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Original Article

Enhancing Cauliflower Growth, Yield, and Water Management: Effects of Drip Irrigation and Manures under Black Polyethylene Mulching in a Local Climate

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Abstract *- Water scarcity can significantly impact food production in regions with limited water resources. To address this challenge and ensure food security, efficient irrigation systems combined with suitable organic fertilizer management practices are essential. In this context, a field trial was performed at the Agricultural Field Research Center, BOU, from November 2021 to March 2022, aiming to evaluate the influence of various irrigation planes and manure types on cauliflower growth, yield and water management beneath drip irrigation and black polyethylene mulches in a local climate. The experiment comprised two irrigation levels (2-day and 4-day intervals) and three fertilizer options (chemical fertilizer, cow dung, and vermicompost), resulting in six treatments as designed by a randomized complete block with three replications. The use of vermicompost in combination with a 4-day irrigation interval and black polyethylene mulching significantly increased plant height throughout the growth stages. Additionally, the application of organic manure positively affected leaf number, leaf size, and overall cauliflower plant development. Regarding cauliflower yield, the curd initiation period was shortened with increased irrigation frequency and the use of vermicompost. The highest curd weight, diameter, stem diameter, yield, and gross yield were observed at 19.48 cm, 3.82 cm, 13.30 kg plot^{-1} and 33.25 t ha^{-1}, respectively, with a 4-day irrigation interval and vermicompost application. In terms of water requirement in a growing seasonal and water use efficiency, the combination of a 4-day irrigation interval with vermicompost demonstrated the lowest water requirement (424.77 mm) and the highest water use efficiency (78.28 kg/ha-mm). Climatic conditions varied during different growth stages, including temperature, humidity, wind speed, and sunshine hours. Overall, the research findings suggest that utilizing a 4-day irrigation interval with vermicompost, in conjunction with drip irrigation, black polyethylene mulching and local climatic content, is a recommended approach to maximize cauliflower yield in Bangladesh. This approach can help address water scarcity challenges and enhance cauliflower production for local farmers.*

Keywords *- Drip irrigation, Manures, Mulching, Cauliflower growth and yield, Water requirement.*

1. Introduction

Bangladesh's fertile agricultural lands nurture various crops, with cauliflower (*Brassica oleracea* L.) being a cherished winter vegetable, both locally and globally. This annual crop, propagated from seeds, is renowned for its edible white curd, rich in nutrients like dietary fibre, folate, vitamin C, and phytochemicals. Notably, a high cauliflower intake reduces the risk of aggressive prostate cancer. In the 2018-2019 season, Bangladesh produced a remarkable 284,327 metric tons of cauliflower on approximately 4.99 hectares of land (BBS, 2019). Despite its significance, cauliflower cultivation faces challenges related to traditional farming practices and low-yield varieties. This research focuses on innovative methods such as efficient drip irrigation, organic manure use, and black polyethylene mulching. These approaches aim to boost cauliflower yield, conserve water, and enhance sustainability, aligning with Bangladesh's goal of achieving self-sufficiency in cauliflower production.

In the context of changing climate patterns and decreased rainfall, efficient irrigation management has become imperative (Kimura et al., 2007). Drip irrigation has demonstrated its advantages compared to traditional irrigation techniques, particularly in horticultural crops, because of its accurate and targeted water delivery to the root area (Malik et al., 1994). Recent research by Neima et al. (2020) emphasized the importance of water use efficiency (WUE) in cauliflower production and the role of alternative irrigation sources in enhancing it. Kumari et al. (2020)

underscored the benefits of drip irrigation over surface irrigation, highlighting its water-saving potential and positive impact on cauliflower yields. Moreover, the combination of drip irrigation with plastic mulching has been particularly effective in improving water use efficiency.

Recent research highlights the significant benefits of organic manures and vermicompost in enhancing cauliflower production (Yeasmin et al., 2021). Organic manures, including cow dung, mustard oilcake, and poultry manure, not only promote plant growth but also offer a cost-effective alternative to inorganic fertilizers (Haque, 2000). Vermicompost improves root formation, fruit set, yield, and nutrient uptake, resulting in organically produced cauliflower with higher nutritional value (Arancon et al., 2005; Tejada et al., 2007).

Mulching, such as black plastic mulch, plays a pivotal role in cauliflower cultivation by maintaining soil temperature (Dodds et al., 2003; Heibner et al., 2005), conserving moisture, controlling weeds (Benoit & Ceustermans, 1996) and have adverse effects on plant growth (Perez et al., 2000). A more recent study conducted by Xie et al. in 2022 highlighted that the joint utilization of straw and plastic film mulching resulted in a notable improvement in dry matter accumulation, yield, and overall quality of cauliflower.

The existing literature on cauliflower production tends to focus on isolated factors, leaving a research gap in understanding their combined impact. Moreover, many studies are region-specific, limiting their broader applicability. This research aims to address these limitations by comprehensively investigating how irrigation levels, organic manures, and mulching interact to influence cauliflower growth and yield across diverse environments. The primary objectives of this study are to assess how various irrigation levels and organic fertilizers applied at different growth stages impact the growth and yield of cauliflower when utilizing a combination of drip irrigation and black polyethylene mulch. Additionally, the study aims to determine the seasonal water requirements for cauliflower cultivation while considering prevailing climatic conditions and to elucidate an effective water management system tailored to local weather patterns for the specific needs of cauliflower cultivation.

2. Materials and Methods

2.1. Location of Experiment and Climatic Condition

The experimental site for this study was located at the Agricultural Field Research Center, situated on the campus of Bangladesh Open University in Gazipur. The site's topography was uniformly level, and the soil exhibited a sandy loam texture with a pH level of 6.06. It is important to note that this region experiences a subtropical monsoon climate, characterized by substantial rainfall during the *Kharif* season, with minimal precipitation during the remainder of the year. The *Rabi* season, spanning from October to March, is marked by ample sunshine and moderately low temperatures, making it conducive to cauliflower cultivation in Bangladesh. Before commencing the experiment, a comprehensive soil analysis was conducted. The soil was identified as sandy loam with a field capacity of 29.60%. Furthermore, previous research by Islam et al. (2022) conducted in the same field provided insights into the levels of calcium (Ca), magnesium (Mg), potassium (K), nitrogen, phosphorus (P), and copper (Cu) for strawberry cultivation. Moreover, monthly weather data, including air temperature, sunshine hours, rainfall, and relative humidity, was collected both from the experimental field and the Gazipur weather station. This data is summarized in Table 1.

2.2. Seed Collection, Preparation of Seedbed and Sowing

F_1 hybrid cauliflower (*Brassica oleracea* L.) seeds were purchased from Kazi Fertilizer in Gazipur, and they were packaged by Seng Heng Huat Seed Co., Ltd. The seedbed measured 3 m × 1 m. Sowing commenced on October 01, 2021, with seeds planted 2 cm deep and spaced at 5 cm intervals. After germination, straw covers were removed, and the seedlings received light watering and weeding. No chemical fertilizers were used during seedling growth, and the seedlings remained free from insect or disease infestations. Healthy seedlings were subsequently transplanted and remained in the seedbed for 30 days.

Table 1. The study period encompassed monthly variations in air temperature, sunshine hours, relative humidity, and rainfall within the experimental area

Months	*Air temperature (^{0}C)			*Sunshine hours	*Mean relative humidity (%)	**Rainfall (mm)
	Max.	Min.	Mean			
November 2021	30.08	18.04	24.06	7.12	84.1	17
December 2021	26.86	15.53	21.195	5.99	84.5	249
January 2022	25.45	13.75	19.6	5.15	82.23	0
February 2022	26.76	18.09	22.425	7.78	78	36

*Monthly average; **Monthly total

Source: Weather Station, Gazipur

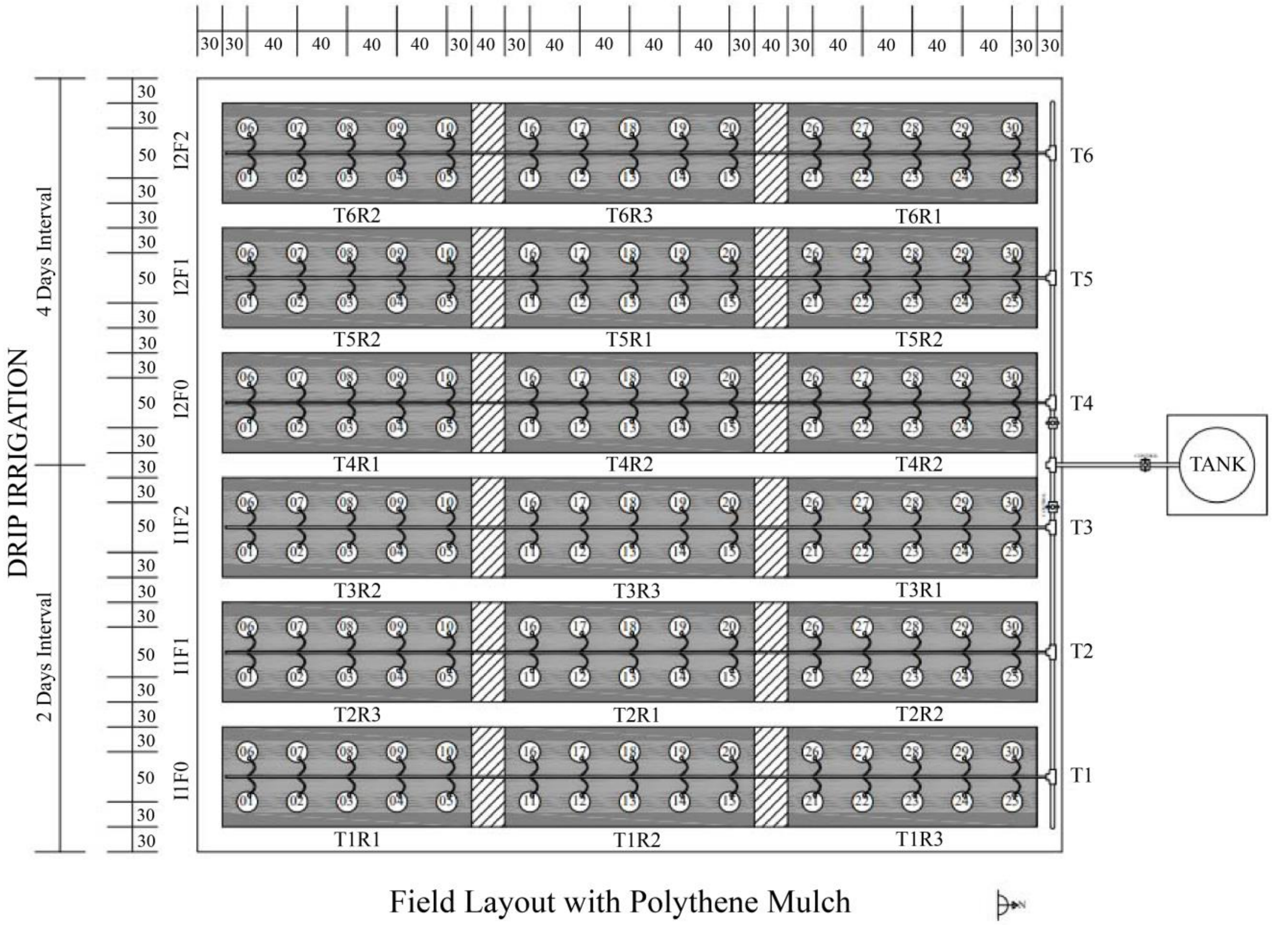


Fig. 1 Layout of the experimental cauliflower cultivation field

2.3. Experimental Design and Factors

The experimental setup adhered to a Randomized Complete Block Design (RCBD), with each replication consisting of three samples. It encompassed two primary factors: three variations in organic manures/fertilizers and two distinctions in irrigation levels. Each individual plot measured 4.0 m × 1.0 m, with plant spacing set at 50 cm × 50 cm. Two irrigation levels were applied, I_1 (2-day intervals) and I_2 (4-day intervals), along with three fertilizer/organic manure doses: F_0 (Chemical fertilizer), F_1 (Cow dung), and F_2 (Vermicompost).

All the plots were covered with black polyethylene mulch. Six treatment combinations were tested: T_1: Drip irrigation @ 2 days interval (I_1) × Chemical fertilizer (F_0); T_2: Drip irrigation @ 2 days interval (I_1) × Cow dung (F_1); T_3: Drip irrigation @ 2 days interval (I_1) × Vermicompost (F_2); T_4: Drip irrigation @ 4 days interval (I_2) × Chemical fertilizer (F_0); T_5: Drip irrigation @ 4 days interval (I_2) × Cow dung (F_1); and T_6: Drip irrigation @ 4 days interval (I_2) × Vermicompost (F_2**)**. Figure 1 shows the experimental field layout for cauliflower cultivation.

2.4. Preparation of the Land and the Management of Fertilizers

The experimental land was ready starting on October 08, 2021, using a tiller. It was exposed to sunlight for a duration of five days to enhance soil conditions for cauliflower cultivation. Multiple ploughing passes with the power tiller were carried out to achieve suitable soil tilth. Efforts were made to remove weeds and stubbles from the field and break down large clods into smaller pieces. The application of fertilizers and organic materials was used according to the treatment requirements of each plot. Chemical fertilizer was applied at a rate of 135-60-135-21-3-1.5 kg ha^{-1} of N-P-K-S-Zn-B (BARC, 2012). Cow dung and vermicompost were applied at 5 t ha-1 each. A uniform dose of manures and fertilizers was manually applied during field preparation. For the plots receiving chemical fertilizer, TSP was used during the last ploughing to meet the total phosphorus (P) requirement. Nitrogen (N) and potassium (K) were evenly distributed in four applications, with 15-day intervals, throughout the growing season. This approach ensured proper nutrient management without repetition.

2.5. Transplanting and Mulching

After 30 days from emergence, the transplantation of the seedlings (with 5-6 true leaves) to the main field took place on November 01, 2021. It is arranged in two rows within each bed, with each plot measuring 4.0 m x 1.0 m and accommodating 16 seedlings spaced at 0.50 m x 0.50 m. Transplanting took place in the afternoon, followed by a light watering. Shading and watering continued until the seedlings were well-established. 200-gauge black polyethylene sheets measuring 1.0 m x 4.0 m were used to implement mulching. Holes were made in the polyethylene sheets at intervals of 0.0254 m x 0.0254 m, corresponding to the plant and row spacing. These prepared polyethylene sheets were placed on the topsoil of randomly selected beds, followed by transplanting.

2.6. Irrigation Management

The plants received immediate watering after transplanting. Subsequently, until the seedlings became established, watering occurred twice with a 1-2 day interval. Following this, irrigation was conducted according to the treatment plans: T_1 to T_3 with 2-day intervals and T_4 to T_6 with 4-day intervals, utilizing drip irrigation. Precautionary measures are implemented to avoid water stress from head development to head maturity. It is worth noting that heavy rainfall occurred twice during the experimental period, necessitating the removal of excess water from the field.

2.7. Data Collection during the Cauliflower Growing Season

Ten plants were chosen randomly from each unit plot, excluding those situated in the outer rows and extreme ends to mitigate border effects. Data related to plant height (in centimeters), the leaf count per plant, and measurements of the largest leaf (both length and width in centimeters), and plant spacing (cm^2) were systematically recorded as outlined in the experimental design. Cauliflower curd did not mature simultaneously; harvest occurred from January 18, 2022, to January 28, 2022. The harvested cauliflower was placed in pre-categorized polyethylene bags and shifted to the experimental laboratory for more investigation.

Data related to yield, including the number of days from transplant to curd initiation, curd initiation to harvest (days), curd fresh weight including leaves (in grams per plant), leaves fresh weight (in grams per plant), curd fresh weight (in grams per plant), curd diameter at the time of harvest (in centimeters), curd stem diameter at the time of harvest (in centimeters), yield per plot (in kilograms), and yield per hectare (in tons), were meticulously documented for each treatment. Additionally, daily weather data, encompassing air temperature, sunshine hours, rainfall, and relative humidity, was gathered from both the research site and the weather station of Gazipur to assess local climatic impacts on cauliflower cultivation.

2.8. Seasonal Water Requirement and Water Use Efficiency

After the plants were established, soil moisture levels were assessed before irrigation initiation and harvest time. The gravimetric method was employed for these measurements. Afterwards, irrigation water is used to restore soil moisture to its optimal level, considering the depth of the root zone. The plants started irrigation treatments once they had become established. In the experimental field, two irrigation levels were implemented by drip methods at 2-day and 4-day intervals. During the experiment, plots with 2-day irrigation intervals (treatments T_1 to T_3) received a total of 20 irrigation applications. In contrast, plots with 4-day irrigation intervals (treatments T_4 to T_6) required a total of 11 irrigations. The depth of irrigation water is calculated based on the provided equation (Michael, 1978):

$$d = \frac{FC - MCi}{100} \times As \times D$$

Where d represents the irrigation depth in cm, FC signifies the soil's field capacity as a percentage (%), MCi indicates the soil's moisture content before irrigation as a percentage (%), A_s is the soil's apparent specific gravity, and D is the effective root zone depth (cm).

Islam et al. calculated the seasonal water requirement in 2022 using the water balance equation. The formula determined water use efficiency (WUE) as:

$$\text{WUE (Kg/ha - mm)} = \frac{\text{Yield of cauliflower (Kg ha}^{-1}\text{)}}{\text{Seasonal water requirement (mm)}}$$

2.9. Statistical Examination

Statistical analysis was conducted employing R 4.2.2 software to evaluate the presence of significant disparities among the outcomes associated with the various irrigation and fertilizer treatments. Mean values within each treatment category underwent a comparative examination utilizing the LSD test, with significance thresholds established at both 1% ($P \leq 0.01$) and 5% ($P \leq 0.05$).

3. Results and Discussion

3.1. Cauliflower Growth Parameters as Affected by Irrigation and Fertilizer/Manure

Table 2 displays the impact of irrigation and fertilizer/manure treatments on cauliflower plant height during distinct growth phases as 30, 45, and 60 DAT and at harvest. Noteworthy changes were noted between irrigation levels, with the 4-day interval resulting in the tallest plants compared to the 2-day interval. Vermicompost led to the highest plant height, while chemical fertilizer resulted in the lowest at all growth stages. Throughout the experiment, the combined effect of irrigation and manure consistently produced the tallest plants with the 4-day irrigation interval when using vermicompost. This highlights the significant influence of vermicompost, likely due to improved soil fertility and nutrient availability over chemical fertilizer. These findings align with earlier investigations (Farzana et al., 2016; Ali et al., 2018). Plant height gradually increased during the growth period, reaching its maximum at harvest across all treatments, consistent with earlier research by Sani et al. (2018) and Eimon et al. (2019). In conclusion, organic manure and irrigation levels significantly impact cauliflower plant height (Akhter et al., 2019).

Table 2. Effects of irrigation and fertilizer/manure on the height of plant (cm) at different growth stages of cauliflower

Factors/Treatments	Plant height (cm) at different DAT			
	30	45	60	During harvest
Irrigation level				
2-days interval (I_1)	22.11	27.11	37.67b	44.89b
4-days interval (I_2)	23.56	28.56	39.33a	47.00a
LSD	1.627^{ns}	1.627^{ns}	0.606***	0.933***
CV (%)	6.785	5.566	1.500	1.933
Level of fertilizer/manures				
Chemical fertilizer (F_0)	21.83	26.83	37.00b	47.00a
Cowdung (F_1)	23.50	28.50	39.17a	46.67a
Vermicompost (F_2)	23.17	28.17	39.33a	44.17b
LSD	1.993^{ns}	1.993^{ns}	0.743***	1.143***
CV (%)	6.785	5.566	1.500	1.933
Interactions				
$T_1= I_1\times F_0$	20.67b	25.67b	36.33c	43.33c
$T_2= I_1\times F_1$	23.00ab	28.00ab	38.33b	46.00b
$T_3 = I_1\times F_2$	22.67ab	27.67ab	38.33b	45.33b
$T_4 = I_2\times F_0$	23.00ab	28.00ab	37.67b	45.00b
$T_5= I_2\times F_1$	24.00a	29.00a	40.00a	48.00a
$T_6= I_2\times F_2$	23.67a	28.67a	40.33a	48.00a
LSD	2.818*	2.818*	1.050*	1.616*
CV (%)	6.785	5.566	1.500	1.933

Note: DAT= Days after transplant; the results were analyzed using the LSD test, and no statistical differences were observed among the groups in the same letter. "ns" means non-significant, "***" indicates a very high 0.1% level, "*" shows 5.0% level.

Table 3. Effects of irrigation and fertilizer/manure on the count of leaves per individual plant at different growth stages of cauliflower

Factors/Treatments	Counting of leaves per individual plant at different DAT			
	30	45	60	During harvest
Irrigation level				
2-days interval (I_1)	8.89	12.44	18.00	19.00
4-days interval (I_2)	9.44	12.78	18.22	19.44
LSD	0.718^{ns}	1.045^{ns}	1.161^{ns}	1.238^{ns}
CV (%)	7.452	7.885	6.104	6.131
Level of fertilizer/manures				
Chemical fertilizer (F_0)	8.17b	11.17b	17.17b	18.17b
Cowdung (F_1)	9.33a	12.83a	18.17ab	19.50ab
Vermicompost (F_2)	10.00a	13.83a	19.00a	20.00a
LSD	0.879**	1.279**	1.422*	1.516*
CV (%)	7.452	7.885	6.104	6.131
Interactions				
$T_1= I_1\times F_0$	8.00c	11.33bc	17.00	18.00
$T_2= I_1\times F_1$	9.00bc	12.67abc	18.00	19.00
$T_3 = I_1\times F_2$	9.67ab	13.33a	19.00	20.00
$T_4 = I_2\times F_0$	8.33c	11.00c	17.33	18.33
$T_5= I_2\times F_1$	9.67ab	13.00ab	18.33	20.00
$T_6= I_2\times F_2$	10.33a	14.33a	19.00	20.00
LSD	1.243*	1.809*	2.011^{ns}	2.144^{ns}
CV (%)	7.452	7.885	6.104	6.131

Note: DAT= Days after transplant; the results were analyzed using the LSD test, and no statistical differences were observed among the groups in the same letter. "ns" means non-significant, "***" indicates a very high 0.1% level, "*" shows 5.0% level.

The effects of irrigation and fertilizer/manures on the number of leaves per cauliflower plant at different growth stages as 30, 45, and 60 DAT and harvest are summarized in Table 3. Plants subjected to 4-day irrigation intervals consistently displayed the leaves number in each plant was highest compared to those under 2-day intervals. Concerning the type of fertilizer/manure used, vermicompost led to the highest count of leaves per individual plant, while chemical fertilizer led to the lowest leaf count throughout the cauliflower growth stages. The combined impact of irrigation and manure revealed that the 4-day irrigation interval with vermicompost consistently produced cauliflower plants with the tallest height. Organic manure application positively influenced leaf number at different DAT stages. The findings indicate that leaf number increased with increasing DAT and was further enhanced by the application of various organic manures, consistent with prior research on broccoli (El-Magd, 2013), Kohlrabi (Uddin et al., 2012), and cabbage (Hasan & Solaiman, 2012).

The impact of irrigation and fertilizer on the length (in centimeters) of cauliflower's largest leaf at various growth stages, including 30, 45, and 60 DAT, as well as at the harvest stage, is outlined in Table 4. Results showed that cauliflower plants subjected to 4-day irrigation intervals consistently exhibited longer leaves compared to those under 2-day intervals. Regarding fertilizer types, vermicompost led to significantly larger leaf sizes at various growth stages, while chemical fertilizer resulted in the smallest leaves. In terms of treatment interactions, the largest leaf lengths were recorded in the T_6 (I_2F_2) treatment, measuring 19.33 cm at 15 DAT, 33.67 cm at 30 DAT, 45.00 cm at 45 DAT, and 56.00 cm at harvest. Conversely, the smallest leaf lengths (16.33 cm at 15 DAT, 30.33 cm at 30 DAT, 41.33 cm at 45 DAT, and 52.00 cm at harvest) were observed in the T_1 (I_1F_0) treatment. This difference could be attributed to the plant's nutrient availability, stemming from organic and inorganic fertilizers. Comparable results were documented by Kachari and Korla (2009) in their study on leaf length.

Table 4. Effects of irrigation and fertilizer/manure on the largest leaf length (cm) of plant at various DATs of cauliflower

Factors/Treatments	Length (cm) of cauliflower's largest leaf at different DAT			
	30	45	60	During harvest
Irrigation level				
2-days interval (I_1)	17.67	31.67b	42.56b	53.89b
4-days interval (I_2)	18.78	33.00a	43.00a	54.67a
LSD	1.223^{ns}	0.996*	1.045***	0.783***
CV (%)	6.389	2.934	2.325	1.373
Level of fertilizer/manures				
Chemical fertilizer (F_0)	17.17b	31.00b	41.00b	52.33b
Cowdung (F_1)	18.50ab	32.67a	43.17a	54.83a
Vermicompost (F_2)	19.00a	33.33a	44.17a	55.67a
LSD	1.498*	1.220**	1.279*	0.959*
CV (%)	6.389	2.934	2.325	1.373
Interactions				
$T_1 = I_1 \times F_0$	16.33b	30.33c	41.33cd	52.00c
$T_2 = I_1 \times F_1$	18.00ab	31.67bc	43.00bc	54.33b
$T_3 = I_1 \times F_2$	18.67a	33.00ab	43.33ab	55.33ab
$T_4 = I_2 \times F_0$	18.00ab	31.67bc	40.67d	52.67c
$T_5 = I_2 \times F_1$	19.00a	33.67a	43.33ab	55.33ab
$T_6 = I_2 \times F_2$	19.33a	33.67a	45.00a	56.00a
LSD	2.118*	1.726*	1.809*	1.356*
CV (%)	6.389	2.934	2.325	1.373

Note: DAT= Days after transplant; the results were analyzed using the LSD test, and no statistical differences were observed among the groups in the same letter. "ns" means non-significant, "***" indicates a very high 0.1% level, "**" directs 1.0% level, "*" shows 5.0% level.

Table 5 illustrates the impact of irrigation and fertilizer varieties on the broadness of the largest cauliflower leaves during different growth phases, including 30, 45, and 60 DAT, and at harvest. Significant variations were perceived across growth stages, with the widest leaves consistently observed in the 4-day irrigation interval compared to the 2-day interval. Vermicompost application consistently resulted in significantly broader leaves, while chemical fertilizer had the narrowest leaves at all growth stages. In terms of treatment interactions, the widest leaves (9.67, 12.67, 16.33, and 20.00 cm at 15, 30, 45 DAT, and harvest, respectively) were recorded in T_6 (I_2F_2), while the narrowest (8.00, 10.00, 13.67, and 16.00 cm at same DAT and at harvest, respectively) were observed in T_1 (I_1F_0). This variation was attributed to vermicompost's positive influence on nitrogen uptake, promoting the vegetative growth of cauliflower plants. Analogous findings were reported in previous studies by Velmurugan et al. (2008).

Table 5. Effects of irrigation and fertilizer/manure on the largest leaf breadth (cm) of plant at different growth stages of cauliflower

Factors/Treatments	Largest leaf breadth (cm) at different DAT			
	30	45	60	During harvest
Irrigation level				
2-days interval (I_1)	8.33	11.33	14.67	17.89
4-days interval (I_2)	9.00	11.67	15.11	18.56
LSD	0.791^{ns}	0.920^{ns}	0.626^{ns}	1.045^{ns}
CV (%)	8.686	7.614	4.005	5.457
Level of fertilizer/manures				
Chemical fertilizer (F_0)	8.17b	10.17b	13.67b	16.33b
Cowdung (F_1)	8.67ab	11.67a	15.17a	18.67a
Vermicompost (F_2)	9.17a	12.67a	15.83a	19.67a
LSD	0.968*	1.126**	0.767***	1.279***
CV (%)	8.686	7.614	4.005	5.457
Interactions				
$T_1 = I_1 \times F_0$	8.00b	10.00b	13.67c	16.00c
$T_2 = I_1 \times F_1$	8.33ab	11.33ab	15.00b	18.33ab
$T_3 = I_1 \times F_2$	8.67ab	12.67a	15.33ab	19.33a
$T_4 = I_2 \times F_0$	8.33ab	10.33b	13.67c	16.67bc
$T_5 = I_2 \times F_1$	9.00ab	12.00a	15.33ab	19.00a
$T_6 = I_2 \times F_2$	9.67a	12.67a	16.33a	20.00a
LSD	1.369*	1.593*	1.085*	1.809*
CV (%)	8.686	7.614	4.005	5.457

Note: DAT= Days after transplant; the results were analyzed using the LSD test, and no statistical differences were observed among the groups in the same letter. "ns" means non-significant, "***" indicates a very high 0.1% level, "**" directs 1.0% level, "*" shows 5.0% level.

Table 6. Effects of irrigation and fertilizer/manure on surface area covered by the cauliflower plant (cm^2) at various growth stages

Factors/Treatments	Surface area covered by the cauliflower plant (cm^2) at various DAT			
	30	45	60	During harvest
Irrigation level				
2-days interval (I_1)	182.56b	262.33a	617.11b	708.11b
4-days interval (I_2)	188.11a	255.22b	628.00a	720.00a
LSD	5.164*	6.686*	8.850*	11.135*
CV (%)	2.652	2.460	1.353	1.485
Level of fertilizer/manures				
Chemical fertilizer (F_0)	169.67b	238.50b	591.00b	680.50b
Cowdung (F_1)	190.83a	266.00a	633.83a	726.00a
Vermicompost (F_2)	195.50a	271.83a	642.83a	735.67a
LSD	6.324***	8.188***	10.839***	13.638***
CV (%)	2.652	2.460	1.353	1.485
Interactions				
$T_1 = I_1 \times F_0$	170.33d	239.67c	592.67d	682.00d
$T_2 = I_1 \times F_1$	186.33c	260.33b	624.67c	716.33c
$T_3 = I_1 \times F_2$	191.00bc	265.67b	634.00bc	726.00bc
$T_4 = I_2 \times F_0$	169.00d	237.33c	589.33d	679.00d
$T_5 = I_2 \times F_1$	195.33ab	271.67ab	643.00ab	735.67ab
$T_6 = I_2 \times F_2$	200.00a	278.00a	651.67a	745.33a
LSD	8.943*	11.581*	15.328*	19.287*
CV (%)	2.652	2.460	1.353	1.485

Note: DAT= Days after transplant; the results were analyzed using the LSD test, and no statistical differences were observed among the groups in the same letter. "ns" means non-significant, "***" indicates a very high 0.1% level, "*" shows 5.0% level.

Table 7. Effects of irrigation and fertilizer/manure on yield parameters of cauliflower

Factors/ Treatments	Days taken for curd initiation from transplant	Days taken for curd initiation to harvest	Fresh weight of curd with leaves (g plant^{-1})	Fresh weight of leaves (g plant^{-1})	Fresh weight of curd (g plant^{-1})
Irrigation level					
2-days interval (I_1)	67a	19.11	1305a	511.44a	793.56b
4-days interval (I_2)	66b	18.11	1284b	486.11b	797.89a
LSD	0.858*	1.079^{ns}	2.029***	0.626***	2.476**
CV (%)	1.228	5.520	0.149	0.120	0.296
Level of fertilizer/manures					
Chemical fertilizer (F_0)	67.50a	17.83b	1282.00b	517.67a	764.33c
Cowdung (F_1)	66.50ab	18.50ab	1271.83c	478.33c	793.50b
Vermicompost (F_2)	65.50b	19.50a	1329.67a	500.33b	829.33a
LSD	1.050**	1.321*	2.486***	0.767***	3.032***
CV (%)	1.228	5.520	0.149	0.120	0.296
Interactions					
$T_1 = I_1 \times F_0$	68a	18.33ab	1292.00c	529.67a	762.33d
$T_2 = I_1 \times F_1$	67ab	19.00ab	1278.33d	487.33d	791.00c
$T_3 = I_1 \times F_2$	66bc	20.00a	1344.67a	517.33b	827.33a
$T_4 = I_2 \times F_0$	67ab	17.33b	1272.00e	505.67c	766.33d
$T_5 = I_2 \times F_1$	66bc	18.00b	1265.33f	469.33f	796.00b
$T_6 = I_2 \times F_2$	65c	19.00ab	1314.67b	483.33e	831.33a
LSD	1.485*	1.869*	3.515***	1.085***	4.288*
CV (%)	1.228	5.520	0.149	0.120	0.296

Note: The results were analyzed using the LSD test, and no statistical differences were observed among the groups in the same letter. "ns" means non-significant, "***" indicates a very high 0.1% level, "**" directs 1.0% level, "*" shows 5.0% level.

The impact of irrigation and fertilizer/manure on the cauliflower plant spreading area at 30, 45, and 60 DAT and harvest is shown in Table 6. Significant variations were observed in the spreading area across different growth stages. The highest spreading area was consistently observed with 4-day irrigation intervals compared to 2-day intervals. Among fertilizer/manure types, vermicompost consistently resulted in the highest spreading area at all cauliflower growth stages, while chemical fertilizer yielded the lowest spreading area.

In terms of treatment interactions, the maximum spreading area was recorded in T_6 (I_2F_2), with values of 200.00 cm^2 at 15 DAT, 278.00 cm^2 at 30 DAT, 651.67 cm^2 at 45 DAT, and 745.33 cm^2 at harvest. Conversely, the minimum spreading area was observed in T_1 (I_1F_0), with values of 170.33 cm^2 at 15 DAT, 239.67 cm^2 at 30 DAT, 592.67 cm^2 at 45 DAT, and 682.00 cm^2 at harvest. In conclusion, the application of vermicompost consistently led to increased canopy spreading in cauliflower plants, consistent with findings stated by Kachari and Korla (2009).

3.2. Cauliflower Yield Parameters as Affected by Irrigation and Fertilizer/Manure

Table 7 provides insights into how irrigation and fertilizer/manure choices influenced various yield-related factors at harvest. Notably, statistically weighty changes were detected concerning irrigation frequencies and the types of fertilizer/manure applied in relation to the days needed for curd initiation from transplant. Specifically, the 2-day irrigation interval required the longest period for curd initiation from transplant (67.00 days), whereas the 4-day interval showed the shortest duration (66.00 days). Additionally, the use of chemical fertilizer resulted in the highest number of days for curd initiation from transplant (67.50 days), while vermicompost led to the shortest duration (65.50 days). The interactive impact of irrigation and fertilizer/manures displayed important variances in the days required for curd formation, with the longest days (68.00) observed in the I_1F_0 (T_1) treatment and the lowest (65.00) in the I_2F_2 (T_6) treatment combination. This suggests that curd initiation in cauliflower plants decreased with increased irrigation frequency and the application of vermicompost, possibly due to improved water and nutrient uptake, as supported by Kumar and Choudhary (2002) and Thy and Buntha (2005). Regarding the days engaged for curd formation to harvest, the maximum (19.11) was recorded with the 2-day irrigation interval and the minimum (18.11) with the 4-day interval. Additionally, the maximum (19.50) was observed with vermicompost and the minimum (17.83) with chemical fertilizer. The integrative effect of irrigation and fertilizer/manures also displayed a substantial difference, with the maximum (20.00) in the I_1F_2 (T_3) treatment and the minimum (of 17.33) in the I_2F_0 (T_4) treatment combination.

Regarding cauliflower yield-related parameters, it is worth noting that the fresh weight of curd with leaves and only leaves exhibited higher values under the 2-day irrigation interval (1305 g plant^{-1} and 511.44 g plant^{-1}, respectively) when compared to the 4-day interval (1284 g plant^{-1} and 486.11 g plant^{-1}, respectively). However, the fresh weight of curd was higher with the 4-day irrigation interval (797.89 g plant^{-1}) compared to the 2-day interval (764.33 g plant^{-1}). When considering the effect of fertilizer/manures, vermicompost led to a higher fresh weight of curd with leaves (1329.67 g plant^{-1}) and fresh weight of curd (829.33 g plant^{-1}) compared to chemical fertilizer (1282 g plant^{-1} and 764.33 g plant^{-1}, respectively). On the other hand, chemical fertilizer resulted in a higher fresh weight of leaves (517.67 g plant^{-1}) compared to cow dung (478.33 g plant^{-1}). The combination of irrigation and fertilizer/manure notably impacted yield parameters, showing important dissimilarity. The highest fresh weight of curd with leaves (1344.67 g plant^{-1}) was recorded for the I_1F_2 (T_3) treatment, followed by 1314.67 g plant^{-1} for the combination of I_2F_2 (T_6) and I_2F_1 (T_5). The fresh weight of curd with leaves (1265.33 g plant^{-1}) was detected lowest for I_1F_0 (T_1). For fresh weight of leaves, the highest (529.67 g plant^{-1}) was in the I_1F_0 (T_1) treatment, followed by 517.33 g plant^{-1} for I_1F_2 (T_3), while the lowest (469.33 g plant^{-1}) was found in I_2F_1 (T_5). Concerning the fresh weight of curd, the highest (831.33 g plant^{-1}) was observed for the I_2F_2 (T_6) treatment, followed by 827.33 g plant^{-1} for I_1F_2 (T_3), while the lowest (762.33 g plant^{-1}) was recorded for I_1F_0 (T_1). The application of vermicompost substantially enhanced curd weight, potentially attributed to its gradual and consistent nutrient release, facilitating consistent curd development. Furthermore, the timing of irrigation application seemed to impact curd weight, potentially due to the interaction between organic manure, soil moisture, and plant water uptake, in agreement with earlier studies by Ghosh and Hasan (1997) and Rahman et al. (1998).

Table 8 displays the impacts of irrigation and fertilizer/organic manure treatments on cauliflower yield-related parameters at harvest time. Noteworthy differences were detected concerning curd diameter, curd stem diameter, yield per plot, and overall yield, stemming from the influence of both individual and combined impacts of irrigation and fertilizer/organic manure treatments. Regarding the impact of irrigation levels, cauliflower exhibited a higher curd diameter, curd stem diameter, yield per plot, and gross yield when subjected to a 4-day irrigation interval (18.51 cm, 3.73 cm, 12.77 kg plot^{-1}, and 31.92 t ha^{-1}, respectively) compared to a 2-days interval (17.89 cm, 3.65 cm, 12.70 kg plot^{-1}, and 31.74 t ha^{-1}, respectively). In terms of fertilizer/organic manures, vermicompost resulted in the highest curd diameter, curd stem diameter, yield, and gross yield (18.98 cm, 3.77 cm, 13.27 kg plot^{-1}, and 33.17 t ha^{-1}, respectively), followed by cow dung (18.30 cm, 3.67 cm, 12.70 kg plot^{-1}, and 31.74 t ha^{-1}, respectively). In comparison, the lowest values were observed with chemical fertilizer (17.32 cm, 3.62 cm, 12.23 kg plot^{-1}, and 30.57 t ha^{-1}, respectively). Yield parameters exhibited noteworthy variations as a result of the combined impact of irrigation and fertilizer/organic manure treatments. The highest values for curd diameter, curd stem diameter, yield, and gross yield were recorded in the I_2F_2 (T_6) treatment (19.48 cm, 3.82 cm, 13.30 kg plot^{-1}, and 33.25 t ha^{-1}, respectively), followed by I_1F_2 (T_3) (18.57 cm, 3.72 cm, 13.24 kg plot^{-1}, and 33.09 t ha^{-1}, respectively). Conversely, the lowest values were detected in the I_1F_0 (T_1) treatment (17.07 cm, 3.59 cm, 12.20 kg plot^{-1}, and 30.49 t ha^{-1}, respectively), with slightly higher values in I_2F_0 (T_4) (17.57 cm, 3.65 cm, 12.26 kg plot^{-1}, and 30.65 t ha^{-1}, respectively). Curd diameter and stem diameter, crucial yield parameters, exhibited significant increases with vermicompost compared to chemical fertilizer during cauliflower growth stages. Studies suggested that organic manures, like vermicompost, provide a slow and continuous nutrient supply, supporting plant growth, energy storage, cell division, and cell enlargement (Ahmed, 1982). The combined effect of irrigation and fertilizer/organic manure significantly influenced cauliflower yield. Vermicompost application particularly enhanced curd diameter and stem diameter, aligning with findings by Steffen et al. (1994) and Murlee et al. (2007). As practical in accordance with Islam et al. in 2022, the performance remained consistent across all irrigation levels, as previously reported by Pervin et al. in 2014, when combined with black polyethylene mulch.

3.3. Seasonal Water Requirement Analysis as Effected by Irrigation and Fertilizer/Manure

Significant variations in water management were observed in cauliflower cultivation at different levels of drip irrigation and fertilizers/manure applications (**Table 9**). Irrigation levels at 2-day and 4-day intervals resulted in cauliflower consuming 546.61 mm and 424.79 mm of water per season, with WUE values of 58.07 kg/ha-mm and 75.13 kg/ha-mm, respectively. Among fertilizers/manures, chemical fertilizer had the highest water requirement at 485.73 mm but achieved a WUE of 69.41 kg/ha-mm. In contrast, vermicompost had a water requirement of 485.69 mm and a WUE of 66.42 kg/ha-mm, while cow dung had a similar water requirement but a lower WUE. Interactive effects of irrigation and fertilizer/manures further influenced water requirements and WUE, with the highest water requirement (546.63 mm) and lowest WUE (55.78 kg/ha-mm) observed in the 2-day interval with chemical fertilizer (T_1), while the lowest water requirement (424.77 mm) and highest WUE (78.28 kg/ha-mm) were observed in the 4-day interval with vermicompost (T_6). The utilization of black polyethylene mulch significantly enhanced cauliflower water use efficiency (WUE), which is in line with prior research (Mukherjee et al., 2012; Biswas et al., 2015). The highest WUE was observed at the lowermost irrigation level, suggesting efficient water utilization (Dunage et al., 2009). The utilization of black poly mulch in this study aligns with the findings reported by Islam in 2023. Drip irrigation, by delivering water directly to the root zone, minimizes losses from deep percolation, runoff, seepage, and soil evaporation, consistent with findings in tomato and other crops (Singandhupe et al., 2003). Notably, employing a 4-day interval with drip irrigation and black plastic mulch effectively reduced soil surface evaporation.

Table 8. Effects of irrigation and fertilizer/manure on yield parameters of cauliflower

Factors/ Treatments	Curd diameter at harvest (cm)	Curd stem diameter at harvest (cm)	Yield (kg plot^{-1})	Yield (t ha^{-1})
Irrigation level				
2-days interval (I_1)	17.89b	3.65b	12.70b	31.74b
4-days interval (I_2)	18.51a	3.73a	12.77a	31.92a
LSD	0.298***	0.03***	0.038**	0.099**
CV (%)	1.557	0.773	0.283	0.296
Level of fertilizer/manures				
Chemical fertilizer (F_0)	17.32c	3.62c	12.23c	30.57c
Cowdung (F_1)	18.30b	3.67b	12.70b	31.74b
Vermicompost (F_2)	18.98a	3.77a	13.27a	33.17a
LSD	0.365***	0.037***	0.046***	0.121***
CV (%)	1.557	0.773	0.283	0.296
Interactions				
$T_1 = I_1 \times F_0$	17.07d	3.65c	12.20d	30.49d
$T_2 = I_1 \times F_1$	18.03c	3.71b	12.66c	31.64c
$T_3 = I_1 \times F_2$	18.57b	3.82a	13.24a	33.09a
$T_4 = I_2 \times F_0$	17.57cd	3.59d	12.26d	30.65d
$T_5 = I_2 \times F_1$	18.57b	3.63cd	12.74b	31.84b
$T_6 = I_2 \times F_2$	19.40a	3.72b	13.30a	33.25a
LSD	0.516*	0.052*	0.066*	0.175*
CV (%)	1.557	0.773	0.283	0.296

Note: The results were analyzed using the LSD test; no statistical differences were observed among the groups in the same letter. "***" indicates a very high 0.1% level, "**" directs a 1.0% level, and "*" shows a 5.0% level.

Figure 2 illustrates the impact of seasonal water requirements on cauliflower production (t ha^{-1}) and water utilization (kg/ha-mm) across dissimilar treatment groups. Notably, treatments T_1 to T_3 exhibited higher seasonal water requirements compared to treatments T_4 to T_6. This difference primarily stemmed from the increased irrigation levels employed in the former set of treatments. In contrast, treatments T_4 to T_6 demonstrated significantly higher water use efficiency compared to T_1 to T_3. This notable improvement in water use efficiency, particularly in the context of drip irrigation with mulch at a 4-day irrigation interval, can be attributed to enhanced moisture retention, effective weed control, and the resulting higher yields. These outcomes are consistent with the previous investigation directed by Bahadur et al. (2009) and Kashyap et al. (2009), highlighting the positive influence of drip irrigation and mulching on water use efficiency and crop yield.

Table 9. Water management for cauliflower irrigation throughout the growing season, under the influence of drip irrigation and various fertilizer/manure treatments

Factors/ Treatments	Irrigation events (Number)	Irrigation water applied (mm)	Effective rainfall (mm)	Soil moisture contribution (mm)	Seasonal water requirement (mm)	Water use efficiency (WUE) (kg/ha-mm)
Irrigation level						
2-days interval (I_1)	20	270	266	10.61a	546.61a	58.07b
4-days interval (I_2)	11	148.5	266	10.29b	424.79b	75.13a
LSD	-	-	-	0.023***	0.021***	0.235***
CV (%)	-	-	-	0.211	0.004	0.336
Level of fertilizer/manures						
Chemical fertilizer (F_0)	-	-	266	10.23c	485.73a	63.97c
Cowdung (F_1)	-	-	266	10.41b	485.69b	66.42b
Vermicompost (F_2)	-	-	266	10.71a	485.68b	69.41a
LSD	-	-	-	0.028***	0.026**	0.288***
CV (%)	-	-	-	0.211	0.004	0.336
Interactions						
$T_1 = I_1 \times F_0$	20	270	266	10.38c	546.63a	55.78f
$T_2 = I_1 \times F_1$	20	270	266	10.57b	546.61ab	57.89e
$T_3 = I_1 \times F_2$	20	270	266	10.87a	546.59b	60.54d
$T_4 = I_2 \times F_0$	11	148.5	266	10.08e	424.83c	72.15c
$T_5 = I_2 \times F_1$	11	148.5	266	10.25d	424.78d	74.96b
$T_6 = I_2 \times F_2$	11	148.5	266	10.55b	424.77d	78.28a
LSD	-	-	-	0.040**	0.036*	0.407**
CV%	-	-	-	0.211	0.004	0.336

Note: The results were analyzed using the LSD test; no statistical differences were observed among the groups in the same letter. "***" indicates a very high 0.1% level, "**" directs a 1.0% level, and "*" shows a 5.0% level.

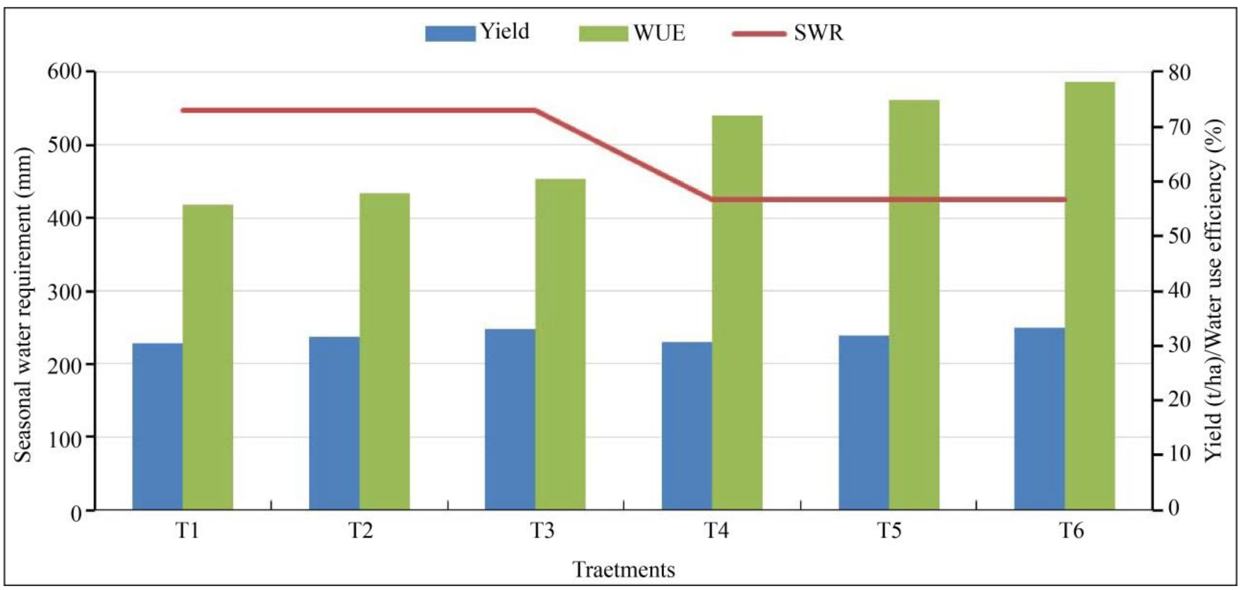


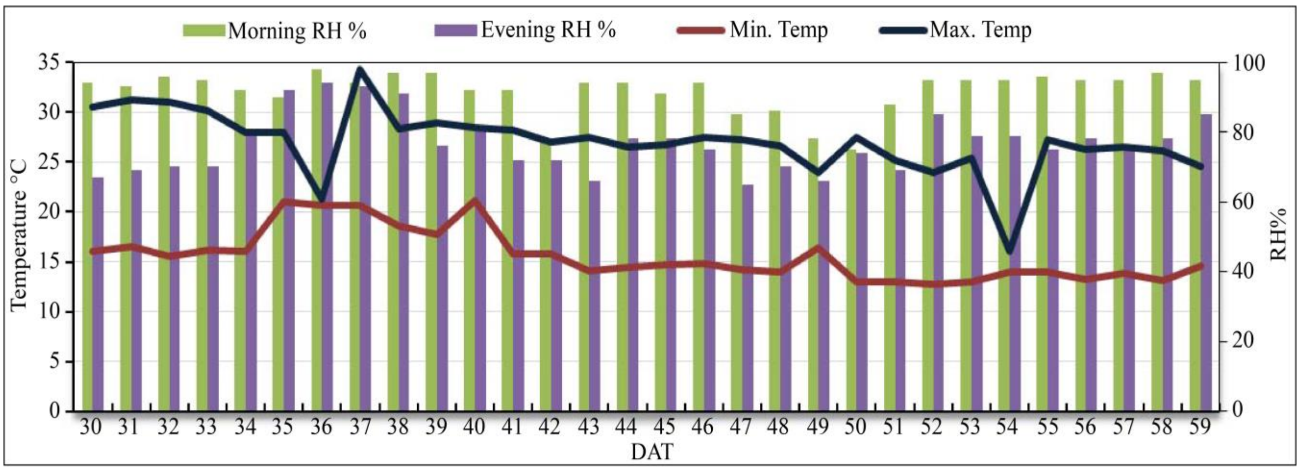
Fig. 2 Effect of seasonal water requirement on cauliflower yield and water use efficiency

3.4. Climatic Conditions Experienced by the Cauliflower Growth and Yield

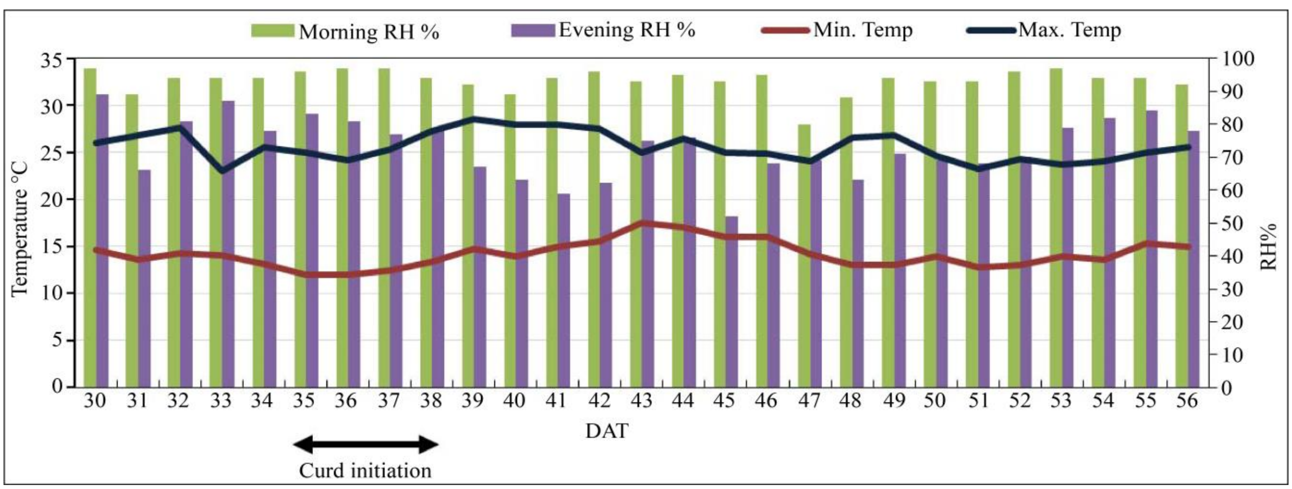
Figure 3 (a & b) illustrates the temperatures (maximum and minimum) along with morning and evening relative humidity (RH) recorded throughout the cauliflower growth period, which spanned from 30 days after transplanting (DAT) to the end of harvesting (86 DAT). Notably, the average maximum and minimum temperatures observed from sowing until just before curd initiation were 28.30°C and 16.62°C, respectively. These temperatures were relatively higher compared to the period during curd initiation (25.45°C and 12.48°C) and the subsequent period from curd initiation to harvest (25.62°C and 14.64°C). These results are consistent with the findings of Rahman et al.

(2007a&b), who emphasized the impact of temperature on cauliflower curd development. They observed that curd size and shape tend to expand as mean temperatures increase following curd initiation. However, this effect is most favorable within a specific temperature range. Beyond this optimal range, higher temperatures can become detrimental. Their research identified the optimal temperature range for curd growth as 21-22°C, which interestingly exceeds the temperature requirements for vegetative components' growth (19°C), with the exception of stem length.

Regarding relative humidity, the average morning RH remained relatively constant from sowing to just before curd development and from curd development to harvest, with an average of 93%. However, during curd initiation, it increased to 96%. Evening relative humidity was 76% from sowing to just before curd initiation, which was lower during curd initiation (80%) and higher than the RH observed after curd initiation to harvest (69.72%). These observations align with Sharma and Parashar (1982), who found that cooler and wetter conditions favor cauliflower growth, particularly in terms of yield-related factors, ultimately boosting cauliflower production. Conversely, maximum temperatures with minimal rainfall were associated with reduced cauliflower yields.



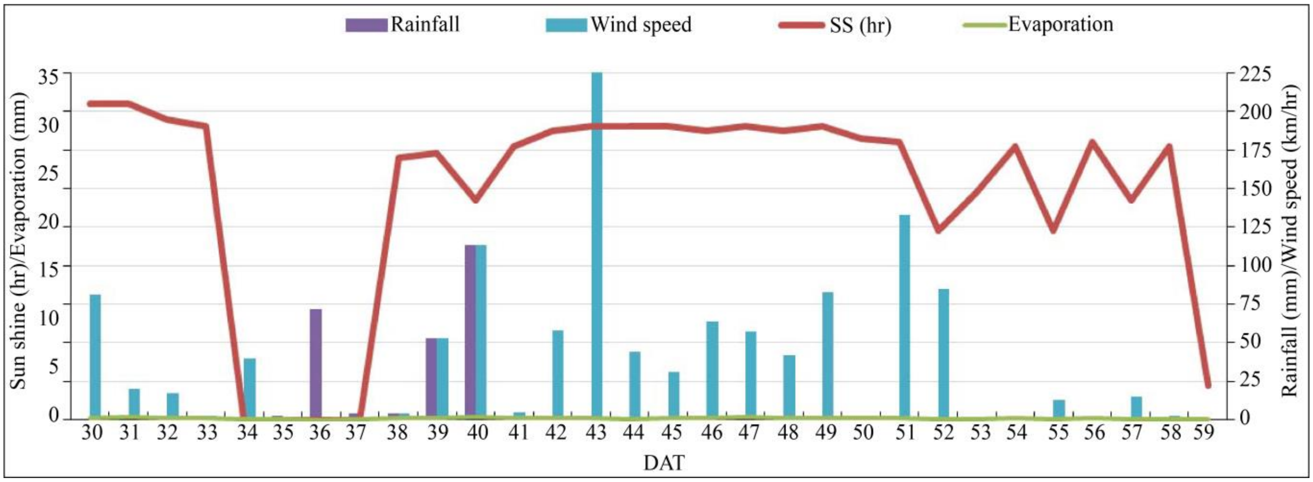
(a) 30 DAT to 59 DAT



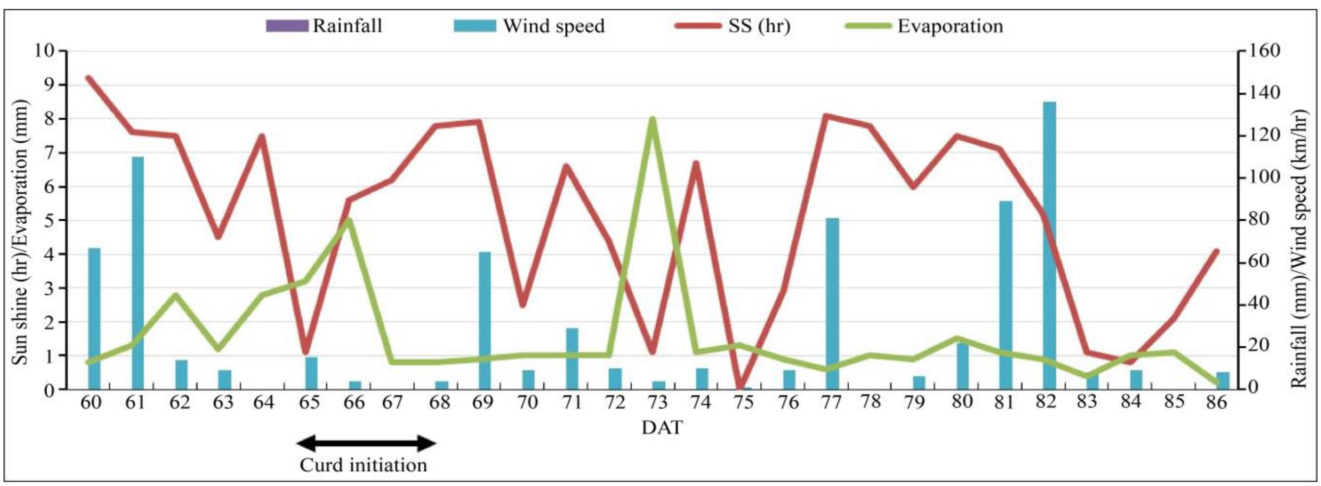
(b) 60 DAT to end of harvesting (86 DAT)

Fig. 3 Temperature (Max. and Min.) with % RH (morning and evening) during cauliflower growth duration of (a) 30 DAT to 59 DAT and (b) 60 DAT to end of harvesting (86 DAT)

Rainfall, wind speed, sunshine hours, and evaporation were monitored during the cauliflower growth period from 30 days after transplanting (DAT) to the end of harvesting (86 DAT), as depicted in Figure 4 (a & b). The highest wind speed was observed during the period from sowing to before curd initiation (52.17 km h^{-1}), followed by the period from after curd initiation to harvesting (27.56 km h^{-1}), with the lowest wind speed occurring during curd initiation (5.75 km h^{-1}). On average, the wind speed throughout the entire crop period was 44.86 km h^{-1}. Interestingly, from the period after curd initiation to the end of harvesting, wind speed did not exhibit a significant negative impact on curd weight, a phenomenon consistent with the findings of Ray and Mishra (2017). The minimum average sunshine hours were recorded during the curd initiation to the end of the harvesting period (4.55 h). However, over the entire growing season, the average sunshine hours were approximately 6.06 hours. This variation was attributed to occasional cloudy weather and sporadic rainfall during this period. Interestingly, curd weight was negatively impacted in the initial phases of vegetative growth and curd formation times due to intense sunshine hours and solar radiation, which has been discussed by Ray and Mishra (2017).



(a) 30 DAT to 59 DAT



(b) 60 DAT to end of harvesting (86 DAT)

Fig. 4 Rainfall and wind speed with sunshine hour and evaporation during cauliflower growth duration of (a) 30 DAT to 59 DAT and (b) 60 DAT to end of harvesting (86 DAT)

4. Conclusion

This study highlights the potential for significantly increasing cauliflower yield and water use efficiency. Employing a 4-day irrigation interval and incorporating vermicompost into the field proved highly effective. Drip irrigation with two-line crop management outperformed conventional methods, especially when combined with black polyethylene mulch.

Overall, a cultivation approach involving vermicompost, a 4-day drip irrigation interval, and black polyethylene mulching improved cauliflower production's water use efficiency and yield. Farmers in Bangladesh are encouraged to adopt these practices, considering local climatic factors, to enhance cauliflower production and food security.

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