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Irrigation scheduling and superabsorbent polymers for enhancing productivity and improving plant water dynamics of *kharif* baby corn (*Zea mays*)

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ABSTRACT

The present study was carried out during rainy (*kharif*) seasons of 2019 and 2020 at Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana to evaluate the impact of polymers with irrigation on baby corn (*Zea mays* L.) crops. The experiment was laid out in a split-plot design (SPD) with four irrigation [(One irrigation at sowing (I_1); Two irrigation at sowing, knee high stage (I_2); Two irrigation at sowing, before tasseling (I_3), Three irrigation at sowing, knee height, before tasseling (I_4)] in main plots and four polymer treatments [(No polymers or control (P_0); Pusa Hydrogel @2.5 kg/ha (P_1); Pusa Hydrogel @5 kg/ha (P_2); *Gondkatira* @5 kg/ha (P_3)] in subplot. The baby corn yield decreased by 20.99 and 25.50% from I_4 to I_3, 22.75 and 35.20% from I_4 to I_2, and 27.47 and 48.89% from I_4 to I_1 during the study period, first and second year, respectively. The polymer treatment was used to increase the baby corn yield. The yield was increased by 27.16, 133.09; 52.62 and 165.98 and 8.38,104.9. By application of hydrogel @2.5 kg/ha, hydrogel @5.0 kg/ha and *gondkatira* @5 kg/ha over to no polymers, during the first and second year, respectively. This might be because of the water that is available when it is dry, which would help avoid the delays in emergence and keep the water available for longer. The application of *gondkatira* in baby corn crops increased the water productivity by 22.25% (first year), 79.97% (second year) while hydrogel @5 kg/ha increased 43.14 and 134.28% during first and second year of study, respectively. Water stress or one irrigation at sowing has a lower Fv/Fm (maximum quantum efficiency of PS II) (0.678 and 0.676) ratio than to no stress or three irrigations (0.682 and 0.676).

Keywords: Maize**,** Photosynthesis, Polymers, Relative water content, Water stress

Agriculture usage accounts for 85% of total water consumption, while industrial and domestic sectors account for 15% and 5%, respectively. Therefore, it is crucial to prioritize water conservation, as the scarcity of water directly impacts the production of crops. Efficient water resources are necessary to minimize water losses (Saini *et al.* 2018). In a study conducted by Mazloom *et al.* (2020), it was found that there was a significant decrease of up to 40% in maize (*Zea mays* L.) output due to the global issue of water shortage. Optimal crop productivity can only be attained through equitable input application. Implementing vertical strategies such as the use of antitranspirants, mulch, polymers, and irrigation schedule can enhance long-term moisture availability.

Applying soil amendments is a method used to alleviate the negative effects of drought stress. Hence, it is imperative to prioritize the development of agronomic methods that may effectively mitigate drought stress in farmed crops. Superabsorbent polymers (SAPs) can serve as a soil supplement to enhance soil health by increasing its water retention capacity and the amount of water accessible to plants. A hydrogel is a partially synthetic polymer composed of cellulose that exhibits the property of swelling when in contact with water, and thereafter releases water gradually into the surrounding soil. Herbal hydrogel or *gondkatira* refers to natural plant components that are utilized in agriculture. These materials possess eco-friendly and non-toxic features, and their unique biochemical and structural characteristics enable them to efficiently absorb and retain water in the soil. Polymers can hold a greater amount of water than their weight and can release around 95% of the water they retain. SAP enhances soil porosity, increasing it within the range of 0.26–6.91%. It also increases water holding capacity, increasing it within the range of 5.68–17.90%. Additionally, SAP can cut soil nitrogen leaching losses by 45% or more (Malik *et al.* 2023).

Maize accounts for 18% of cereal acreage, 25% of

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productivity and 28% production of world. India ranks 6th in production and 4th in area (Shweta *et al.* 2022). In 2023–24, the production volume of corn across India was 33.5 million metric tonnes (Anonymous 2023).

Baby corn, which is an ear of corn with the husk removed, is harvested before pollination, often within 2–3 days of the silk appearing (Shweta *et al.* 2017 and Anu *et al.* 2023). Baby corn is a dual-purpose crop, serving both as a cash crop and a catch crop. Crucially, baby corn is devoid of pesticides and its nutritional worth is equivalent to well-liked veggies such as cauliflower, cabbage, tomato, eggplant, and cucumber. The by-products of corn, such as tassel, young husk, silk, and green stalks, are valuable as cow fodder. Baby corn is highly abundant in minerals and exhibits exceptional nutritional qualities, including 17.90 g of protein, 73.3 g of carbs, 95 mg of calcium, 898.62 mg of phosphorous, 0.10 mg of iron, 345 mg of magnesium, 670 mg of b-carotene, 5.43 mg of ascorbic acid, 5.89 g of crude fibre, and 2.3 g of fat, among others (Kadagonda *et al.* 2023). This plant variety is highly attractive because of its medium height, resistance to lodging, high productivity, and ability to respond well to large amounts of fertilizers. Additionally, the plant retains its green colour even after harvesting baby corn. It is typical to have three to four harvests. Green plants also offer high-quality forage to cattle. Supplementary revenue is also acquired by engaging in intercropping with vegetables, legumes, flowers, and other crops.

MATERIALS AND METHODS

The present study was carried out during rainy (*kharif*) seasons of 2019 and 2020 at Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar (29º 10'N latitude, 75º 46' E longitude, and 215 m a msl), Haryana. The study was conducted in a split-plot design (SPD) with four irrigation [(One irrigation at sowing(I_1), Two irrigation at sowing, knee high stage (I_2), Two irrigation at sowing, before tasseling (I_3), Three irrigation at sowing, knee height stage, before tasseling (I_4)] and four polymer treatments [(No polymers or control (P_0), Pusa Hydrogel @2.5 kg/ha (P_1), Pusa Hydrogel @5 kg/ha (P_2), *Gondkatira* @5 kg/ha (P_3)] in the main and subplot, respectively. Half of the basal nitrogen, together with full amounts of phosphorus and potassium, was administered at sowing. The remaining half of the nitrogen was divided into two equal doses and applied as top dressing. The first dosage was applied when the plants reached knee height, and the second dose was applied before the tasseling stage.

Leaf relative water content: The leaf RWC (Relative Water Content) of each treatment was assessed in the topmost leaf between 9:00–10:00 AM using the following method (Shweta *et al.* 2021 and 2022)

$$RWC = (FW\text{-}DW/TW\text{-}DW) \times 100$$

Where FW, Fresh weight; DW, Dry weight; TW, Turgid weight of leaf sample.

SPAD value: The chlorophyll content in the leaf was measured using a CCM (SPAD-502). The values were computed by considering the light intensity received by the leaf in two distinct zones characterized by different ranges of wavelengths that chlorophyll can absorb. The device utilizes a non-invasive technique to measure data and relies on the measurement of light intensity that is absorbed by the sample.

Chlorophyll fluorescence: Using a Chlorophyll Fluorescence Meter (Plant stress meter, Bio monitor, Sweden), the chlorophyll fluorescence properties, namely Fv/Fm, were measured between 12:00 and 2:00 PM. The measurements were taken on the two highest completely grown leaves of baby corn. The leaves were incubated in cuvettes for 30 min in the absence of light before measurement. The highest level of PS II activity was determined by the Fv/Fm ratio.

Optical nitrogen sensor: The Green Seeker is an optical sensor device that quantifies crop reflectance in order to determine the normalized difference vegetation index (NDVI). The NDVI is the proportion of visible red and infrared light that is emitted from the field monitored, passing above the canopy at 0.5–1.0 m above the plant. It can be described as:

$$NDVI = (NIR\text{-}RED)/(NIR+RED)$$

Where NDVI, Normalized difference vegetation index; NIR, Reflectance of light in the near infrared; RED; Reflectance of light in the visible red spectrum.

Excised leaf water loss: The leaf samples were gathered using the same method as described for the RWC measurement. The fresh weight of the removed leaves was promptly measured and the leaf samples were placed on a laboratory bench for 6 h at room temperature (20°C) to allow them to wilt. The leaves were reweighed after 6 h to determine their wilted weight. The leaves were subsequently dehydrated in an oven for 72 h at a temperature of 70°C, and the weight of the leaves after dehydration was measured. The calculation of Excised Leaf Water Loss (ELWL) (g/g) was performed using the following equation:

$$ELWL = (\text{Fresh Wt. - Wilted Wt.}) / \text{Dry Wt.}$$

Water productivity: The water productivity refers to the amount of crop produced per unit of water consumed. The calculation for water productivity (WP) was performed as follows:

$$WP = \text{Yield (kg/ha)/Water used (mm)}$$

Proline content: Leaf segments weighing 0.5 g were collected from each replication of every treatment for the purpose of estimating proline levels. The proline content of baby corn leaves was determined using the colorimetric assay technique as described by Bates *et al.* (1973). The proline content was determined by utilizing a standard curve based on fresh weight measurements.

Proline of fresh plant material (µmoles/g) = {proline (µg/ml) × (toluene used ml)/115.5 µg/µmoles}/(g sample/5).

Gas exchange characteristics: The infrared gas analyzer (IRGA LCi-SD, ADC Biosciences) was used to determine the leaf gas exchange properties, namely stomatal conductance (GS), transpiration rate (E), and net photosynthetic rate (P_N). The fully extended leaf from the top of each plant was selected for this analysis. The assessment of photosynthetic parameters was conducted between 9.00 am and 11.00 am.

Statistical analysis: Baby corn's chlorophyll content, proline content, water productivity, yield characteristics, and yield were all subjected to a two-way analysis of variance (ANOVA). We utilized OPSTAT to check if the changes in the means were statistically significant at the 5% level of probability.

RESULTS AND DISCUSSION

Yield and yield attributes: The results indicated that the irrigation schedule and polymers had a substantial impact on the plant height, number of cobs/ha, and cob diameter. In three irrigations, the highest and lowest values of these yield qualities were recorded in one irrigation. Baby corn and fodder yield in I_3 were significantly higher compared to other irrigation treatments. Irrigation produced a significantly higher economic yield of baby corn than other irrigation treatments. The baby corn yield decreased by 20.99 and 25.50% from I_4 to I_3, 22.75 and 35.20% from I_4 to I_2, and 27.47 and 48.89% from I_4 to I_1 during the study period, first and second year, respectively (Table 1 and Fig. 1a and b). Water crises and excessive evapotranspiration cause crops to develop perpetually under water stress. It is exceedingly difficult to get a decent level of production when there is little water. Dar *et al.* (2017) and Anu *et al.* (2023b) found that the growth and yield characteristics were to blame for the decreased fodder and cob yield.

The baby corn yield was varied as a result of the polymer treatments implemented. The use of polymers resulted in the maximum cob production, whereas the absence of polymers (control) led to the lowest cob yield. The yield had a significant rise of 27.16%, 133.09%, 52.62%, 165.98%, as well as 8.38% and 104.9%. The application of hydrogel at a rate of 2.5 kg/ha, hydrogel at a rate of 5.0 kg/ha, and *goundkatira* @5 kg/ha, compared to no polymers, during the first and second year, respectively, may be attributed to the increased water availability in dry conditions. This application helps to prevent delays in emergence and prolongs water availability, as supported by Mandal *et al.* 2015 and Shweta *et al.* 2022b.

Water productivity: The water productivity was considerably higher when only one irrigation was applied at sowing (I1), compared to the other irrigation treatments (Table 1 and Fig. 1a and b). However, the lowest water productivity was recorded while using three irrigation events, with the first one occurring during planting. The second stage occurs when the plant is at knee height, and the third stage occurs before tasseling. The decrease in water productivity resulting from three irrigation methods was smaller than the increase in irrigation due to the proportional increase in yield utilizing three irrigation cycles resulted in higher evaporation losses compared to utilizing only one irrigation cycle, leading to reduced water production (Singh *et al.* 2015, Shweta *et al.* 2022b, Anu *et al.* 2023a).

The impact of polymers was substantial since the utilization of hydrogel enhanced water production. The incorporation of *goundkatira* in baby corn resulted in a 22.25% rise in the first year and a 79.97% increase in the second year. Additionally, the application of hydrogel @5.0 kg/ha led to a 43.14% increase in water productivity in the first year and a 134.28% increase in the second year. This phenomenon can be attributed to the presence of polymers, which enhance the soil's capacity to absorb and retain a greater amount of moisture, while also facilitating a controlled and progressive release of the stored moisture (Nutan Kujur *et al.* 2022 and Shweta *et al.* 2022b). Applying polymers can lead to an augmentation in grain production, since polymers aid in facilitating the plant's physiological processes during periods

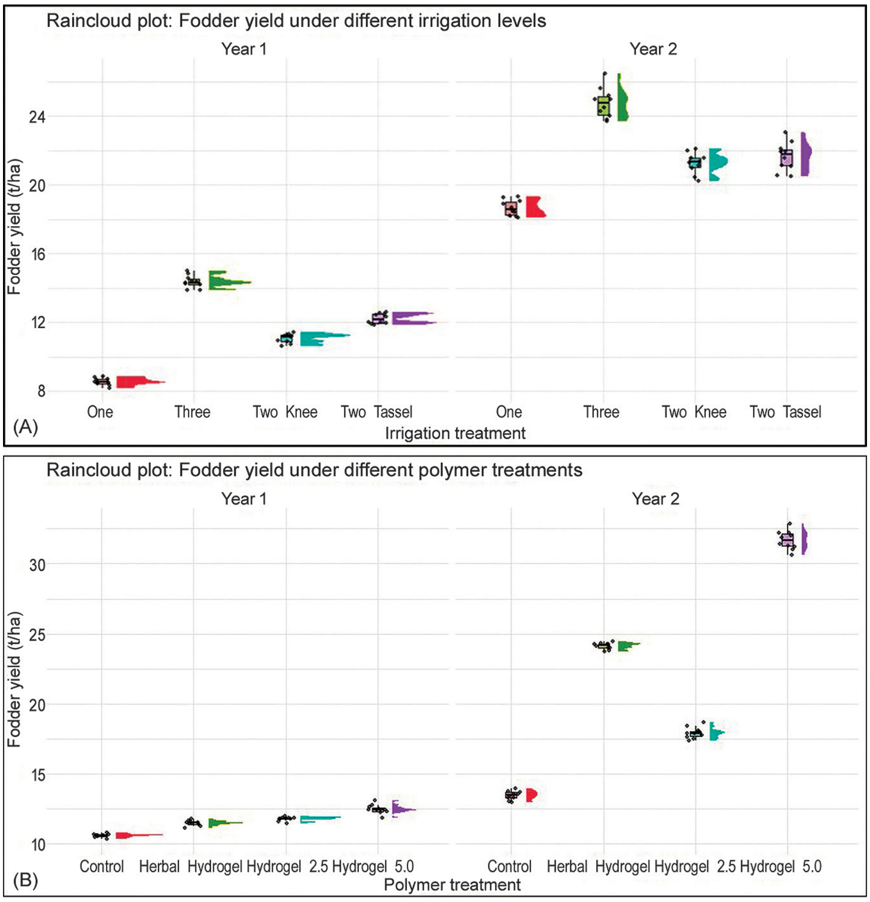

Fig 1 (A) Raincloud plot fodder yield under different irrigation levels; (B) Fodder yield under different polymers.

Table 1 Effect of irrigation and polymer treatments on baby corn yield and attributes (2019 and 2020)

Treatments	Plant height at harvest (cm)		No. of cobs/ ha		Cob diameter (cm)		Cob length (cm)		Fodder yield (t/ha)		Cob wt without husk (kg/ha)		WUE (kg/ha-mm)	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Irrigation levels (4)														
I_1, One irrigation at sowing	122.8	143.0	55675	52,461	1.04	1.06	5.70	5.6	8.62	18.84	435.38	138.5	17.31	7.37
I_2, Two irrigations, 1st at sowing; 2nd at knee high stage	142.8	146.0	59157	57,884	1.13	1.15	5.87	5.75	11.16	21.14	463.66	175.6	9.73	6.92
I_3, Two irrigations, 1st at sowing; 2nd at before tasseling	147.7	154.8	65527	62,731	1.23	1.25	5.90	5.9	12.20	22.18	474.24	201.9	12.02	7.26
I_4, Three irrigations, 1st at sowing; 2nd at knee high stage; 3rd before tasseling	150.6	162.0	69475	73,671	1.29	1.30	6.34	6.4	14.45	25.15	600.24	271.0	9.49	7.07
CD (*P*=0.05)	3.4	4.3	7208	3556	0.03	0.04	0.10	0.10	0.20	0.65	38.01	2.4	1.67	0.20
Polymers (4)														
P_1, Control	137.5	142.0	56185	54,447	1.16	1.17	5.90	5.86	10.68	13.53	404.31	97.9	10.02	4.42
P_2, Hydrogel @2.5 kg/ha	143.3	149.5	63148	62,748	1.15	1.16	5.93	5.8	11.76	18.02	513.94	228.2	12.25	5.878
P_3, Hydrogel @5.0 kg/ha	144.6	166.0	72407	68,068	1.21	1.23	5.94	5.89	12.45	31.37	617.07	260.4	14.34	10.355
P_4, Herbal hydrogel (*goandkatira*) @5 kg/ha	138.4	148.3	58096	61,484	1.17	1.18	6.03	6.1	11.53	24.38	438.20	200.6	12.25	7.955
CD (*P*=0.05)	3.8	3.9	11636	3513	0.04	0.04	NS	NS	0.19	0.36	73.81	2.7	1.16	0.11

WUE, Water use efficiency (kg/ha mm).

of water stress. The utilization of hydrogel and *goundkatira* can be a viable method for cultivating crops in soils with little water retention capacity. This is particularly beneficial in situations when rainfall or irrigation water, together with fertilizers, quickly drain below the root zone, resulting in inefficient utilization of water and fertilizers.

Plant water relation: The plant's water relation features, namely the relative water content (RWC) and the electrolyte leakage (ELWL), were measured on totally enclosed leaves located in the sun, in the uppermost third of the canopy, under various experimental conditions (Table 2).The root water content (RWC) of baby corn leaves was significantly lower when only one irrigation was applied at sowing, compared to the conditions where two irrigations were applied (at sowing and knee height stage), two irrigations were applied (at sowing and before tasseling), and three irrigations were applied (at sowing, knee height stage, and before tasseling). However, the equivalent leaf water loss (ELWL) was higher under low irrigation frequencies. This phenomenon might be attributed to the ongoing transpiration process in the presence of water scarcity (Sharma and Kumar 2014, Shweta *et al.* 2020). Enhancing water stress or decreasing irrigation frequency resulted in an augmentation of plant water relations.

The impact of polymers on plant water relations was much greater than that of the control. The utilization of Hydrogel resulted in greater levels of RWC and ELWL compared to the control, with the exception of the first year where ELWL was higher in the control group. Increased RWC of leaves leads to improved physiological functioning, specifically enhanced efficiency under low moisture conditions (Chena *et al.* 2012). The utilization of hydrogel and *groundkatira* can effectively save water and enhance the soil's water retention capacity. This results in a greater availability of water, leading to a rise in the RWC of leaves, as well as improved plant development and production, even under circumstances of water stress.

Photosynthesis activity and SPAD value: Different irrigation treatments had a notable impact on chlorophyll levels. During the first year, the SPAD values of the three irrigation treatments were 5.50% higher than the SPAD values of the one irrigation treatment at sowing. In the second year, the SPAD values of the three irrigation treatments were 20.69% higher than the SPAD values of the one irrigation treatment at sowing (Table 2). The SPAD values and photosynthesis exhibited a positive correlation and served as a measure of photosynthetic activity (Zhang *et al.* 2014). A high concentration of chlorophyll suggested a minimal level of light-induced damage and minimizes the loss of carbohydrates during the growth of grains. The foliar chlorophyll concentration of a leaf serves as an indication of a plant's photosynthetic activity. The variations in the chlorophyll composition of polymers are especially noteworthy (Table 2). The data indicated that the use of hydrogel had a growth of 11.66–14.8% in the first year and 7.71–14.14% in the second year. Additionally, *goundkatira* resulted in a rise of 10.54% and 3.08% in chlorophyll content during the first and second years, respectively.

Data predicted (Table 2) that The NDVI was not considerably influenced by either irrigation or polymers. The

Table 2 Effect of irrigation and polymer treatments on physiological parameters of baby corn

Treatment	SPAD Value		NDVI		RWC%		ELWL%		FV/FM	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Irrigation levels (4)										
I_1, One irrigation at sowing	47.3	37.2	0.68	0.65	76.9	70.2	44.5	37.5	0.678	0.676
I_2, Two irrigations, 1st at sowing; 2nd at knee high stage	48.4	40.4	0.70	0.68	80.7	74.7	40.5	43.5	0.682	0.678
I_3, Two irrigations, 1st at sowing; 2nd at before tasseling	49.3	42.8	0.71	0.70	84.1	78.2	41.8	44.6	0.684	0.680
I_4, Three irrigations, 1st at sowing; 2nd at knee high stage; 3rd before tasseling	49.9	44.9	0.72	0.71	86.9	80.3	38.8	47.8	0.690	0.692
CD (P=0.05)	1.66	1.19	NS	NS	1.88	2.29	2.59	4.42	NS	NS
Polymers (4)										
P_1, Control	44.6	38.9	0.69	0.66	79.4	73.8	43.9	41.6	0.670	0.672
P_2, Hydrogel @2.5 kg/ha	49.8	41.9	0.71	0.70	83.0	74.6	39.7	43.0	0.688	0.682
P_3, Hydrogel @5.0 kg/ha	51.2	44.4	0.72	0.71	84.6	79.1	42.8	46.7	0.689	0.691
P_4, Herbal hydrogel (*goandkatira*) @5 kg/ha	49.3	40.1	0.70	0.69	81.5	76.0	39.3	42.1	0.687	0.681
CD (P=0.05)	1.33	1.13	NS	NS	1.73	2.04	2.53	2.72	-	-

SPAD, Soil plant analysis development; NDVI, Normalized difference vegetation index; RWC, Relative water content; ELWL, Excised leaf water loss (g/g); FV, Variable fluorescence; FM, Maximum fluorescence.

study's findings indicated that the NDVI reached its peak in plots that received three irrigation sessions, whereas the lowest NDVI value was seen in plots that received only one irrigation at the time of planting. The addition of polymers resulted in an increase in NDVI values. *Goundkatira* improved NDVI by 1.45 and 4.54% in the first and second year, respectively. The application of hydrogel @2.5 kg/ha increased NDVI by 2.90% in the first year and 6.06% in the second year. Similarly, the application of hydrogel @5.0 kg/ha increased NDVI values by 4.35% in the first year and 7.58% in the second year.

Chlorophyll fluorescence is considered crucial for assessing plant health and is useful in identifying stress tolerance. Lichtenthaler *et al.* (2005), found a substantial association between the ratio of fluorescence variable (Fv) and maximum fluorescence (Fm) and water stress. A study found that the use of irrigation treatment and polymer application did not have a significant impact on the Fv/Fm (maximum quantum efficiency of PS II) under water stress conditions. Specifically, when comparing one irrigation at sowing to no stress or three irrigations, the Fv/Fm ratio was lower (0.678 and 0.676) during the first and second year of the study, respectively. Chlorophyll fluorescence functioned as a non-invasive method for assessing drought resistance

Gas exchange characteristics: The gaseous exchange characteristics, such as Ps, stomatal conductance, and transpiration, exhibit a decline when water stress levels increase (Table 3). The percentage decrease in photosynthesis (PN), transpiration (E), and stomatal conductance (GS) after one irrigation at sowing compared to three irrigations at sowing, knee high, and before tasseling was 16.09% and 29.38%; 17.90% and 16.92%; and 14.97% and 15.79% during the first and second years of the study, respectively. The improved root water capacity (RWC) facilitated the plants' execution of physiological functions such as stomatal conductance, photosynthesis, transpiration, and biochemical metabolism, enabling them to operate more effectively even in situations of limited soil moisture (Chena *et al.* 2012).

The hydrogel at a dosage of 5 kg/ha exhibited the greatest polymerization number among the polymers, closely followed by the hydrogel at a dosage of 2.5 kg/ha and *goundkatira* at a dosage of 5 kg/ha. The presence of a cooler canopy can be linked to improved water absorption, more effective root function, and sustained water levels for a longer duration. This leads to the opening of stomata and the continuation of transpiration even under conditions of moisture stress (Wasson *et al.* 2012, Sharma and Kumar 2014).

Treatments that maintained greater relative water content (RWC) exhibited a cooler canopy (increased canopy temperature depression, CTD) and higher rates of photosynthetic assimilation (PN), and vice versa. Treatments with higher relative water content (RWC) exhibited a larger number of grains per spike, increased biomass, and improved seed output. A robust and favorable connection was observed between relative water content (RWC) and photosynthetic rate (PN), suggesting that genotypes with elevated RWC exhibited increased rates of photosynthesis.

Therefore, based on the findings from these two years, it can be inferred that the parameters related to the relationship between the plant and water directly influenced the development of yield through yield characteristics. The utilization of polymers such as hydrogel and *goundkatira* has promise in mitigating drought by improving plant

Table 3 Effect of irrigation and polymer treatments on physiological parameters of baby corn

Treatment	Proline content (µg/FW)		Photosynthesis rate (µ mole/m^2/s)		Transpiration rate (m mole/m^2/s)		Stomatal conductance	
Irrigation levels (4)	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
I_1, One irrigation at sowing	143.7	147.9	14.6	12.5	3.90	4.86	0.142	0.144
I_2, Two irrigations, 1st at sowing; 2nd at knee high stage	128.4	130.0	16.0	16.2	4.49	5.43	0.162	0.165
I_3, Two irrigations, 1st at sowing; 2nd at before tasseling	138.0	113.8	17.3	18.1	4.70	5.81	0.169	0.175
I_4, Three irrigations, 1st at sowing; 2nd at knee high stage; 3rd before tasseling	100.0	110.9	17.4	17.7	4.75	5.85	0.167	0.171
CD (P=0.05)	4.44	8.19	1.83	0.87	0.050	0.346	0.018	0.020
Polymers (4)								
P_1, Control	142.6	141.5	12.3	15.0	3.53	5.18	0.14	0.143
P_2, Hydrogel @2.5 kg/ha	137.3	121.5	17.3	16.5	4.80	5.47	0.16	0.163
P_3, Hydrogel @5.0 kg/ha	99.9	115.0	18.0	17.2	5.02	5.87	0.178	0.183
P_4, Herbal hydrogel (*goandkatira*) @5 kg/ha	130.3	124.7	17.8	15.8	4.49	5.43	0.162	0.165
CD (P=0.05)	2.52	7.79	1.56	0.81	0.59	0.133	0.024	0.026

water status and gaseous exchange in field crops under varying levels of moisture stress. This application should be employed to achieve higher production and economic gains.

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