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# DETERMINATION OF CROP CO-EFFICIENTS OF CAULIFLOWER AT DIFFERENT GROWTH STAGES BY DRAINAGE LYSIMETER

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## Abstract

Crop coefficient ($K_c$) values are essential in estimating the water requirements of crops. The $K_c$ values depend on crop evapotranspiration ($ET_c$) and reference crop evapotranspiration ($ET_0$). Again, $ET_o$ is a function of climatic factors like temperature, humidity, wind speed, and sunshine hours, together with latitude, longitude, and altitude. These climatic factors vary from location to location, hence, the $K_c$ values. So, location-specific $K_c$ values are essential to determine crop water requirements on a regional basis. One of the most reliable methods of determining the $K_c$ values of crops is the drainage lysimeter. Thus, the experiment was conducted in the research farm of the Irrigation and Water Management Division of Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, to determine $ET_c$ using a drainage lysimeter during the *rabi* season of 2009-10. In the experiment, there were four irrigation treatments: irrigation at 15, 25, 35, 45, and 55 days after planting (DAP) ($T_1$), irrigation at 15, 25, 35, 50 and 60 DAP ($T_2$), irrigation at 15, 25 and 40 DAP ($T_3$), and irrigation at 15, 30 and 45 DAP ($T_4$). The highest curd yield (43.0 t/ha) of cauliflower was recorded from treatment $T_1$ and was considered ideal for estimating $ET_c$ and $K_c$ values. The seasonal $ET_c$ under the local agro-climatic conditions was 135 mm, and the $K_c$ values were 0.37, 0.99, 1.29, and 0.84 for initial, development, mid- and late-season stages, respectively. The estimated mean $K_c$ value was 0.87. These $K_c$ values can also be required to calculate the crop water requirement for similar agro-climatic conditions in Bangladesh.

Keywords**:** Crop Coefficient, Crop evapotranspiration, Curd yield, Micro-lysimeter, Penman-Monteith method, Yield attributes.

## Introduction

Global fresh water availability among countries varies; some are sufficient but unevenly distributed, while others face severe water crises. It is projected that global crop productivity needs to increase by 0.5% per year to feed 9.3 billion people by 2050 (Grafton *et al.*, 2015). It can be done by increasing the area under cultivation or increasing the productivity of the land by introducing high-yielding

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and high-value crop cultivars through efficient irrigation and water management (Hossain *et al.*, 2023). At the same time, the focus should be on increasing water use efficiency or water productivity. In this case, the knowledge of crop coefficient values is essential. In addition, this information is necessary for policy planning on regional-scale water management (Mainuddin *et al.*, 2015) and fitting crops in cropping patterns for increasing net farm income (Mila *et al.*, 2016a).

Cauliflower (*Brassica oleracea* var. *botrytis* L.), a member of the Brassicaceae family, is one of the popular winter vegetables in Bangladesh, which is characterized by biannual and herbaceous nature. It is popularly known as 'foolkopy' in Bangladesh and grows well throughout the country. In Bangladesh, it covers an area of 22,853 hectares with a production of 343758.71 metric tons in 2022-23 (Anon., 2024). It grows well in a cool moist climate. In addition, proper irrigation is an important criterion for getting a potential yield of cauliflower in Bangladesh (Hossain *et al.*, 2016) and other countries (Job *et al.*, 2018; Kumar *et al.*, 2022; Sidhartha *et al.*, 2021; Yanglem and Tumbare, 2014). A three-year study on cauliflower in Bangladesh showed that irrigation at 10-day intervals through check basin method gave higher curd yield and water productivity (Hossain *et al.*, 2016). In India, the highest curd yield of cauliflower was recorded using drip irrigation at 90%-100% of potential evapotranspiration along with mulch (Job *et al.*, 2018; Kumar *et al.*, 2022; Sidhartha *et al.*, 2021; Subhan *et al.*, 2021; Yanglem and Tumbare, 2014). A study in Pakistan found higher cauliflower yield from 100% irrigation requirements through the conventional furrow irrigation method, while higher water productivity was recorded at 100% irrigation requirement through alternate furrow irrigation method (Subhan *et al.*, 2021). In semi-arid regions like Bangladesh, full and supplemental irrigation plays an important role in winter (November–March) and *kharf 1* (March–July) crops for increasing yield (Mila *et al.*, 2016a).

The crop coefficient ($K_c$) is estimated by the ratio of the actual crop evapotranspiration ($ET_c$) to potential evapotranspiration ($ET_0$) (Allen *et al.*, 1998). $K_c$ values are required to estimate crop water requirement or crop evapotranspiration (ET) to irrigate the crops of similar agro-climatic conditions where this value is unknown. The determination of water requirements of a particular crop cultivar in slightly varied climates and soils by conducting experiments repeatedly is cumbersome. But, it is possible to accurately estimate crop ET using the above formula (i.e., a product of $K_c$ and $ET_0$). However, $K_c$ values for different crops are available in the literature (Allen *et al.*, 1998; Doorenbos and Pruitt, 1977). In addition, these values can be estimated from the tabulated values by adjusting some factors like temperature, humidity, irrigation sequences, and soil textures (Allen *et al.,* 1998). However, for the best output, it is recommended to determine the factors locally. Further, the physiological characteristics of a crop cultivar differ from others within crop seasons, soil types, and agroclimatic zones. Consequently, it shows varying physiological demands that give rise to a change in the ET process. Therefore, the local estimation of the $K_c$ values is paramount.

Crop evapotranspiration and crop coefficient can either be estimated by lysimeter (Akanda *et al.,* 2017; Khan *et al.,* 1993; Mila *et al.,* 2016a and 2016b; Mila et al., 2018) or by remote sensing approaches of spectral vegetation indices, METRIC and SEBAL (Elsayed *et al.,* 2022; Pôças *et al.,* 2020; Taheri *et al.,* 2021). Among them, the lysimeter method is more accurate and reliable because of its capacity to estimate regional-scale $K_c$ value. A lysimeter is a device hydrologically protected from the surrounding soil by inserting a container where plants are grown (Michael, 2014). Drainage lysimeter was used because of its simple, and multipurpose uses (Khan *et al.,* 1993). Previously, many researchers determined crop coefficient values of cauliflower using different lysimeters in various locations around the world (Allen *et al.,* 1998; Andrean *et al.,* 2021; Doorenbos and Pruitt, 1977; Martin *et al.*, 1996; NRCS, 2010; Sahin *et al.,* 2009; Simonne *et al.,* 2004; Van der Gulik and Nyvall, 2001). No information is available for the determination of $K_c$ values of cauliflower by drainage lysimeter in Bangladesh environment. Therefore, this study was conducted to determine crop coefficient values of cauliflower by drainage micro-lysimeter in Bangladesh Agricultural Research Institute, Gazipur, Bangladesh.

## Materials and Methods

### Information on study location, soil, and weather conditions

The experiment was conducted at the research farm of Irrigation and Water Management Division, Bangladesh Agricultural Research Institute, Gazipur (latitude, longitude, and elevation from MSL were $24^0 00'$N, $90^0 25'$E and 8.4 m) during 2009-10. The weather data during the crop period was collected from an agro-meteorological station close to the experimental field. The soil was silty clay loam with field capacity and bulk density of 28% (dry weight basis) and 1.5 g $cm^{-3}$, respectively. Maximum and minimum temperatures during the day and night varied from 16.0-29.5°C and 8.0-15.8°C (Figure 1a). The maximum and minimum relative humidity during the day and night periods varied from 39-89% and 82-99%, respectively (Figure 1b). Similarly, maximum wind speeds during the season ranged from 0 to 49 m $s^{-1}$ and the minimum from 0 to 25 m $s^{-1}$ (Figure 1c). Total rainfall during the season was only 6 mm at planting (Figure 1d). Solar radiation over the season varied from 6 to 18 $MJm^{-2}s^{-1}$ (Figure 1d).

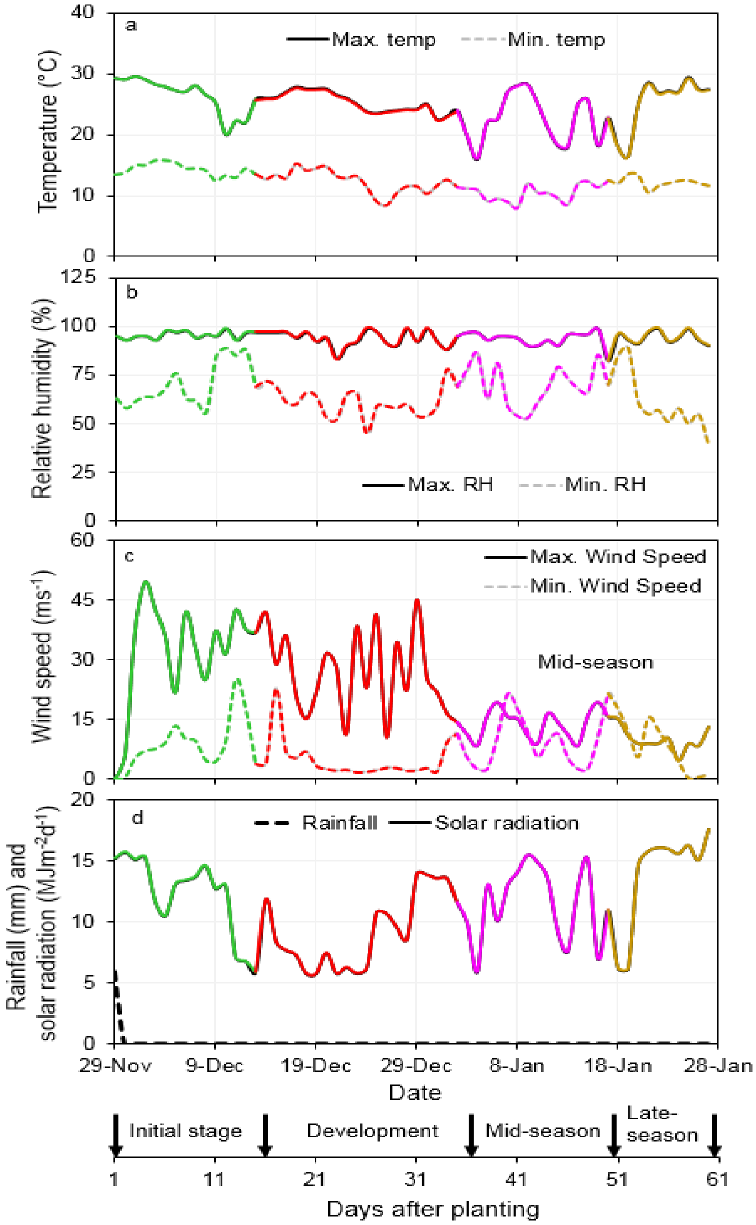


Fig. 1. Daily maximum and minimum air temperatures (a), relative humidity (b), wind speed (c), rainfall, and solar radiation (d) during the 2009-10 crop season. In Fig. shown against date or days after planting. Green, red, purple, and gold lines are used on top of the total crop season line for four crop growth stages- initial, development, mid-season, and late season. In the x-

axis, the duration of crop growth stages is marked as a black-filled downward arrow.

**Experimental design and crop management**

Thirty day-old cauliflower seedlings (variety: Snow white) were planted on 29 November 2009 in four lysimeter tanks with row-to-row and plant-to-plant spacing of 60 cm and 45 cm, respectively. To create a similar environment, the same crop was grown in the entire field around the lysimeter tanks. The intercultural operation was done as and when necessary. Recommended fertilizer was applied following Anon. (2011). The crop was harvested on 27 January 2010. The selected treatments were:

$T_1$ = Irrigations at 15, 25, 35, 45 and 55 days after planting (DAP) allowing drainage

$T_2$ = Irrigations at 15, 25, 35, 50 and 60 DAP allowing drainage

$T_3$ = Irrigations at 15, 25, and 40 DAP allowing drainage

$T_4$ = Irrigations at 15, 30, and 45 DAP allowing drainage

The micro-lysimeter contained four tanks, each having an area of 1 m x 1 m, designed and installed by Khan *et al.* (1993). A similar approach was also used by other researchers (Akanda, *et al.*, 2017; Mila *et al.,* 2016a and 2026b; Mila *et al.*, 2018) for estimating $K_c$ values of sunflower, jute, soybean, and potato at Gazipur. The crop was irrigated as per design of the treatments. The measured quantity of water was applied to the tanks ensuring drainage. Soil moisture was measured during planting, before irrigation, and at maturity to determine the irrigation quantity and depleted residual soil moisture.

**Determination of crop evapotranspiration ($ET_c$)**

$ET_c$ of cauliflower was determined from the best yielder treatment grown in a lysimeter tank. For each treatment, $ET_c$ was calculated as shown in Table 2. It was determined by subtracting stored soil moisture during the period under consideration and drainage amount from the applied water and rainfall. The following formula was used:

$$ET_c = (W_a + R_e) – (D_w + S_s)$$

where $ET_c$ = crop evapotranspiration, mm

$W_a$ = applied water, mm

$R_e$ = effective rainfall, mm

$D_w$ = drainage water, mm

$S_s$ = stored soil moisture, mm

### Estimation of reference evapotranspiration ($ET_0$)

Daily reference evapotranspiration ($ET_0$) was estimated by the CROPWAT model (version 8). The Penman-Monteith Equation was used in the above model to estimate $ET_0$ by inserting daily weather parameters of minimum and maximum temperatures, relative humidity, wind speed, and sunshine hour together with location information of altitude, latitude, and longitude (Smith *et al.*, 1992). Then $ET_0$ for each of the frequencies of irrigation for the highest yield treatment was determined.

### Estimation of Crop coefficients

The crop coefficient ($K_c$) for the frequency of irrigation events for the highest yield treatment was calculated by the ratio of $ET_c/ET_0$. Then, the length of the crop growth stages (initial, development, mid, and late season stages) were identified and adjusted for the calculated $K_c$ values (Allen *et al.*, 1998 and Table 3).

### Collection of crop and water data

During harvest, the data on curd length, curd diameter, individual curd weight, and curd yield were recorded from all four plants in each lysimeter. However, no data were recorded from the non-lysimetric plots adjacent to the lysimeter. Applied water and percolation data were recorded after each irrigation event, as shown in Table 2.

## Results and Discussion

### Curd yield and yield attributes of cauliflower

The data on curd yield and yield attributes of cauliflower are presented in Table 1. The treatment $T_1$ (irrigation at 15, 25, 35, 45, and 55 DAP) produced the highest curd yield (43.2 t ha$^{-1}$) among the treatments. Irrigation at 10-day intervals created favourable soil moisture conditions for the successful growth of the cauliflower plants. As a result, the highest individual curd weight (1148 g) was found from this treatment. In addition, cauliflower, a shallow-rooted vegetable crop (20–30 cm), and frequent irrigation application were necessary to provide optimal soil moisture throughout its growing period. Treatment $T_2$ gave the second-highest curd yield (42 t ha$^{-1}$) by receiving five irrigations at 15, 25, 35, 50, and 60 DAP. The yield gap between the two treatments was 1.2 t ha$^{-1}$. By contrast, treatments $T_3$ and $T_4$ received three irrigations but 15-day intervals produced the lowest curd yield (34.8 t ha$^{-1}$). Therefore, it was obvious that irrigation at the 10-day interval was found suitable to maximize the curd yield of cauliflower under the studied environment. Doorenbos and Pruitt (1977) recommended that the best-growing plants producing the highest yields are appropriate for calculating the crop coefficients for different growth stages. Therefore, the treatment $T_1$ was selected to determine the crop coefficient values of cauliflower.

**Table 1. Curd yield and yield attributes of cauliflower**

| Treatments | Plant population (no. $m^{-2}$) | Curd length (cm) | Curd diameter (cm) | Individual curd weight (g) | Curd yield (t $ha^{-1}$) |
|---|---|---|---|---|---|
| $T_1$ | 4 | 9.8 | 14.7 | 1148 | 43.2 |
| $T_2$ | 4 | 9.7 | 15.1 | 1100 | 42.0 |
| $T_3$ | 4 | 7.8 | 13.7 | 880 | 36.0 |
| $T_4$ | 4 | 7.6 | 12.4 | 900 | 34.8 |

### Determination of crop evapotranspiration ($ET_c$) from Lysimeter

Table 2 presents the stage-wise $ET_c$ for the irrigation events during the growing season. Total $ET_c$ over the season was 135 mm for $T_1$. A study in the Research Institute of Soil and Water Conservation in Melnik, Czech Republic, determined seasonal $ET_c$ of late-grown cauliflower using the water balance method and found seasonal $ET_c$ of 278, 252, and 211 mm from 2003 to 2005 cropping seasons (Zavadil, 2006). The $ET_c$ values were double that of the present study because they used different varieties (cv. Fremont), and the crop season was 36 days longer than the present study. Usually, the longer growing season costs higher crop water requirements for a particular crop. Another study at the Agricultural Research Station of Ataturk University, Erzurum, Turkey, revealed that the seasonal $ET_c$ of cauliflower was 475 mm (Sahin *et al.*, 2009). The crop duration lasted from May to August, and the daily evaporation remained about 3 times higher than that of the present study. The daily evaporation recorded in the present study varied from 0.94 to 2.1 mm over the season. The calculated $ET_c$ value of the present study was lower than the value found by other researchers. The variation in the growing season, crop duration, crop variety, location, and weather conditions might affect $ET_{c,}$ showing the changes between this and the other studies.

**Table 2. Crop evapotranspiration ($ET_c$) determination by drainage lysimeter**

| Duration in days | Applied water (mm) | Effective rainfall (mm) | Percolation (mm) | Soil water content† storage (mm) | $ET_c$ (mm) |
|---|---|---|---|---|---|
| 0–15 | 5 | - | 0 | (–)10.8 | 15.8 |
| 15–25 | 30 | - | 4.0 | 8.5 | 17.5 |
| 25–35 | 40 | - | 5.9 | (–)3.3 | 37.4 |
| 35–45 | 45 | - | 4.6 | 6.3 | 34.1 |
| 45–55 | 50 | - | 4.7 | 15.1 | 30.2 |
| Total | - | - | - | - | 134.9 |

The negative sign in stored soil water content indicates the depleted soil water used by the crop. On the other hand, the positive values indicate water stored in the soil above ET.

**Determination of crop coefficient ($K_c$)**

The duration of the crop growth stage depends on the duration of the growing season of a particular crop and climate (Doorenbos and Pruitt, 1977; Smith *et al.*, 1992). Here, the crop duration was 60 days, and the individual durations of the crop growth stages were identified, as mentioned earlier (Table 3). The estimated $K_c$ values for the frequency of irrigation events from Figure 3a were adjusted for the crop growth stages. Then, $K_c$ values of 0.37, 0.99, 1.29, and 0.84 were found to be the initial, development, mid, and late-season stages (Table 3 and Figure 3b). The highest $K_c$ value was recorded at the mid-season stage and the lowest (0.37) at the initial stage. The variation of $K_c$ among the stages contributed to the variation of crop water requirements. $K_c$ value was initially low (0.37), then gradually increased to 1.29 at the mid-season stage and again decreased to 0.84 at the late-season stage (Table 3 and Figure 3b). The mean $K_c$ value over the season was 0.87 mm (Table 3).

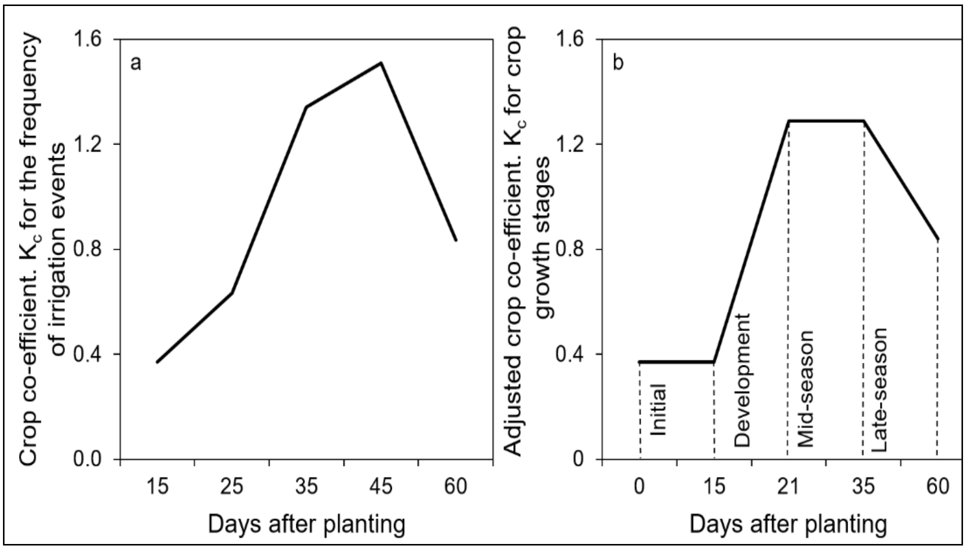


Fig. 3. Crop coefficient of cauliflower for (a) the frequency of irrigation events for 15, 25, 35, 45, and 55 days after planting and (b) the crop growth stages for initial development, mid and late season stage.

**Table 3. Estimated crop co-efficient values of cauliflower**

| Crop growth stage† | Duration (days) | Crop water requirement (mm) | Reference crop ET ($ET_0$ ) (mm) | Crop co-efficient, $K_c$ |
|---|---|---|---|---|
| Initial (1–15 DAP) | 15 | 15.8 | 42.6 | 0.37 |
| Development (16–35 DAP) | 20 | 55.0 | 55.6 | 0.99 |
| Mid-season (36–50 DAP) | 15 | 42.3 | 32.8 | 1.29 |
| Late season (51–60 DAP) | 10 | 21.8 | 25.9 | 0.84 |
| Total | 60 | 135 | 157 | 0.87 (mean) |

DAP denotes days after planting.

$K_c$ is sensitive to weather parameters. It can not be changed without field experimentation because it depends on two variables- actual crop water requirement and reference crop evapotranspiration. Actual crop water requirements can accurately be determined using a lysimeter study. By contrast, reference crop evapotranspiration can be determined using known climatic parameters (See Results sub-sections of Reference evapotranspiration).

Several studies at different locations across the world determined the $K_c$ values of cauliflower (Doorenbos and Pruitt, 1977; Martin *et al*., 1996; NRCS, 2010; Sahin *et al.,* 2009; Simonne *et al.*, 2004; Van der Gulik and Nyvall, 2001). A study on cauliflower at the Agricultural Research Station of Atatürk University, Erzurum, Turkey found a seasonal $K_c$ value of 0.84 (Sahin *et al.,* 2009). Simonne *et al.* (2004) in Florida, USA, reported that $K_c$ values of cauliflower for the head development stage ranged from 0.9 to 1.0, and the crop growing season ranged from 70–84 days. Another study in British Columbia found the cauliflower $K_c$ values to be 0.70, 1.05, and 0.95 for the initial, mid-season, and late-season stages (Van der Gulik and Nyvall, 2001). A study at the Maricopa Agricultural Center in Maricopa, Arizona, found the $K_c$ values of cauliflower at initial, development, mid-, and late season 0.50, 0.61, 0.75, and 0.38 (Martin *et al*., 1996). Doorenbos and Pruitt (1977) reported that the $K_c$ values of cauliflower for mid-season and at harvest were 0.95–1.0 and 0.80–0.85, respectively, depending on the minimum relative humidity of >70% and those were 1.05–1.10 and 0.9–0.95 depending on the minimum relative humidity of <20%. Another study in the USA reported that the $K_c$ values of cauliflower for the 10% to 100% growing season were 0.25, 0.28, 0.44, 0.59, 0.75, 0.90, 0.95, 0.95, 0.94, and 0.80, respectively, and their growing season lasted from 20 June to 30 September (NRCS, 2010). These $K_c$ values were slightly different from those recommended by FAO (Doorenbos and Pruitt, 1977). Besides, FAO values are the standard values and need calibration for a specific region or location as per guidelines suggested in FAO Irrigation and Drainage paper no 56 (Allen *et al.,* 1998). They did an experiment in the California Desert, USA, and the planting date was September, and the total crop period was 140 days (Initial–40, development–50, mid-season–40, and late season–15). They reported that the $K_c$ values of cauliflower for initial, development, and late season were 0.70, 1.05, and 0.95.

## Determination of crop water requirement

The crop water requirement of cauliflower was 15.8, 55.0, 42.3, and 21.8 mm for the initial, development, mid, and late seasons, respectively. These values can be used in similar agro-climatic conditions where $K_c$ values are not available or the values have not been determined precisely. Therefore, $K_c$ value determination using the lysimetric method is paramount for efficient irrigation water management on the regional level.

## Conclusion

Irrigation at 10-day intervals gave the highest curd yield of cauliflower in semi-arid regions like Bangladesh. Seasonal crop evapotranspiration under this study for 10 days irrigation interval was 135 mm. The study revealed that cauliflower required 16, 55, 42, and 22 mm water for irrigation at initial, development, mid-season, and late-season stages to achieve the potential curd yield. The crop coefficient values of cauliflower (Snow White) from the lysimeter study were 0.37, 0.99, 1.29, and 0.84 for the initial, development, mid-season, and late-season stages, respectively. The mean value of $K_c$ was 0.87. This locally determined crop coefficient value is more reliable and recommended for determining the crop water requirement of cauliflower for Joydebpur and similar other environments.

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