



Determination of Crop Co-efficient Values of Soybean (*Glycine max* [L.] Merrill) by Lysimeter Study

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Abstract

Local level calibration of crop coefficient (K_c) values is critical for regional level planning and allocation of water resources for irrigation. In this regard, an experiment was conducted at the Irrigation and Water Management Division of Bangladesh Agricultural Research Institute (BARI), Gazipur, in order to estimate crop coefficient values of soybean under the local climatic condition. An improved crop variety- BARI Soybean-6 was used in this experiment. The crop was grown under four irrigation treatments, allowing irrigation at an interval of 10, 15, 20 and 25 days. The treatments were so designed that drainage was allowed between the consecutive irrigations. Irrigation at 15 days interval produced the highest seed yield of 1.26 t/ha and was considered to be suitable for estimating seasonal crop evapotranspiration (ET_c) and K_c values. The seasonal highest cumulative ET_c was 308.43 mm under this treatment. The K_c values of soybean at initial, development, mid-season and late season stages were found as 0.67, 1.46, 1.59 and 0.62, respectively.

Keywords: Reference evapotranspiration, crop evapotranspiration, micro-lysimeter, Penman-Monteith method.

1. Introduction

Irrigation has now turned into a costly input for agricultural production worldwide due to increasing demand of water. The competition for scarce water resources is hard-felt in the subtropical agricultural lands that often face semi-arid conditions. For instance, the winter season in Bangladesh is characterized by semi-arid conditions, resulting in an acute shortage of water. Under such scenario, efficient irrigation management is crucial for winter crops in this country. In order to achieve this, an effective irrigation schedule is of utmost importance that requires crop coefficient (K_c) data. However, the

customized crop coefficient data for many crops are still not available in Bangladesh. For instance, the crop coefficient data of soybean (*Glycine max* [L.] Merrill), an important oil seed crop of the country, is yet to be found out. Consequently, scientists depend on the generic values of K_c provided by the Food and Agriculture Organization (FAO) of the United Nations (Allen *et al.*, 1998).

To estimate crop evapotranspiration (ET_c) for irrigation planning on a regional scale, the crop coefficient data is of prime importance. It is the ratio of ET_c to reference evapotranspiration (ET_o) of alfalfa grass. Crop coefficient represents

crop specific water use and is essential for accurate estimation of irrigation requirement of different crops in an area. Crop coefficient values for a number of crops grown under different climatic conditions have been suggested by Doorenbos and Pruitt (1977). The variation of the crop coefficient during crop growing season is obtained experimentally (Pruitt *et al.*, 1972; Jensen, 1974; Doorenbos and Pruitt, 1977; Burman *et al.*, 1980; Wright, 1982; Pruitt *et al.*, 1987). Although there are published K_c values for different crops, these are commonly used in places where local data are not available. As these values vary from place to place, and also from season to season, there is a strong necessity for local calibration of K_c values under specific climatic conditions (Tyagi *et al.*, 2000). Such calibration will ensure proper irrigation scheduling and efficient water management of crops on a regional scale.

Although several agronomic experiments (e.g., Rahman *et al.*, 2013a; Rahman *et al.*, 2013b; Ahmed *et al.*, 2014; Khan *et al.*, 2014; Khan *et al.*, 2015) were conducted with soybean in Bangladesh, none of them has reported the crop coefficient values. Lysimeter studies, in particular, have not been yet done for this important oilseed crop in Bangladesh. In consideration of these knowledge gaps in the literature, this study was undertaken with the objective of determining the crop coefficient values of soybean at its different growth stages.

2. Materials and Methods

An experiment on soybean cultivation was conducted in a micro-lysimeter installed at the research farm of Bangladesh Agricultural Research Institute, Gazipur, during the rabi season (November to March) of 2015–2016. The climate was warm and dry with average temperature of 22.5°C. The maximum and minimum relative humidity, and maximum and average wind speed were 93%, 34%, 10.64 m/s and 1.60m/s, respectively. The highest rainfall of 25 mm occurred on 8 March 2016, and the highest solar radiation was 22.8 MJ/m²/day

(Table 1). The soil of the experimental field was silty clay loam, with field capacity and bulk density of 29.5% and 1.50 g/cm³, respectively.

A hybrid variety of soybean (BARI Soybean-6) was selected for the lysimeter experiment. Seeds were sown in a 1 m × 1m micro-lysimeter platform at a spacing of 0.30 m × 0.10 m on 19 November 2015. The seeds were treated using Bavistin @ 2 g/kg of seed. The same crop was grown surrounding the lysimeter tanks with a view to create a similar cropping environment as in the lysimeter (Figure 1). Recommended fertilizer doses (FRG, 2012) were applied and necessary intercultural operations were done as and when required. In order to reduce fruit fly infestation, Sumethion 57 EC @ 2ml/L of water was sprayed at 35, 47 and 17 days after sowing.

The drainage type micro-lysimeter contains four tanks each of area 1 square meter. The crop was grown in the lysimeter in a controlled environment since the lysimeter was hydrologically separated from the surrounding soil (Michael, 2014). When crops are grown under such conditions, there is no need for further replication as argued by Khan *et al.* (1993). The similar system was used by other researchers (Islam and Hossain, 2010; Mila *et al.*, 2016) for estimating crop coefficient values of hybrid maize and sunflower. Our experiment comprised four treatments as:

- T₁ = Irrigation at 10 days interval allowing drainage until receive the next irrigation
- T₂ = Irrigation at 15 days interval allowing drainage until receive the next irrigation
- T₃ = Irrigation at 20 days interval allowing drainage until receive the next irrigation
- T₄ = Irrigation at 25 days interval allowing drainage until receive the next irrigation

Measured quantity of water was applied as irrigation to the crops grown in the lysimeter tanks by ensuring provision of adequate drainage. In addition, the soybean plots adjacent to the tanks were also irrigated (Figure 1). Drainage water from the lysimeter tanks was collected and measured using graduated

cylinders. The crop evapotranspiration, ET_c , was calculated from the irrigation and drainage quantities by using water balance principle (Equation 1) (Itier *et al.*, 1997). Prior to irrigation, soil moisture was measured in order to determine soil-water depletion during a particular time period. The crop evapotranspiration was calculated by using water balance equation given by:

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

where, ET_c is crop evapotranspiration during a specified time period (mm), W_a is applied water plus rainfall during the time period (mm), D_w is drainage water during the time period (mm) and ΔS_s is stored soil moisture during the time period (mm).

There are several methods for determining reference evapotranspiration, ET_o . Among them, Penman-Monteith method has been recommended for empirical determination of ET_o using climatic data viz., temperature, humidity, sunshine duration and wind speed (Allen *et al.*, 1998; Michael, 2014). According to Smith *et al.* (1992), FAO Penman-Monteith method gives more consistent ET_o estimates and has been shown to perform better than other methods. In this study, reference evapotranspiration, ET_o , was estimated by using CROPWAT software that uses Penman-Monteith model to calculate ET_o . This model requires only insertion of location (latitude, longitude and elevation), and climate data (maximum and minimum air temperature, humidity, sunshine hour and wind speed).

The crop coefficient, K_c , was estimated by using the following formula:

$$ET_c = K_c \times ET_o \dots\dots\dots(2)$$

At 111 days after sowing, the data on plant height and number of branches per plant were recorded from 10 plant samples in each lysimeter. Pods were collected three times during the crop maturity stage as flowering and pod formation occurred simultaneously. Data for leaf

area index (LAI) was collected during the crop period starting from vegetative stage. The yield and yield contributing data were collected during and after harvesting of the crop.

3. Results and Discussion

3.1 Effect of irrigation on growth and yield

Table 2 represents growth, yield and yield contributing attributes of BARI Soybean-6. Treatment T_2 (irrigation at 15 days interval) produced the highest plant height, number of branches per plant, pods per plant and seed yield, while treatment T_4 (irrigation at 25 days interval) gave the highest number of seeds per pod and 100-seed weight compared to the other three treatments. It (treatment T_4) took maximum 7 to 10 days to get completely drainage and rest of days (15-18 days) its root zone was becoming dry prior to receive next irrigation. On the other hand, treatment T_2 (irrigated at 15 days interval) got 8–10 days to receive the next irrigation. As a result, the soil moisture content of the lysimeter tank experienced minimal fluctuation within the range of available soil moisture (Figure 2b). This treatment (T_2) also gave the highest leaf area index (LAI) of 12.34 at 85 days after sowing (Figure 3). Treatment T_4 was particularly devastating for the crop since the 25-days irrigation interval induced almost intolerable water stress to the crop in the tank as illustrated in Figure 2d. By contrast, treatment T_1 produced the lowest yield among the treatments, probably, due to the fact that this treatment experienced frequent irrigation (total 10) during the growth period. As a result, soil was almost saturated during the crop period, which significantly increases pod number and seed number per plant but most of the seed was immature. It also increases insect infestation. Eventually, this condition was translated into lower yield of soybean. In fact, it took 5 to 7 days to complete drainage from the tanks. Thus, there were only 3-5 days left for this treatment to receive irrigation water again. So, the soil moisture condition in this treatment was within the limit of available soil moisture ($ASM = FC-PWP$) throughout the growing season (Figure 2a).



Figure 1. Photographic view of lysimeters in the experimental field. The age of plant was 26 days at the time of taking the photograph

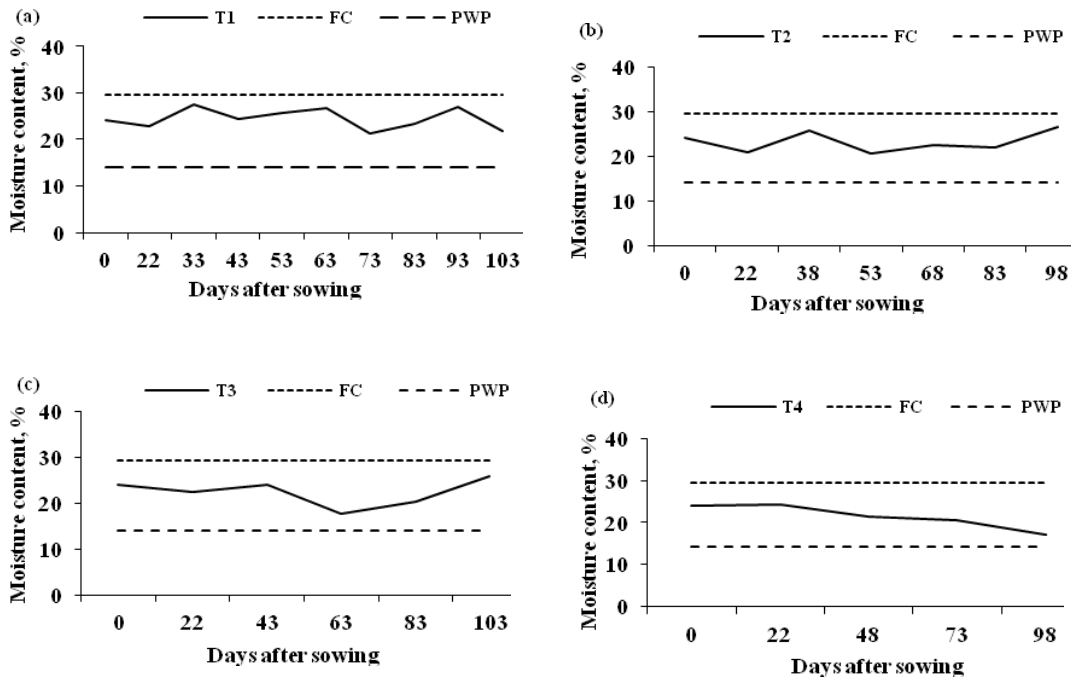


Figure 2. Soil-moisture content under different treatments during the crop period

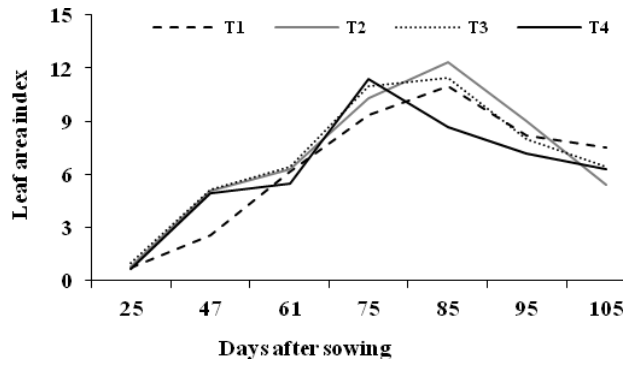


Figure 3. Effect of irrigation on leaf area index of soybean during the crop period

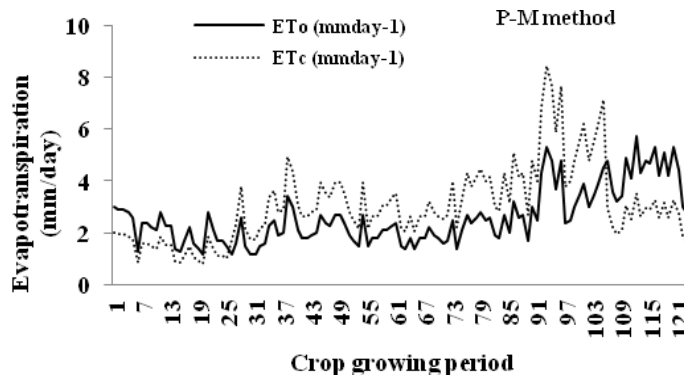


Figure 4. Crop evapotranspiration (ET_c) and reference evapotranspiration (ET₀) of soybean during the growth period

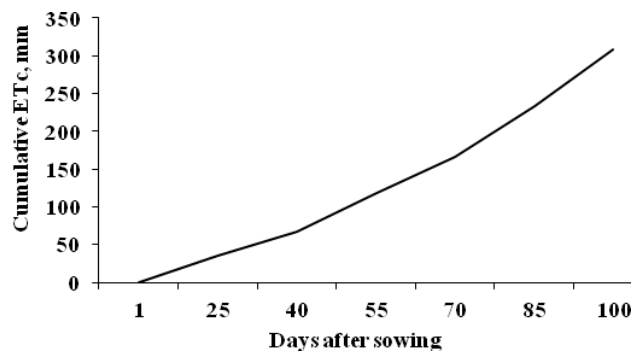


Figure 5. Cumulative crop evapotranspiration (ET_c) of soybean during the crop growth period

In contrast, in treatment T_2 , soil moisture was within the limit of readily available moisture (RAM = 50-75% of ASM). This treatment (T_1) also showed the lowest LAI during the crop period (Figure 3). These results imply that the 15days irrigation interval was more favorable for the growth and yield of the crop compared to the other treatments. Therefore, the growing conditions associated with T_1 , T_3 and T_4 cannot be taken as the reference regimes of crop growth as Doorenbos and Pruitt (1977) recommended that the optimum K_c values should be obtained from the best growing plants, i.e., the plants producing the highest yield. In consideration of this, treatment T_2 was selected for determining the crop co-efficient values of soybean.

3.2 Crop evapotranspiration, ET_c

Table 2 represents crop evapotranspiration value of treatment T_2 where irrigation interval was 15 days. At 25 days after sowing, first irrigation was applied when leaf area index ranged from 0.65 – 0.99 for treatment T_1 to T_4 (Figure 3). The last irrigation was applied at 100 days after sowing (LAI was 6.44) and the harvesting of soybean was done 23 days after that. Total ET_c during the crop period was estimated to be 308.43 mm. Karam *et al.* (2005) carried out a series of experiments on soybean crop under deficit irrigation condition. Their estimation showed that the total ET_c was 800 mm and 725 mm

during the year 2000 and 2001, respectively for the corresponding growing period of 140 and 138 days. The current experiment, however, produced much lower total ET_c values compared to Karam *et al.* (2005). Also, Karam *et al.* (2005)'s growing period was at least 15 days more. On the other hand, the reported values of seasonal ET_c value of soybean of Doorenbos and Pruitt (1977) ranged from 450 to 825 mm, which are relatively closer to our ET_c values.

Before harvest, a total rainfall of 5.0 mm was occurred during 119 to 122 days after sowing (Table 1). The negative sign in the value of soil moisture storage indicates that the plants extracted water from the soil in excess of that stored due to irrigation applications. By contrast, the positive sign indicates that water was stored in the soil in excess of initial water content.

3.3. Crop coefficient (K_c)

The internationally recognized crop growth stages for the calculation of crop coefficients are initial, development, mid-season and late season stages (Allen *et al.*, 1998). The duration of each stage depends on the length of growing season of a particular crop and climate (Doorenbos and Pruitt, 1977; Smith *et al.*, 1992). The duration of crops with respect to stage of growth in the current experiment is provided in Table 4.

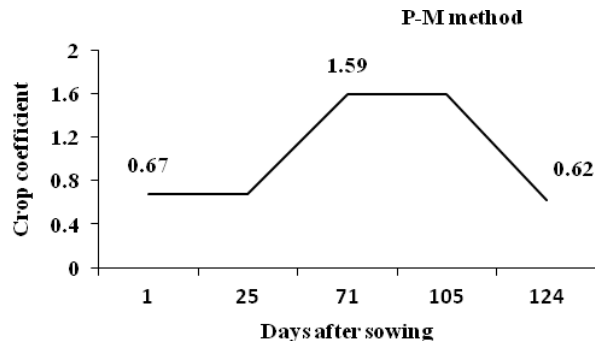


Figure 6. Crop coefficients (K_c) of soybean during the growth period

Table 1. Monthly weather parameter values of study area during the crop period

Month	Temperature (°C)		Relative humidity (%)		Wind speed (m/s)		Precipitation (mm)	Solar radiation (MJ/m ² /day)
	Max	Min	Max	Min	Max	Mean		
November	30.45	16.33	94.58	84.67	1.56	0.79	0	15.33
December	26.52	12.98	91.65	74.84	3.29	1.76	0	10.44
January	23.43	13.95	91.35	66.81	2.67	1.51	8	12.32
February	29.38	17.06	90.03	58.1	2.59	1.32	0	14.69
March	33.08	19.9	88.71	53.62	4.29	2.36	41	18.34

Table 2. Average growth, yield and yield contributing parameters of BARI Soybean-6 under four irrigation regimes

Treatments	Plant height (cm)	Branch number/plant	Pod number/plant	Seed number/pod	100-seed weight (g)	Seed yield (t/ha)
T ₁	76.4	3.6	25.2	2.0	11.38	0.78
T ₂	86.4	3.9	29.6	2.0	11.82	1.26
T ₃	85.4	3.2	22.4	1.7	12.22	1.02
T ₄	74.3	3.2	16.7	2.2	13.27	0.98

Table 3. Crop evapotranspiration, ET_c, of soybean grown under treatment T₂ in the lysimeter tank during the growing season

Days after sowing	Applied water (mm)	Drainage water (mm)	Change in soil water storage (mm)	Crop ET (mm)
25	50	19.83	5.18	35.35
40	25	1.11	7.76	31.65
55	80	34.08	4.95	50.87
70	65	25.09	8.36	48.27
85	80	3.56	-9.00	67.44
100	80	2.19	-2.96	74.85
Total	-	-	-	308.43

Here, Drainage water was calculated from after irrigation application up to before the next irrigation. In case of changing soil moisture storage, calculation was done change in moisture content before receive irrigation and after receive irrigation just prior to next irrigation at the root zone depth of known bulk density.

Table 4. Length of growth stages (days) of soybean

Crop	Growth cycle	Crop growth stages			
		Initial (I)	Crop development (II)	Mid-season (III)	Late season (IV)
Soybean	124	25	45	35	19

Table 5. Crop co-efficient values of BARI Soybean-6

Crop growth stages	Duration (Days)	Crop ET (mm)	ET _o (mm)	Crop co-efficient
Initial	25 (1-25 days after sowing)	35.24	52.6	0.67
Development	45 (26-70 days after sowing)	130.88	89.7	1.46
Mid-season	35 (71-105 days after sowing)	162.34	102.1	1.59
Late season	19 (106-124 days after sowing)	50.72	81.8	0.62

Evapotranspiration and crop coefficients vary with the crop growth stages. Figures 4 to 6 illustrate the crop evapotranspiration, ET_c, reference evapotranspiration, ET_o, cumulative ET_c and crop coefficient, K_c, values of soybean at different growth stages. At the initial stage, the average ET_c was 1.94 mm/day, which fluctuated throughout the growth period. It reached at the peak (8.43 mm/day) during the period of 93 days after sowing, and dropped down to 1.86 mm/day at 122 days after sowing. Similarly, ET_o being 2.90 mm/day at the primary stage fluctuated over 1.40 to 5.70 mm/day. The mid-season ET_o was interestingly lower than the primary stage but it increased again to reach 8.43 mm/day prior to harvest (Figure 4). As can be seen from Figure 5, the cumulative ET_c values increased steadily and reached to 35.35 mm at 25 days after sowing, 131 mm during 26-70 days after sowing and 178 mm during 71-105 days after sowing. During harvest, the cumulative ET_c was 308.43 mm.

The crop coefficient values were found to be 0.67, 1.46, 1.59 and 0.62 at the four growth stages (Table 5). By taking average (Biswas *et al.*, 2014) for the consecutive growth stages the K_c values of three growth stages are illustrated in Figure 6. The findings of several investigators conform to the findings of the current study. For instance, Karam *et al.* (2005) found that K_c

values of soybean were 0.62, 1.0 and 0.81 at the initial, pod formation and mature pod stage at Tal Amara Research Station, Lebanon. Allen *et al.* (1998) found the K_c values of 0.40, 1.15 and 0.50 for the initial, mid-season and late-season stage, respectively. Doorenbos and Pruitt (1977) reported the K_c values of soybean for mid-season and at harvest as 1.0 to 1.05 and 0.45, respectively, depending on minimum relative humidity of >70% and 1.1 to 1.15 and 0.45, respectively, depending on minimum relative humidity of <20%. Doorenbos and Kassam (1979) reported K_c values of 0.3-0.4, 0.7-0.8, 1.0-1.15 and 0.7-0.8 for initial, crop development, mid-season and late season stages, respectively. The K_c values obtained in our experiment were much higher than the FAO recommended values except for the late season stage. Such variations are common and are expected because of the fact that different varieties perform differently in terms of their growth and development.

4. Conclusions

An experiment was carried out at the research field of Irrigation and Water Management Division, Bangladesh Agricultural Research Institute, Gazipur to know the crop evapotranspiration and crop coefficient values of

soybean. Results showed that irrigation at 15 days interval including drainage within two consecutive irrigations gave the highest yield of soybean in this semi-arid region. Seasonal crop evapotranspiration of soybean was 308.43 mm when irrigation was provided at 15 days interval. The crop coefficient values of BARI Soybean-6 were 0.67, 1.46, 1.59 and 0.62 at the initial, development, mid-season and late season stages, respectively. The estimated values of crop coefficient for soybean vary considerably over the growth stages from those recommended by FAO except for the late season stage. Nevertheless, the locally calibrated values of the crop co-efficient can be used for more reliable planning and distribution of regional water resources for irrigation.

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