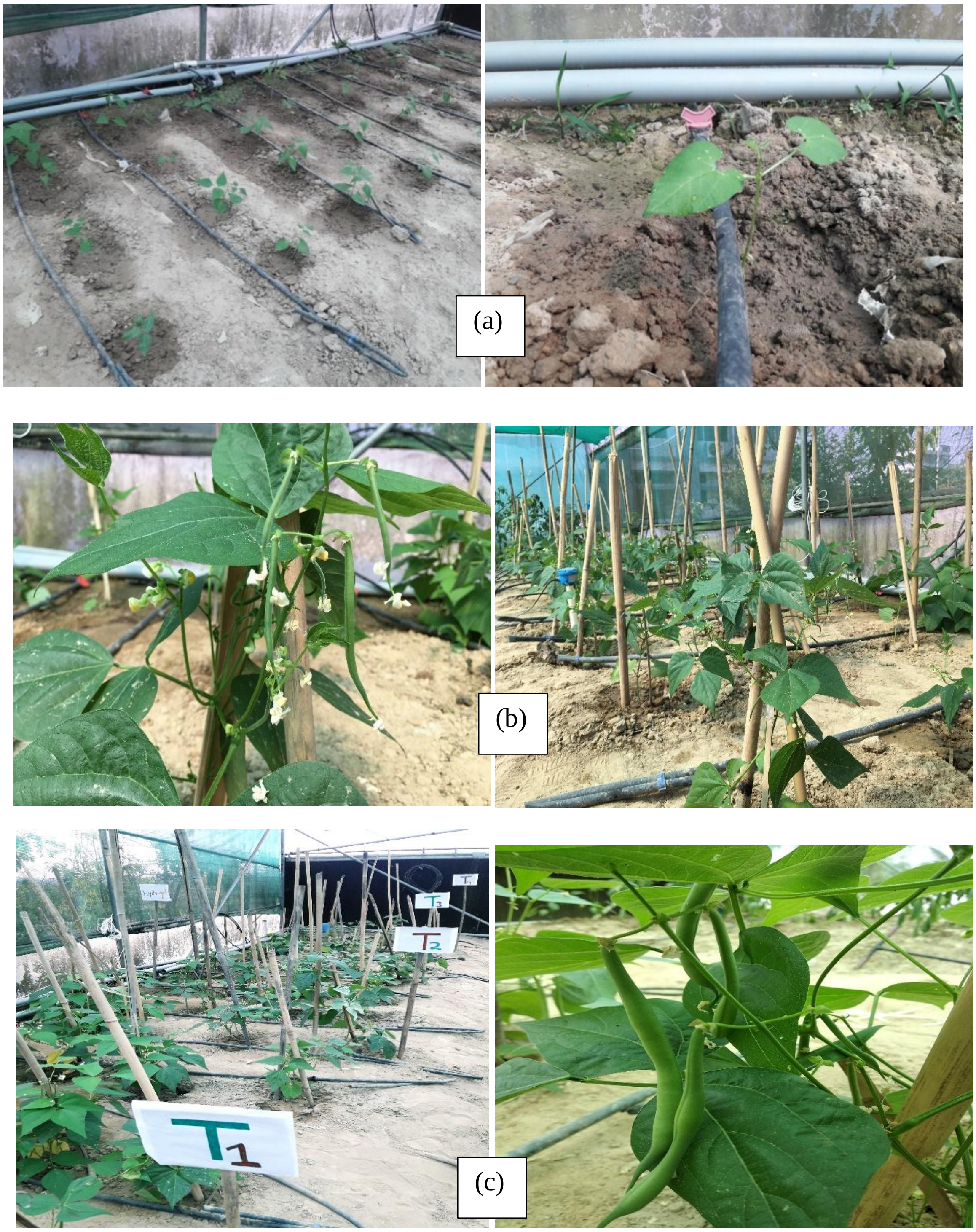

Fig. I Pictorial view illustrating the different growth stages of the bean plant (a) Nursery stage (b) Flowering stage (c) Pod development stage

RESULTS AND DISCUSSION

Status and variation of the soil physical and chemical properties

The texture analysis of soil in each treatment reflected the presence of more silt content followed by clay and sand whereas clay loam was identified as the textural classes for all the treatments. The average soil moisture content and the average bulk density is shown in Table II. The soil water content at field capacity was found maximum at depth 0-15 cm (32.5%) and minimum at 15-30 cm (31.54%). The soil water content at wilting point was found maximum at depth 0-15 cm (7.52%) and minimum at 15-30 cm (6.4%). The pH of the soil samples was found to be in the range of 4.7 and 5.3 which shows that the soil is acidic in nature.

Table II Soil Moisture Content (SMC) and Bulk Density (BD) values of various treatments

Treatment	Average SMC on dry basis (%)	Average SMC on wet basis (%)	Average BD on dry basis (g/cc)	Average BD on wet basis (g/cc)
T1	20.9	17.2	1.07	1.3
T2	23.7	19.1	1.03	1.28
T3	18.2	15.4	1.16	1.38
T4	19.1	15.9	1.08	1.29

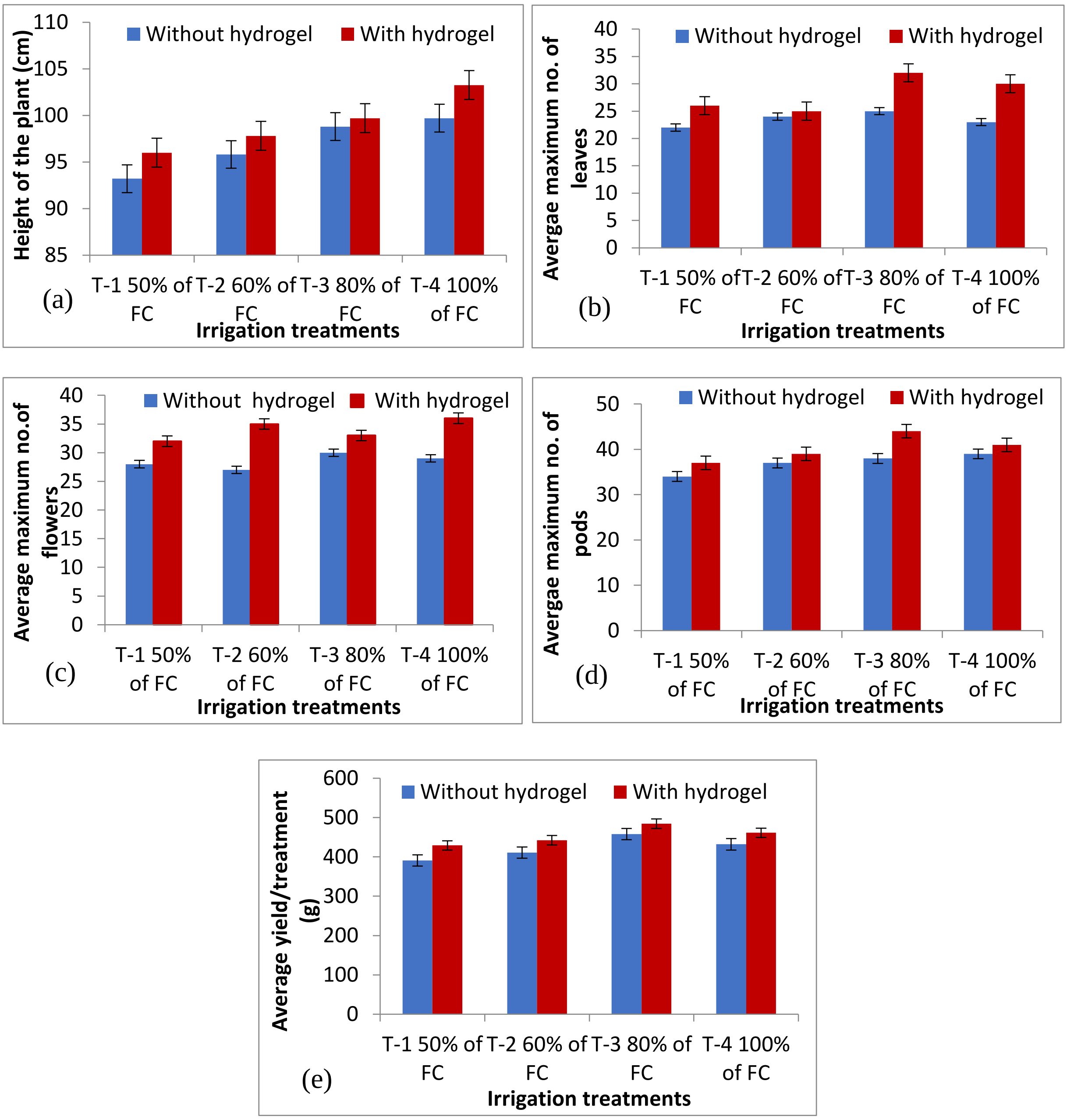

Fig. II Average height of the plant (a), maximum number of leaves (b), flowers (c), pods (d) and average yield per treatment (e) observed in the experimental site with and without hydrogel.

Monitoring and Analysis of the Agricultural Production

It was observed that the average maximum height of the plant with hydrogel was seen in T4-WH (103.25 cm) and the average maximum height of the plant without hydrogel is also seen in T4-WOH (99.7 cm). The minimum average height without hydrogel was observed in T1-WOH (93.2 cm) and the minimum average height with hydrogel is observed in T1-WH (96 cm) (Fig II a). It was observed that T3-WH with 32 leaves had the highest maximum average number of leaves in treatment with hydrogel and T3-WOH with 25 leaves had the highest maximum average number of leaves in treatment without hydrogel (Fig II b). The minimum number of average leaves was observed in T2-WH with 25 leaves in treatment with hydrogel and T1-WOH with 22 leaves had the minimum number of leaves in treatment without hydrogel.

The maximum average flowers were observed in T4-WOH with 36 flowers (Fig II c). The minimum average flowers were observed in T2-WOH with 27 flowers. Because of deficit irrigation the number of flowers is less in T1-WOH. It was observed that T3-WH with 44 pods have the maximum average number of pods and T1-WOH with 34 pods have the minimum average number of pods (Fig II d)

With the hydrogel system, there was a significant difference ($P < 0.05$) in crop growth parameters such as plant height, number of leaves, number of flowers, and number of pods compared to those without the hydrogel system. Similar findings were also observed in El Idrissi *et al.,* (2023) on tomato, Kaur *et al.,* (2023) on wheat and moong bean, Diomande *et al.,* (2023) on okra.

The average maximum total yield was observed in T3-WH (484.8 g) in the condition with hydrogel and T3-WOH (458.8 g) in the condition without hydrogel compared to other treatments (Fig II e). The total yield in with and without hydrogel application was 10.89 kg and 10.16 kg respectively. The total yield was 21.05 kg. After statistical analysis set at 5% significant difference there was no significant difference observed in the yield between with and without hydrogel application for all the treatments. Even though there were no significant difference the treatments with hydrogel had slightly higher yield compared to without hydrogel treatments thus maintaining the productivity. This might be of practical importance to farmers looking to optimize their yield with similar conditions. One of the limitations which contributed to lack of statistical difference may be attributed to the relatively small sample size. The number of plants grown and the number of replications in each treatment were limited, which may have reduced the influence of the statistical analysis to detect significant differences.

Irrigation requirement

To maintain the soil moisture at different treatments of 50, 60, 80 and 100% of FC irrigation was applied according to the soil moisture level demand with and without hydrogel. The highest irrigation amount was required in T4-WOH with a total of 21.5 litres during the 90-day span. The lowest irrigation amount was required in T1-WH with a total of 2.6 litres (Fig III). The irrigation requirement is more in with hydrogel application as compared to without hydrogel application. This is because hydrogels have high water holding capacity and moisture conservation (Ashraf *et al.,* 2021). The irrigation amount is reduced to almost half thus saving huge water, energy and other resources (Table III). After statistical analysis, with 5% significant difference there was a significant difference observed in the irrigation amount between with and without hydrogel application for all the treatments. Zhu *et al.,* (2022) had similar findings that the use of hydrogel on leafy vegetables had significant water saving per crop cycle. Sadullaev and Nafiddinovich (2023) stated that hydrogel will save 20 to 40% of irrigation water for most agricultural crops.

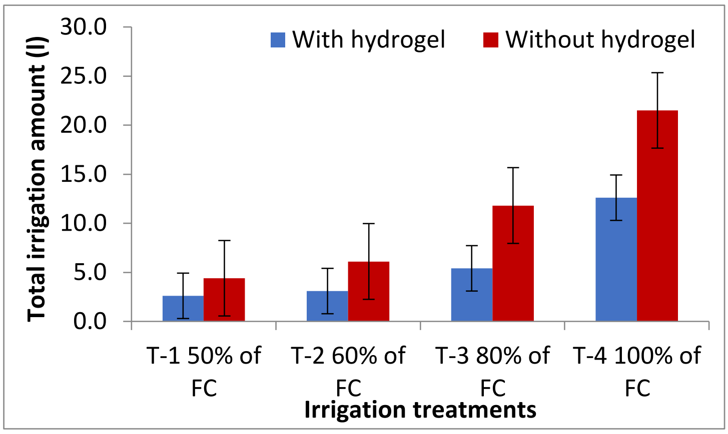

Fig. III Treatment wise total irrigation amount (litres) required in with and without hydrogel system.

Table III: Yield, Irrigation water applied and WUE across different treatments

Treatment	Yield(t/ha)	Irrigation water applied (mm)	WUE(t/ha/mm)
T1-WH	19.59	137.5	0.142
T2-WH	20.20	145.81	0.139
T3-WH	22.10	175.44	0.126
T4-WH	21.04	232.69	0.09
T1-WOH	17.91	163.86	0.109
T2-WOH	18.75	182.71	0.103
T3-WOH	20.96	227.66	0.092
T4-WOH	19.82	278.06	0.071

Water Use Efficiency (WUE)

The water use efficiency was calculated based on the different treatments provided during the whole experimental period. There was a significant difference between the various treatments. The values of the WUE were in order with T-1 (50% of FC) with the highest value and the lowest being T-4(100% of FC). The WUE increases with the decrease in Field capacity. The highest among all the treatments with the two conditions was observed in T1-WH (50% of FC) (0.142 t/ha mm) with hydrogel condition and the lowest in T4-WOH (0.071 t/ha mm) in the condition without hydrogel (Table III). Higher water use efficiencies with hydrogel application were also observed in other studies (El Idrissi *et al*., 2023; Ray *et al*., 2023). These findings highlight the potential of Hydrogel as a helpful tool in water conservation techniques for agricultural practices (Jaramillo *et al*., 2023).

Agricultural Production Economics

Cost of Production for beans

The agricultural production economics of Bean crop was calculated and estimated considering the various factors of cost of production and presented in Table IV and Table V. Each factor was considered and analysed for the cost of production. The setup of drip irrigation system is not included in the cost of production. The experiment was carried out with the existing poly house and drip irrigation system. The crop production data were collected for 90 days. The maximum cost in the cost of production was the hired labour which is followed by the cost of fertilizers and manures and seeds.

Economics of vegetable production

Economics analysis was carried out bearing in mind the investment, procedure and production costs and the results are presented in Table IV and V. As the production costs values varies in different conditions of cultivations, the gross return (₹ /ha), net return per unit area (₹ /ha), net profit per unit production (₹ /ton) and BC ratio values was found significantly higher in T3-WH compared to other treatments. The lowest BC ratio values was observed in T1-WOH. According to the economic evaluation, considering the selling price (₹ /ha) for beans was ₹ 80.00. The maximum net return per unit area for Beans was found as ₹ 1120609 in T3WH. As compared to cost of cultivation of beans in different irrigation treatments, net return was found highest from the irrigation treatments with hydrogel.

Higher net returns and BC ratio were also found to be higher in hydrogel system in a study reported by Kumar *et al.,* (2021). Therefore, it is suggested to grow beans inside polyhouse with hydrogel for maximum output.

The study suggests that the integration of hydrogel and drip irrigation systems has the potential to address water scarcity issues by reducing the irrigation water input, enhance water use efficiency and contribute to sustainable agriculture in hilly terrains. Our results are confirmed by a study conducted by Satriani *et al.,* (2018) stating that the production of beans with hydrogel and drip irrigation has reduced the use of irrigation water and increased water use efficiency while maintaining the crop productivity.

Table IV. Cost of production and economic analysis for beans grown with hydrogel in the experimental site

Cost of production of French bean in each treatment (with hydrogel)				
Components	T_1	T_2	T_3	T_4
Nursery/Seedlings	20	20	20	20
Manures and Fertilizers	20	20	20	20
Hydrogel	25	25	25	25
Hired Human Labour	25	25	25	25
Total cost for 1.31 m^2	90	90	90	90
Total cost in □ /Ha	687023	687023	687023	687023
Economics of production of French bean in each treatment (with hydrogel)				
Yield (kg/plot)	2.57	2.65	2.9	2.76
Selling price(□ /kg)	80	80	80	80
Cost of cultivation(□ /ha)	687023	687023	687023	687023
Total yield (kg/ha)	19769.2	20384.6	22307.6	21230.7
Gross returns ((□ /ha)	1581536	1630768	1784608	1698456
Net returns per unit area	894513	943745	1097585	1011433
B:C Ratio	1.3021	1.3736	1.5975	1.4721

Table V. Cost of production and economic analysis for beans grown without hydrogel in the experimental site

Cost of production of French bean in each treatment (without hydrogel)				
Components	**T_1**	**T_2**	**T_3**	**T_4**
Nursery/Seedlings	20	20	20	20
Manures and Fertilizers	20	20	20	20
Hired Human Labour	50	50	50	50
Total cost for 1.31 m^2	90	90	90	90
Total cost in /Ha	687023	687023	687023	687023
Economics of production of French bean in each treatment (without hydrogel)				
Yield (kg/plot)	2.35	2.46	2.75	2.6
Selling price(/kg)	80	80	80	80
Cost of cultivation(/ha)	687023	687023	687023	687023
Total yield (kg/ha)	17938.9	18778.62	20992.3	19847.32
Gross returns ((/ha)	1435112	1502290	1679384	1587786
Net returns per unit area	748089	815267	992361	900763
B:C Ratio	1.08889	1.18667	1.44445	1.31112

CONCLUSION

The results show that application of hydrogel reduced the required amount of irrigation significantly, increased water use efficiency and significantly improved plant growth parameters. The BC ratio and net return were higher in the hydrogel system underscoring the economic viability of this approach. These findings suggest that the combination of drip irrigation, hydrogel and poly house can be a profitable strategy for farmers in water deficit regions and climatic conditions similar to North East India. Even though agricultural production was maintained the lack of significant difference may be attributed to the reduced sample size. Future studies could benefit from increasing the number of plants grown per treatment and the number of replications. The successful implementation of hydrogel and drip irrigation systems requires proper training and awareness among farmers. Extension services, government agencies can play a vital role in disseminating knowledge about these technologies and providing training programs to help farmers adopt these practices effectively.

Declaration of interest statement

The authors report there are no competing interests to declare.

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