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Crop Co-efficient Values of Sunflower for Different Growth Stages by Lysimeter Study

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Authors' contributions

This work was carried out in collaboration of all authors. Author AJM designed the study, analyzed and interprets the data and prepared the manuscript. Finally, all authors read and approved the final manuscript.

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ABSTRACT

The experiment was conducted on sunflower (variety BARI Surjomukhi-2) crop during the month of mid-November, 2014 to mid-March, 2015, in a lysimeter (dimension:1 m X 1 m X 1 m size) to measure crop evapotranspiration (ET_c) and determine crop coefficient (k_c) values at Irrigation and Water Management Division, Bangladesh Agricultural Research Institute, Gazipur. The study was examined by applying four irrigation at an interval of 10, 15, 20, and 25 days allowing drainage within and adjacent the tank. Results reveals that irrigation at 15 days interval produced the highest yield and was considered suitable for estimating ET_c and k_c. Seasonal total ET_c was found as 270.89 mm. The k_c values of sunflower under different ET_0 methods for initial, development, mid-season and late season ranged from 0.34 to 0.48, 0.80 to 1.10, 1.06 to 1.55, and 0.27 to 0.36, respectively. Among different methods, P-M method gave relatively higher value than those of other methods and also FAO recommended value. Therefore, this information would be a helpful tool for crop water requirement and irrigation scheduling for similar semi-arid climates.

Keywords: Reference evapotranspiration; crop evapotranspiration; micro-lysimeter; radiation method; temperature method; Penman-Monteith method; Hargreaves method.

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1. INTRODUCTION

Globally, water is considered as a precious element for agricultural sector as well as other sectors due to climate change. In developing country, like Bangladesh, most of the non-rice crops are cultivated in the winter season from the month of November to March and have to rely on irrigation water because of unavailability of natural rainfall [1,2]. In increased agricultural production, irrigation plays a vital role in cultivating winter crop and supplementing in kharif crop. As we know water requirement vary from crop to crop according to season. Therefore, it is necessary to know the actual crop water requirement, and water management will thus play a significant role in minimizing water loss by optimizing water use. Also, information on crop water requirement is necessary for policy planning on water management [3]. In addition to, for fitting crop in a cropping pattern for a specific location, the knowledge of water requirement is essential for increasing net farm income. Hence, the estimation of crop coefficient for the specific crop will be more beneficial and economic. However, there are some available k_c values recommended by FAO for some crops and are used where local data are not available. Besides, these values differ from location to location as well as from season to season. So, Tyagi [4] recommend utmost importance for the locally calibrated k_c value for a given climatic condition. Also, proper irrigation scheduling and efficient water management will be impossible without the exact estimation of crop coefficient values. In this study, sunflower is selected which is one of the most important oil seed crops grown all over the world [5]. Sunflower is the world's fourth oil-seed crop [6,7]. Therefore, increased production of this crop is necessary for meeting country's oil demand.

Evapotranspiration and crop coefficients can be estimated by lysimeter study [8,9] and remote sensing approaches such as Metric, SEBAL etc. [10-12]. The estimated k_c and crop ET obtained from using remote sensing technique has many limitations and not capable to represent exact regional scale k_c value. This is because of variation in space and in time, variability in emergence date, land use pattern, antecedent rainfall, emissivity, amount of vegetation and atmospheric conditions [10]. On the other hand, lysimeter is a device which is hydrologically separated from the adjacent soil by using a container in which a volume of soil is planted with vegetation [13]. Water loss and gain can be found easily and crop evapotranspiration can be calculated by using water balance equation [14]. In this study lysimeter is used to calculate crop water requirement (ET_c).

Reference evapotranspiration (ET_0) can be estimated by using local atmospheric boundary conditions such as sunshine, temperature, humidity and wind speed. Previously, many researchers estimated ET_0 for various climatic conditions [15,4]. Tyagi [4] determined stage wise crop coefficients for sunflower and rice using different methods of reference evapotranspiration (ET_0) estimation at the research farm of Central Soil Salinity Research Institute, Karnal, India studied from 1991 to 1998. The used ET_0 methods were Penman ± Monteith (PMon), FAO-ID-24 corrected Penman (FcPn), 63 version of original Penman (Pn63), FAO-ID-24 Radiation (FRad), FAO-ID-24 Blaney and Criddle (FB-C), and US Class A Pan. In this study, ET_0 was calculated by using four methods such as, FAO Penman-Monteith (P-M), FAO temperature (FAO-T), FAO radiation (FAO-R) and Hargreaves (H) methods.

The crop coefficient (k_c) is estimated by the ratio of crop evapotranspiration (ET_c) and grass reference evapotranspiration (ET_0) [16]. This value expresses crop exact water need in regional basis which is necessary for the estimation of exact irrigation requirement of various crops for that specific area. As a result, water productivity will be increased. Doorenbos and Pruitt [17] derived crop coefficient values of different crops which were grown under various climatic conditions. Many researchers have found that the crop coefficient varies during the crop period [18,19,4,17,20] mainly due to the variation of crop growth stage and climate.

Many researchers have used weighing type lysimeter for the exact estimation of water balance for different crop [18,21]. Kar [22] did experiment on dry season oilseed crop (linseed, safflower, and Mustard) to find out water use efficiency and crop co-efficients by using field water balance approach in Eastern India. They found a correlation between leaf area index and k_c value. Karam [8] did 2-year study on sunflower crop using drainage lysimeter under full and deficit irrigation conditions at Tal Amara Research Station in the Bekaa Valley of Lebannon. They found average k_c values of 0.3, 0.9, >1.0 and <1.0 at initial, development, mid and late season. Previously, many researchers find out the crop water requirement and k_c value of some important crop like wheat, potato, maize, etc. using lysimeter study at various agro-meteorological conditions of Bangladesh and other countries [23-27]. But, crop coefficient values of sunflower by Lysimeter study have not been estimated previously under semi-arid climatic conditions of Bangladesh and other Asian countries. Therefore, this study was undertaken with the objective of developing regional scale crop coefficient data for sunflower using different methods of ET_0 estimation and for different growth stages that may be useful in the irrigation scheduling program.

2. MATERIALS AND METHODS

2.1 Experimental Site, Soil and Climate

The experiment was conducted in a non-weighing type micro-lysimeter at the research farm of Irrigation and Water Management, Bangladesh Agricultural Research Institute, Gazipur, during 2014 - 2015. It is located at the elevation of 8.40 m from MSL with latitude and longitude of 24°00´N and 90°25´E. It was a semi-arid climate, with the maximum and minimum temperature of 33.00°C and 9.80°C. The average relative humidity, sunshine hour and wind speed were 75.30%, 4.48, and 13.86 km/hr (Fig. 1). Total rainfall during this period was about 9.00 mm (Fig. 1). The soil characteristic of experimental field was silty clay loam, with field capacity and bulk density were 29.50% and 1.50 g/cc.

2.2 Crop Details

Sunflower (variety BARI Surjomukhi-2) was sown in a 1m × 1m micro-lysimeter at a spacing of 70 cm × 25 cm on 17th November, 2014. Also, the same crop was sown adjacent to the lysimeter tank with the objective of creating similar micro-climatic condition (Fig. 2). Recommended fertilizer, intercultural operation and other necessities were provided according to requirement. The crop was harvested on 10th March 2015. The following treatments were used in this experiment.

T_1 = Irrigation at 10 days interval allowing drainage
T_2 = Irrigation at 15 days interval allowing drainage
T_3 = Irrigation at 20 days interval allowing drainage
T_4 = Irrigation at 25 days interval allowing drainage

2.3 Lysimeter

The micro–lysimeter contains 4-tanks, with the area of 1 sq. m and depth of 1 m which was designed and installed by Khan [9] at Irrigation and Water Management Division, BARI, Gazipur, Bangladesh. They explained detailed about the structure of this lysimeter. Many scientists have previously used this lysimeter for estimating crop coefficients for different crops in this area [23,28,25,29,30].

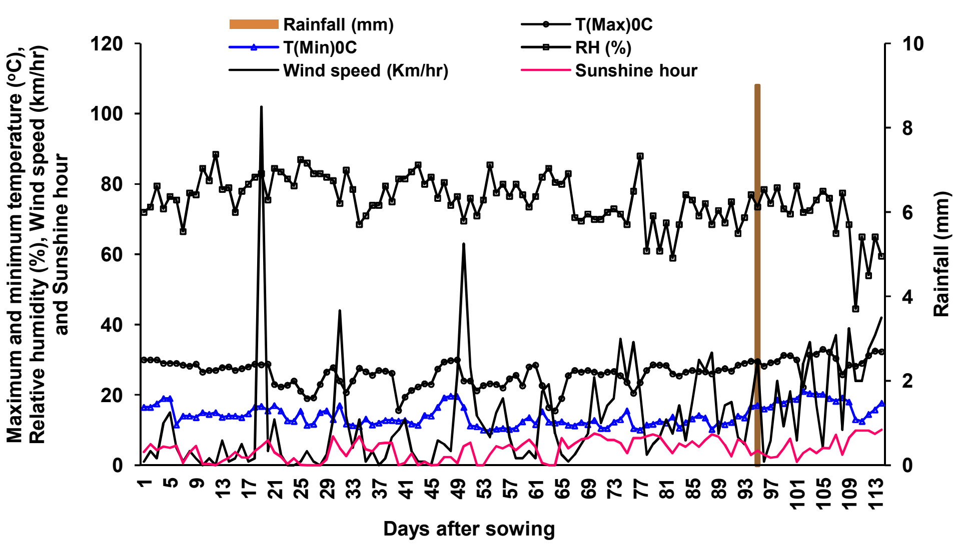

Fig. 1. Weather parameters in the study area

Fig. 2. Image of lysimeter taken during the experiment. The age of plant was 25 days and only single irrigation was applied in all treatments just before 10 days

2.4 Soil Moisture Monitoring and Irrigation

Soil moisture was measured by gravimetric method before sowing, and prior to irrigation from different treatments. Soil moisture was collected at different soil depths which vary from 0.15 to 0.90 m. Measured soil moisture in weight basis was converted into volume basis by multiplying with bulk density. Irrigation water was applied in the unit plots using hose pipe by calibrating the rate with large bucket of known volume.

2.5 Determination of Crop Evapotranspiration

Many scientists [31-32] recognized lysimeter as a primary method for direct ET measurements. In this system, crop is grown in a totally controlled environment and gives accurate and precise ET_c value. Besides, this system is not affected by other parameters such as surface runoff, interflow, deep percolation, and ground water contribution. Therefore, it is recommended and published that no further replication is necessary. The crop was irrigated according to the design of the experiment. Measured quantity of water was applied to the tank as well as adjacent plot outside of the tank. Drainage water from lysimeters were collected and measured by graduated cylinder and ET_c was calculated by following water balance equation (1) [14]. Before irrigation, soil moisture was measured from different depths to determine the depleted soil water. Therefore, drainage collected as a part of rainfall and stored soil moisture was recorded at the considerable time was subtracted from total water application to calculate crop water use (ET_c). The following formula was used to calculate the crop evapotranspiration for the specific period:

$$ET_c = W_a - (D_w \pm \Delta S_s) \quad (1)$$

Where,

ET_c = Crop evapotranspiration in mm for time, t
W_a = Applied water + rainfall, mm, for time, t
D_w = Drainage water, mm, for time, t
ΔS_s = Change in soil moisture, mm, for time, t

2.6 Determination of Reference Crop Evapotranspiration

Reference crop ET (ET_0) is the potential evaporation of a well-watered grass crop and a set of surrounding (advective) conditions. Doorenbos and Pruitt [17] defined reference crop ET as the “ET from an extensive surface of 8 to 15 cm (3 to 6 ins) tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water”. Although several methods exist to determine ET_0, the Penman-Monteith Method has been recommended as the appropriate combination method to determine ET_0 from climatic data of temperature, humidity, sunshine, and wind speed [13,16]. According to Smith, Droogers and Allen [15,33], FAO Penman-Monteith gives more consistent ET_0 estimates and has shown to perform better than other ET_0 methods. They also recommended the Blaney-Criddle (referred as FAO temperature), Makkink (FAO radiation), and Hargreaves method for estimation of ET_0 in conditions where sufficient climatic data is not available. In this study, ET_0 was calculated according to FAO Penman-Monteith, FAO temperature, FAO radiation and Hargreaves methods. The methods are defined in the following way:

2.6.1 Penman-Monteith method

According to Smith [33] the Penman-Monteith (P-M) equation is reduced in the form:

$$ET_0 = \frac{0.0864}{\lambda} \frac{\Delta(R_n - G) + c_p \rho_a DPV/r_a}{\Delta + \gamma(1 + r_c/r_a)} \quad (2)$$

where λ is the latent heat of vaporization ($MJkg^{-1}$); Δ is the slope of the vapor pressure versus temperature curve ($kPa°C^{-1}$); γ is the psychrometric constant ($kPa°C^{-1}$); R_n is the net radiation (Wm^{-2}); G is the soil heat flux (Wm^{-2}); c_p is the specific heat of air (1013 $Jkg^{-1}C^{-1}$); ρ_a is the atmospheric density (kgm^{-3}); DPV is the vapour pressure deficit (kPa); r_a is the aerodynamic resistance (sm^{-1}); r_c is the bulk canopy resistance (sm^{-1}); and the ratio of 0.0864/λ was used to transform Wm^{-2} to mm per day.

2.6.2 FAO temperature method

The equation is written as:

$$ET_0 = c\,[p\,(0.46T + 8)] \quad (3)$$

Where,

ET_0 = Reference crop evapotranspiration in mm/day
T = Mean daily temperature in °C
P = Daily percentage of total annual daytime hours
C = Adjustment factor

2.6.3 FAO radiation method

The equation is expressed as:

$$ET_0 = c\,(W.R_s) \quad (4)$$

Where,

ET_0 = Reference crop evapotranspiration in mm/day
R_s = Solar radiation in equivalent evaporation in mm/day
W = Weighing factor which depends on temperature and altitude
c = Adjustment factor

The R_s data was not available for the site. It was estimated from measured sunshine duration record using the following equation [33]:

$$R_s = (0.25 + 0.50\,n/N)R_a \quad (5)$$

Where, n/N is the ratio between actual measured bright sunshine hours and maximum possible sunshine hours; and R_a is the extra-terrestrial radiation, and was estimated following the procedure outlined by [33].

2.6.4 Hargreaves method

Hargreaves and Samani [34] suggested a method where only temperature and radiation data was used. The relationship is written as:

$$ET_0 = (0.00023\,R_a)\,(T_{mean} + 17.8)\,TD^{0.5} \quad (6)$$

Where, R_a is the extra-terrestrial radiation in equivalent mm of water evaporation for the period, T_{mean} is the mean temperature in ^0C, and TD is the difference between maximum and minimum temperatures.

2.6.5 Calculation of ET_0

A software package of 'ET_0', developed by Katholic University of Leuven, Belgium [35] was used to calculate sunflower ET_0 value. The procedure was as follows-

- At first, ET_0 software was opened
- Then, defined the station characteristics (latitude, longitude, and altitude), mentioned the input data such as maximum and minimum temperatures, air humidity, sunshine, and wind speed.
- After that filled the automated data sheet using daily values of the meteorological variables.
- Finally, different ET_0 values were found by just mention the calculation method.

2.7 Determination of Crop Coefficient

The crop coefficient (k_c) for different growth stages was calculated by using the equation:

$$k_c = ET_c\ /\ ET_0 \quad (7)$$

2.8 Growth and Yield Data

At 65 days after sowing, the data on plant height, leaf number/plant were recorded from 8 plants in each lysimeter. The yield and yield contributing data were collected during and after harvest.

3. RESULTS AND DISCUSSION

3.1 Irrigation Effect on Growth and Yield

As we know crop coefficients are determined in a controlled environment where adequate soil moisture, good plant height, and cultural practices are provided. In consideration of this, four irrigation treatments are applied and results of plant growth and yield, and yield contributing data are presented in Table 1. It was noticed that treatment T_2 produced the highest plant height, leaf number per plant, number of seed per head, seed weight per head, 100-seed weight and yield in compared to the other three treatments and lowest was found in treatment T_1. Besides, this treatment received 6 irrigations, whereas T_1 received 10 numbers. This might be due to the cause of treatment T_1 received irrigation more frequently allowing less aeration facilities at the root zone resulting in lower yield of sunflower. It took 5-7 days to complete the drainage from the tanks. Thus, there were only 3-5 days left for this treatment to receive irrigation water again. So, the soil moisture situations in this treatment did not allow plants get favorable growing conditions throughout the season. This observation was found similar with the observation done by Islam and Hossain [23] in maize crop where 10 days interval produced the lowest yield in compared to other treatments. On the other hand, treatment T_2, irrigated at 15 days interval, got 8-10 days time to receive the next irrigation. This interval seems much more favorable for plant growth and yield followed by treatment T_3. Watering at 25 days interval (T_4) seems too long to provide adequate moisture to plants for normal growth and yield. There might have some sort of water stress in the tank that affected crop. Doorenbos and Pruitt [17] suggested that the optimum crop coefficients at different growth stages are recommended to calculate from the best growing plants producing the highest yields. Therefore, treatment T_2 was selected for determining the crop co-efficient values of the crop.

3.2 Determination of Crop Evapotranspiration (ET_C)

Table 2 represents values of crop evapotranspiration under treatment T_2 where irrigation water interval was 15 days and performed best in compare with irrigation interval of 10, 20, and 25 days. After 100% seed germination, first irrigation was applied at 0-15 days. The last irrigation was done 105 days after sowing and harvest was done after 9 days from the last irrigation. Total crop ET during the crop period was 270.89 mm.

Table 1. Effect of irrigation on growth, yield and yield contributing parameters of BARI Surjomukhi-2

Treatments	Plant height (cm)	Leaf number/ plant	Number of seed/head	Seed weight/ head (g)	100-seed weight (g)	Yield (t/ha)
T_1	150.13	23.50	830.88	59.33	7.83	3.60
T_2	155.25	25.00	998.38	71.93	9.29	4.82
T_3	143.63	23.25	771.75	54.14	7.01	3.32
T_4	153.88	24.13	887.25	61.67	8.47	4.35

Table 2. Crop evapotranspiration during the crop season in the lysimeter tank

Duration (days)	Applied water (mm)	Percolation (mm)	Change in soil water storage (mm)	Crop ET (mm)
0-15	10	0	-3.18	13.18
16-30	40	7.19	5.55	27.26
31-45	70	22.61	12.39	35.00
46-60	85	15.39	-6.39	76.00
61-75	85	5.95	11.05	68.00
76-90	70	20.01	16.02	33.97
91-105	40	0	22.52	17.48
Total	-	-	-	270.89

Karam [8] did experiment on sunflower crop under both full and deficit irrigation condition by using drip irrigation method and they estimated total crop evapotranspiration was 765 mm and 882 mm in 2003 and 2004 at 139 and 131 days, respectively. Our estimated value was found much lower that the value found by Karam. This may be the reason of variety, and weather condition as they did experiment during Kharif-1 season. Tyagi [4] reported that crop evapotranspiration varied with season and duration of crop growth. They found seasonal ET_c of sunflower was 655.40 mm although it was grown during both summer and kharif period.

Before harvest a rainfall of 9.00 mm was recorded at 95 days after sowing which was not enough to meet up the crop water requirement so further watering was done as a supplemental irrigation. The negative sign in the value of soil moisture storage indicate that the water was depleted from the initial soil moisture content and was utilized by the crop. By contrast, the positive sign indicates that soil retained more water than the initial soil water content.

3.3 Determination of Crop Coefficient (k_c) According to Crop Growth Stage

The internationally recognized crop growth stages are initial, development, mid-season and late season for the calculation of crop coefficients. The duration of each stage depends on the length of growing season of a particular crop and climate [17,33]. The duration of crops with respect to stage of growth is given in Table 3. The total length of crop growth stages were 114 days.

Table 4 presents crop evapotranspiration, reference evapotranspiration and crop coefficient values of sunflower for different methods. It was found that P-M method gave lower ET_0 values than other methods. The ET_0 value for different methods varies from 49.1 to 68.4, 46.2 to 63.9, 107.5 to 156.8, 83.2 to 111.6, and 286 to 400.7 for initial, development, reproductive, late season, and total growing season, respectively. The maximum k_c value was found at reproductive stage and the lowest was found at late season for all methods. This was because of higher ET_c value at reproductive stage compared to respective ET_0. This was caused by higher temperature resulted in a decrease in soil water and a decline of NDVI [10]. Boegh [36] reported that higher evapotranspiration occurred by dense vegetation. Hunsaker [37] reported that dense vegetation is the cause of increased evapotranspiration and decreased the land surface temperature. Kar [22] obtained the higher k_c values in the development and mid-season stage than that of FAO proposed value due to local advection. The k_c under different ET_0 methods for initial, development, reproductive, late season and whole growing season ranged from 0.34 to 0.48, 0.80 to 1.10, 1.06 to 1.55, 0.27 to 0.36, and 0.68 to 0.95, respectively. Doorenbos and Kassam [38] reported k_c values of 0.3-0.4, 0.7-0.8, 1.05-1.20, 0.35-0.45, and 0.75-0.85 for initial, development, mid-season, late season stages and total growing period, respectively. The P–M method gave relatively higher k_c value than those of other methods and also FAO recommended value. This is because, calculation of ET_0 by using P-M method requires many climatic data, while in other methods ET_0 calculation is possible with the application of limited data [39].

Table 3. Length of growing stages (days) of sunflower at Gazipur

Crop	Growth cycle	Crop growth stages			
		Initial	Development	Reproductive	Late season
Sunflower	114	20	25	45	24

Table 4. Crop coefficient values of sunflower under different ET_0 methods during 2014-15. Here, FAO-T, FAO-R, and H means FAO- Temperature, FAO- Radiation, and Hargreaves

Stage	Crop ET	ET_0 for different method				Kc for different method			
		P-M method	FAO-T method	FAO-R method	H method	P-M method	FAO-T method	FAO-R method	H method
Initial	23.46	49.1	66.6	68.4	65.6	0.48	0.35	0.34	0.36
Development	50.99	46.2	58.2	63.9	62	1.1	0.88	0.8	0.82
Reproductive	166.16	107.5	137	156.8	140.8	1.55	1.21	1.06	1.18
Late season	30.28	83.2	97.3	111.6	99.2	0.36	0.31	0.27	0.31
Total growing period	270.89	286	359.1	400.7	367.6	0.95	0.75	0.68	0.74

Allen [16] reported that ET_0 calculation by using P-M method is recommended by FAO experts as a standard method of crop water requirement calculation. In addition to, a study was carried out by American Society of Civil Engineers (ASCE) and European Studies to test the performance of 20 different ET_0 methods under various climatological conditions. They found the P-M method gave relatively accurate and consistent value than other methods in both arid and humid climates [13]. However, in case of limited data, FAO temperature method can be used, whose value differed from P-M method at 27%, 20%, 21%, 14%, and 21% for different growth stages. Michael [13] reported that in calculating ET_0 only weather parameter values of temperature and day light hour is needed and popular due to simplicity.

Reference evapotranspiration (ET_0) and crop evapotranspiration (ET_c) during the growing season was presented in Fig. 3. For all method, the difference between two values were highest from 46 to 75 days and this was the mid- season for this crop. As a result, the k_c values were found highest at that stage. In ET_c curve the fluctuation is regulated by crop growth and development, while in ET_0 curve the fluctuation is regulated by weather parameter values.

Cumulative crop evapotranspiration (ET_c) values of sunflower at different days after sowing is presented in Fig. 4. Initially ET_c was low due to crop was small, after that ET_c increased with the increase of crop growth and development up to 75 days after sowing. After that crop growth was not occurred and head development occurred as a result, trend was gradually increased. Finally, the total cumulative ET_c was found 270.89 mm.

The trend of crop co-efficient values of sunflower for different ET_0 method is shown in Fig. 5. It is clear that at the initial stage crop coefficients was minimum, rose steeply to the point and continued and after that sharply fall to a certain point.

Tyagi [4] determined k_c values of sunflower using different methods. In P-M method, the k_c values were 0.63, 1.09, 1.29, and 0.40 at initial, crop development, mid-season, and late season, while FAO-Corrected-Penman, FAO-Radiation, Pen-Evaporation values range from 0.37 to 1.14, 0.41 to 1.32, and 0.39 to 1.25, respectively in the Central Soil Salinity Research Institute, Karnal, India. This value was little bit different what we found in Bangladesh may be they did the experiment in summer season, from the month of March to June. Sanchez [40] found that the k_c values of sunflower as 0.3, >1, and <1 during crop establishment, flowering, and seed maturity stages though they used two-source energy balance and thermal radiometry for estimating these values. Karam [8] estimated k_c values of sunflower as 0.3, 0.9, >1.0 and <1.0 at crop establishment, late crop development, flowering, and maturity stage, respectively. Also, these values contradict with FAO recommended value because of the influence of local climatic conditions.

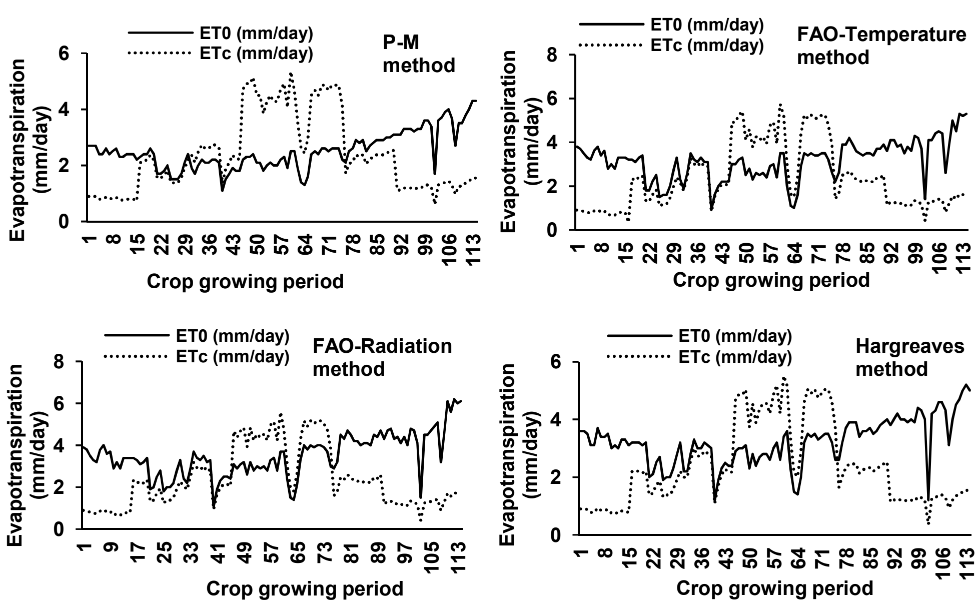

Fig. 3. Crop evapotranspiration and reference evapotranspiration during crop growing period

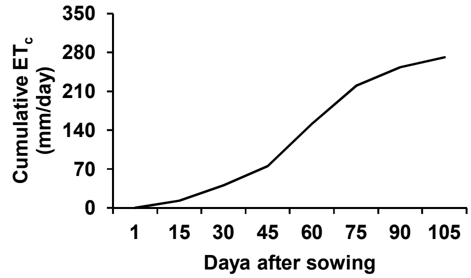

Fig. 4. Cumulative ET_0 during crop period

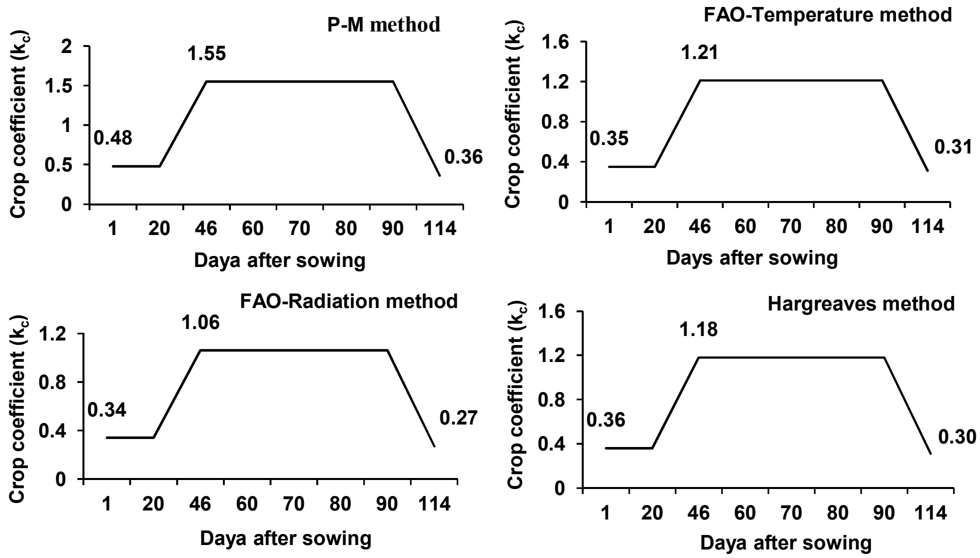

Fig. 5. Crop coefficient of sunflower during crop growing period (averaging method)

4. CONCLUSION

It was found from the study that the crop coefficient values of BARI Surjumukhi-2 for P-M method was 0.48, 1.10, 1.55, 0.36, and 0.95 for initial, development, mid-season, late season and total growing season for semi-arid climate of Gazipur, Bangladesh. The estimated values of crop coefficients for sunflower vary considerably at all the stages from those recommended by FAO. The variations were due to location and environmental effects on crop growth and yield. However, the estimated location specific crop coefficients values are preferred to use in irrigation planning and estimation of crop water requirement and irrigation scheduling.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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