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Determination of crop coefficient for bean (*Phaseolus vulgaris L.*) plants under drip irrigation system

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Abstract: Two Field experiments were carried out during two consecutive seasons (2012 and 2013). The experiments were conducted at Shalakan Experimental Farm of the Faculty of Agriculture, Ain Shams University, Kalubia Governorate (30.13° N, 31.4° E and 14 m above sea level). The experimental site represents the old alluvial soil of the Nile Delta. The soil was clay loam in texture. The main objective of this study was to determine the values of crop coefficient (KC) for bean (*Phaseolus vulgaris* L.) varieties Contender and Bronco under Egyptian conditions in case of using surface drip irrigation (SDI) and subsurface drip irrigation (SSDI).

The crop coefficient was calculated during the growing season for each treatment and reaching to the length of the different stages of bean in each treatment. Crop coefficient ranged between (0.63- 0.64) for initial, (0.87 - 0.82) for development, (0.99 - 1.09) for midseason and (0.80-0.95) for harvesting stage in case of Bronco variety at three levels of water application (80%, 60% and 40%) of available water with both irrigation systems. While it ranged between (0.59- 0.61) for initial, (0.78 - 0.98) for development, (1.07 - 1.19) for midseason and (0.73-0.88) for harvesting stage in case of Contender variety with both irrigation systems and the same three levels of water application.

Keywords: *Phaseolus vulgaris*, irrigation treatments, available water, surface and subsurface drip irrigation, crop coefficient, evapotranspiration.

Introduction

Green bean *(Phaseolus vulgaris L.)* is one of the important vegetable crops grown in Egypt. The cultivated area of green beans in Egypt is 70571 feddan in both old and new lands. The productivity of green beans is 4.33 t/fed. and the total production from the cultivated area is 305560 tons[1].

In Egypt, River Nile which floods about 55.5 billion m^3 water a year is the most important water resource for agricultural, industrial, and urban activities. Rainfall which is about 130 mm a year and occurs only in winter season is not sufficient even for an irrigation interval. Even though, most of ground water comes due to infiltrating and moving water from Nile or its irrigated fields. More than 85% of water consumption is due to agricultural related activities. Moreover, a large number of small scale farmers who owns dispersed plots over an area irrigate their crops from small earthen ditches where it is impossible to measure the water used by individual farmers. Farmers rationally endeavor to obtain more water during its flowing in ditches to achieve maximum crop production, but, not all of them can have the same quantity of water under the limited availability of water. Therefore, modern irrigation techniques are demanded in order to use water more efficiently and sustain the increase of both cultivated land and populations[2].

The crop coefficient plays an essential role in various agricultural practices and it has been widely used to estimate the actual ET in irrigation scheduling[3].

Crop coefficients are a widely used and universally accepted method for estimating the crop evapotranspiration (ET_c) component in irrigation scheduling programs. However, uncertainties of generalized basal crop coefficient (K_{cb}) curves can contribute to ET_c estimates that are substantially different from actual ET_c [4].

An accurate estimation of crop evapotranspiration (ET_c) is very useful for appropriate water management[5].

A correct evaluation of water losses as evapotranspiration (ET) by crops is important for allocating irrigation water and improving water use efficiency[6].

The time-domain Reflectometry (TDR) values of soil moisture are generally lower than the results obtained from VIRRIB sensors. The explanation of this fact should be that the used TDR measurements involve bigger interval of soil profile than VIRRIB sensors which measure smaller area of soil. The other reason could be the different way of probe installation for each method. The results were compared with the data obtained from VIRRIB sensors, and where possible, the TDR data was used for giving precision to the VIRRIB data[7].

Drip irrigation provides greater efficiency in terms of water usage and energy. These factors are very important in light of the current competition for water resources between the various users, especially in the Mediterranean region due to water scarcity. The shape and dimensions of the volume of wet soil below the emitter are some of the most influential variables in the optimal design and management of drip irrigation systems[8].

In designing subsurface drip irrigation systems(SSDI) for row crops, the dimensions of the wetted volume and the distribution of soil moisture within this volume are two of the main factors in determining installation depth and spacing of drippers to obtain an optimum distribution of water in the crop root zone. Since the source of water is at a certain depth when SSDI is used, the soil surface usually remains drier than for the surface drip irrigation. This leads to the reduction of evaporation from the soil surface, and consequently to an increase in transpiration and overall water use efficiency[9].

2. Materials and Methods

2.1. Field experimental work

Bean crop was grown during two consecutive seasons (2012 and 2013) in clay soil located at an arid site in northern Egypt (Shalakan Experimental Farm of the Faculty of Agriculture, Ain Shams University, Kalubia Governorate, 30.13° N, 31.4° E and 14 m above the sea level). The crop was planted on 1st March in the two experimental seasons. Plants were sown in rows 70 cm apart and hills were spaced 10 cm apart. Thinning was practiced before the first irrigation to secure two plants per every hill. Green pods were picked four times, during harvesting stage for the two growing seasons. The applied statistical design of the experiments used was split-split plot with three replications, the treatments were irrigation systems (surface and subsurface drip irrigation), water treatments (80 %, 60% and 40 % of available water) and bean varieties (Contender and Bronco) were assigned as main plots, sub main plots and sub-sub main plots, respectively. Water requirements were calculated by measuring the amount of irrigation water for beans which was applied by flow meter after the measuring of it using a VIRRIB soil moisture sensor based on the theory of electromagnetic waves at 80, 60 and 40 % of available water in the soil profile.

Two drip irrigation systems (surface and subsurface) were constructed and tested before used in the experimental location. Laterals (16mm diameter, P.E.) and the emitters were built-in with an average discharge 4.0 L/h and 0.3 m emitter spacing. Laterals spacing were 0.70 m. In the subsurface drip irrigation system, lateral drip lines were buried at 20cm depth under the soil surface. Fertilizer requirements of bean crop were applied according to recommendations of Horticulture Research Institute, ARC, Ministry of Agriculture and Land Reclamation. The used doses of fertilizers were 200 kg/ fed. of calcium super phosphate (15.5 % P_2O_5), 50 kg/ fed. of ammonium sulphate (20.5 % N) and 25 kg/ fed. of potassium sulphate (48 % K_2O) and were added during the seed bed preparation. While additional 50 kg/fed. of ammonium sulphate and 25 kg/fed. of potassium sulphate were added at the first irrigation. The other doses from the different fertilizers after sowing were added according to recommendations of Horticulture Research Institute, ARC, Ministry of Agriculture and Land Reclamation.

Soil was classified as clay loam with 1.28 g cm^{-3} bulk density, Field capacity =30.78%, wilting point 16.1%, profile were distributed as 0.6 % coarse sand, 28.7% fine sand, 37% silt, and 33.7% clay. The studied area was irrigated by water having EC = 0.54 dSm^{-1}, SAR = 2.4, and pH= 7.2. Chemical analysis and hydro-physical properties were carried out according to the method described by **Klute & Dirksen (1986)[10].** Field capacity (F.C.) and permanent wilting point (P.W.P.) were determined according to **Black (1965)[11].**

2.2. Water requirements and crop coefficient

Water requirements calculated by measuring the amount of irrigation water required for beans which was applied after measuring soil moisture content using a VIRRIB soil moisture sensor based on the theory of electromagnetic waves. Water application rate was added at 80, 60 and 40 % of available water to reach field capacity.

Each level of water application rate was calculated according the following equation:

$$d = \left[\frac{(Fc - PWP) * DRZ * Kr}{Ea}\right](1 - SMD) \qquad \text{.......................... (1)}$$

Where,

d = Irrigation water applied (mm);
FC = Field capacity (%),
PWP= Permanent Wilting Point (%);
Kr = Reduction factor (Keller and Karmeli, 1975)
Ea = Irrigation efficiency, 90%;
DRZ = Depth of root zone,
SMD = Soil Moisture Deficit (40%, 60%, 80%).

Crop coefficient (Kc) of bean plants was determined by divided the measured crop evapotranspiration (ETc) on the calculated reference evapotranspiration (ETo) that obtained from the modified **Penman-Monteith (FAO-56)** [12] as follows:

Kc = ETc/ ETo .... (2)

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad \text{.............................. (3)}$$

Where:

ET_o = reference evapotranspiration [mm day^{-1}],
R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}],
G = soil heat flux density [MJ m^{-2} day^{-1}],
T = mean daily air temperature at 2 m height [°C],
u_2= wind speed at 2 m height [m s^{-1}],
e_s = saturation vapour pressure [kPa],
e_a = actual vapour pressure [kPa],
$e_s - e_a$ = saturation vapour pressure deficit [kPa],
Δ= slope vapour pressure curve [kPa $°C^{-1}$],

γ= psychrometric constant [kPa °C^{-1}].

Then, the mean values of both (ETc) and (Kc) water determined considering the growing stages proposed by **Allen et al. (1998)**[12]: I) initial: planting up to 10 % of ground cover; II) development phase: from the end of the initial stage up to 80 % of ground cover; III) mid-season: from 80 % of ground cover to the beginning of fruit maturation; IV) harvesting: from the beginning of maturation until harvest.

At every irrigation event, water applied was computed based on the average soil moisture content in effective root zone. The level of water application was dependent on the value of the available water percent, where three levels of water application were considered for both the two bean varieties (40%, 60%, 80% of the available water). The irrigation interval between two consecutive irrigations was changed according to the level of the available water along the growing season for the two varieties. Crop evapotranspiration (ETc) was calculated for each irrigation duration. The value of reference evapotranspiration (ETo) was obtained from **FAO Penman-Monteith** method by using software of ETo calculator which developed by the Land and Water Division of FAO (ETo calculator, land and water digital media series No 36, 2012). All of the metrological data for experimental site were obtained from Central Laboratory for Agricultural Climate (CLAC). Basal crop coefficient (Kc) for each level of the available water can be consequently obtained.

The calculation of reference evapotranspiration (ETo) using equation (3.3) needs to measure all climatic parameters that are involved the equation. The daily values was used, the monthly average values of the main parameters was measured and listed in Table (1).

Table (1): Average monthly climatic parameters measured at the experimental site.

	Temperature		Average Wind speed	Average relative humidity	Solar radiation
Month	**Max.**	**Min.**	**m s^{-1}**	**%**	**[mJ m^{-2}] Aver**
March	27.5	13.5	0.3	50	12.9
April	28.7	15.3	0.2	49.3	15.1
May	34.9	20.2	0.3	49.2	20.6

2. Results and Discussion

3.1. Crop coefficient under subsurface drip irrigation system.

Subsurface drip irrigation system (30 cm, emitter space) was used to irrigate the two studied varieties and the crop coefficient (Kc) could be derived. Crop coefficient was changed due to both level of water application rate and bean variety.

3.1.1. Crop coefficient at 40 % of the available water

Table (2) represents the calculated crop coefficient (Kc), crop evapotranspiration (ETc) and Referance evapotranspiration (ETo) for two bean varieties at 40% of the available water under subsurface drip irrigation system. For both two varieties, (Kc) increased along the growing season until reached to its peak point at the midseason. After that it decreased and reached to its lower value during the harvesting stage.

For Bronco bean variety, the crop coefficient (Kc) reached to peak value after 56 days from planting where it was 1.04 while for Contender bean variety, it reached to its peak value (1.10) after 60 days from planting as presented in fig. (1).

3.1.2. Crop coefficient at 60 % of the available water

Crop coefficient of the two bean varieties irrigated at 60 % of the available water was presented in table (3). The crop coefficient for Bronco variety reached to its peak value (1.18) after 58 days from planting. As for Contender variety, Kc reached to its peak value (1.21) after 57 days from planting. The values of the crop coefficient along the growing season were almost closed for the two varieties. This was evident from figure (2) which presents the changing of the crop coefficient for the two varieties along the growing season. In this figure the four growing stages for the two varieties were approximately similar in both length and trend. The figure also showed that the values of the crop coefficient were higher at initial and harvesting stages for Bronco while it was higher at development and mid season for Contender variety.

3.1.3. Crop coefficient at 80 % of the available water

Application of the irrigation water by subsurface drip irrigation at 80 % of the available water have been conducted with small intervals between irrigation events. The changing of the crop coefficient (Kc) in this case was presented in table (4). The peak value of crop coefficient for Bronco variety (1.00) was observed after 50 days from planting. While for Contender bean variety, the peak value of (Kc) extended along the mid season stage and ranged between 1.00 to 1.07 and being started 60 days after planting.

Figure (3) showed the changing values of the crop coefficient for the two bean varieties along the growing season. It illustrated that the values of (Kc) at the beginning of the growing season was higher with Bronco variety. At the end of growing season the values of (Kc) varied strongly for the two varieties. Based on the closed irrigation intervals, the length of each growing stage was the same for the two varieties but with different values of crop coefficient.

Table (2): Crop coefficient of the two bean varieties under subsurface drip irrigation at 40% of the available water.

Bean Variety							
Bronco				Contender			
Irrigation duration (days)	Crop evapotranspiration ETc (mm/day)	Referance evapotranspiration ETo (mm/day)	Crop coefficient (Kc)	Irrigation duration (days)	Crop evapotranspiration ETc (mm/day)	Referance evapotranspiration ETo (mm/day)	Crop coefficient (Kc)
0				0			
19	1.53	2.34	0.65	21	1.38	2.34	0.59
15	1.93	2.51	0.77	18	1.61	2.62	0.61
12	2.42	2.75	0.88	13	2.23	2.64	0.84
10	2.90	2.79	1.04	8	3.63	3.29	1.10
9	3.22	3.62	0.89	7	4.14	3.80	1.09
9	3.22	3.98	0.81	9	3.22	4.00	0.81
9	3.22	4.13	0.78	9	3.22	4.16	0.77

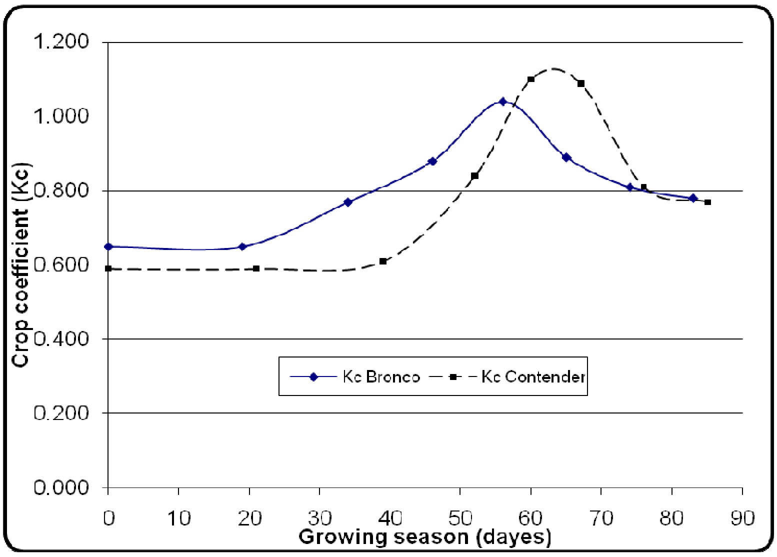

Figure (1): Crop coefficient along the growing season for the two varieties at 40 % of the available water under subsurface drip irrigation system.

Table (3): Crop coefficient of the bean varieties under subsurface drip irrigation at 60 % of the available water

Bean Variety							
Bronco				Contender			
Irrigation duration (days)	Crop evapotranspiration ETc (mm/day)	Referance evapotranspiration ETo (mm/day)	Crop coefficient (Kc)	Irrigation duration (days)	Crop evapotranspiration ETc (mm/day)	Referance evapotranspiration ETo (mm/day)	Crop coefficient (Kc)
0				0			
13	1.49	2.29	0.65	15	1.29	2.37	0.55
14	1.39	2.45	0.57	12	1.62	2.38	0.68
10	1.94	2.61	0.74	9	2.16	2.6	0.83
9	2.16	2.78	0.78	9	2.16	2.72	0.79
7	2.77	2.60	1.07	7	2.77	2.64	1.05
5	3.88	3.28	1.18	5	3.88	3.2	1.21
6	3.23	3.67	0.88	5	3.88	3.62	1.07
6	3.23	3.87	0.83	5	3.88	3.8	1.02
6	3.23	4.10	0.79	5	3.88	3.92	0.99
7	2.77	4.14	0.67	6	3.23	4.05	0.80
				7	2.77	4.2	0.66

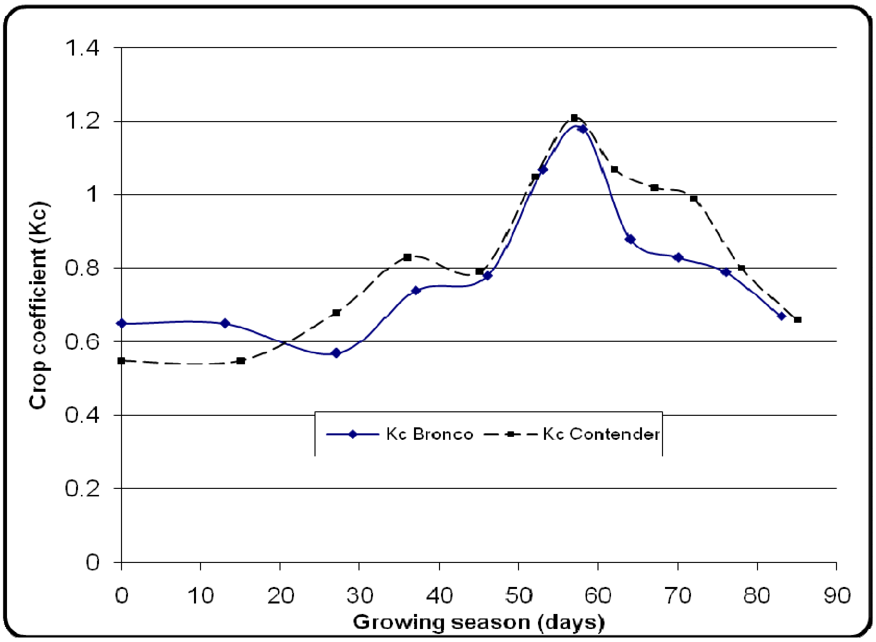

Figure (2): crop coefficient along the growing season for the two varieties at 60% of the available water under subsurface drip irrigation system.

Table (4): Crop coefficient of bean varieties under subsurface drip irrigation at 80 % of the available water

Bean Variety							
Bronco				Contender			
Irrigation duration (days)	Crop evapotranspiration ETc (mm/day)	Referance evapotranspiration ETo (mm/day)	Crop coefficient (Kc)	Irrigation duration (days)	Crop evapotranspiration ETc (mm/day)	Referance evapotranspiration ETo (mm/day)	Crop coefficient (Kc)
0				0			
8	1.21	2.41	0.50	9	1.08	3.36	0.46
8	1.21	2.29	0.53	8	1.21	2.43	0.50
7	1.39	2.31	0.60	6	1.62	2.48	0.65
6	1.62	2.67	0.61	5	1.94	2.52	0.77
5	1.94	2.82	0.69	4	2.43	2.75	0.88
5	1.94	2.48	0.78	4	2.43	2.83	0.86
4	2.43	3.03	0.80	4	2.43	2.78	0.87
4	2.43	2.63	0.92	4	2.43	2.70	0.90
3	3.23	3.23	1.00	4	2.43	2.65	0.92
3	3.23	3.33	0.96	3	3.23	3.40	0.95
3	3.23	3.30	0.95	3	3.23	3.40	0.95
3	3.23	3.23	0.92	3	3.23	3.27	0.99
2	4.85	5.05	0.94	3	3.23	3.27	0.99
3	3.23	3.40	0.95	2	4.85	4.85	1.00
3	3.23	3.50	0.92	2	4.85	4.75	1.02
2	4.85	5.15	0.94	3	3.23	3.13	1.03
2	4.85	5.10	0.95	2	4.85	4.70	1.03
2	4.85	5.25	0.92	2	4.85	4.55	1.07
3	3.23	3.83	0.84	3	3.23	4.17	0.77
3	3.23	4.13	0.78	4	2.43	4.00	0.61
3	3.23	4.40	0.78	4	2.43	4.25	0.57

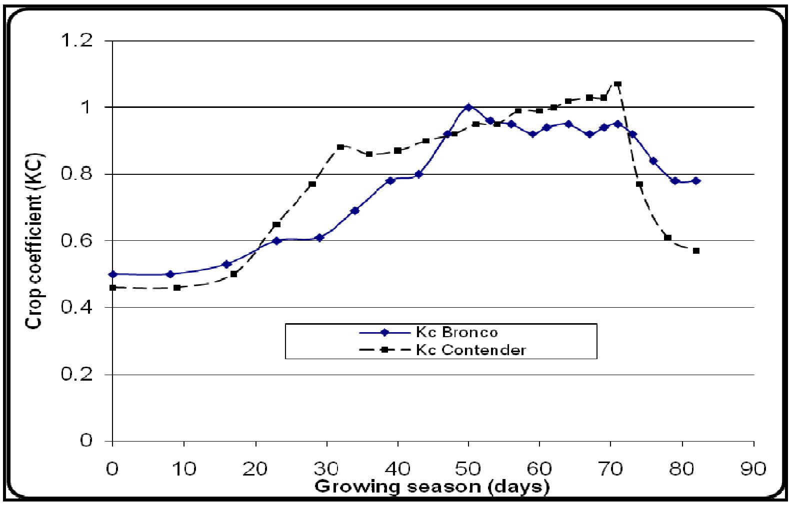

Figure (3): Crop coefficient along the growing season for the two varieties at 80 % of the available water under subsurface drip irrigation system

3.2. Crop coefficient under surface drip irrigation system.

At studied water application levels, the values of crop coefficient along the growing season may be affected due to using surface drip irrigation system. These values and that obtained with subsurface drip irrigation system will gave a clear image of the effect of water application rate and the used system of irrigation.

3.2.1. Crop coefficient at 40 % of the available water

Table (5) represents the calculated values of crop coefficient (Kc) for the two bean varieties at 40% of the available water under surface drip irrigation system. In both varieties, crop coefficient (Kc) started with low values and increased along the growing season until it reached the peak point and then decreased sharply at the end of the growing season. The highest values were 1.07 and 1.18 for Bronco and Contender varieties, respectively. It can be observed that irrigation with surface drip irrigation at 40% of the available water indicates a remarkable fluctuation in crop coefficient values especially at the middle of the growing season for the two studied varieties. Hence, this was resulted in more than one peak point for both varieties. But the trend of changing the crop coefficient at this level of the available water being normal along the growing season.

Fig. (4) shows the trend of the crop coefficient along the growing season for both Bronco and Contender varieties. Contender variety achieved approximately higher values of crop coefficient than Bronco. The difference was only in period at which the crop coefficient was calculated.

3.2.2 Crop coefficient at 60 % of the available water

Irrigation at 60% of the available water in soil profile led to a decrease in the irrigation interval along the growing season. The obtained results that presented in table (6) showed the closed intervals between irrigation events especially at the end of the growing season. The calculated values of the crop coefficient for the two bean varieties have the same trend but with different magnitudes in both intervals and crop coefficient values. The peak value of the crop coefficient in case of Bronco variety (1.07) was achieved after 56 days from planting, while the beak value of the crop coefficient for Contender variety (1.27) was achieved after 63 days from planting. These closed results which were observed under surface drip irrigation system showed a normal behavior of bean plants which did not depend upon its variety. Also, there was no great difference between these values and that obtained with subsurface drip irrigation system.

Fig. (5) showed the changing values of bean crop coefficient along the growing season for the two bean varieties. It showed that in almost all points, crop coefficient values were closed to each other either with Bronco or with Contender variety. The average value of the crop coefficient of each stage was approximately similar for the two varieties. The differences of the four known stages of growing season (initial, development, midseason and harvesting) can be observed for each variety.

Table (5): Crop coefficient of bean varieties under surface drip irrigation at 40% of the available water along the growing season.

Bean Variety							
Bronco				Contender			
Irrigation duration (days)	Crop evapotranspiration ETc (mm/day)	Reference evapotranspiration ETo (mm/day)	Crop coefficient (Kc)	Irrigation duration (days)	Crop evapotranspiration ETc (mm/day)	Reference evapotranspiration ETo (mm/day)	Crop coefficient (Kc)
0	-	-	-	0			
18	1.61	2.54	0.63	20	2.39	1.45	0.61
13	2.23	2.61	0.86	13	2.61	2.23	0.86
12	2.42	2.69	0.90	9	2.78	3.22	1.16
9	3.22	3.04	1.06	10	2.75	2.90	1.05
8	3.63	3.71	0.98	7	3.60	4.14	1.15
7	4.14	3.87	1.07	7	3.83	4.14	1.08
8	3.63	4.20	0.86	6	4.10	4.83	1.18
10	2.90	4.14	0.70	8	4.11	3.63	0.88
				8	4.19	3.63	0.87

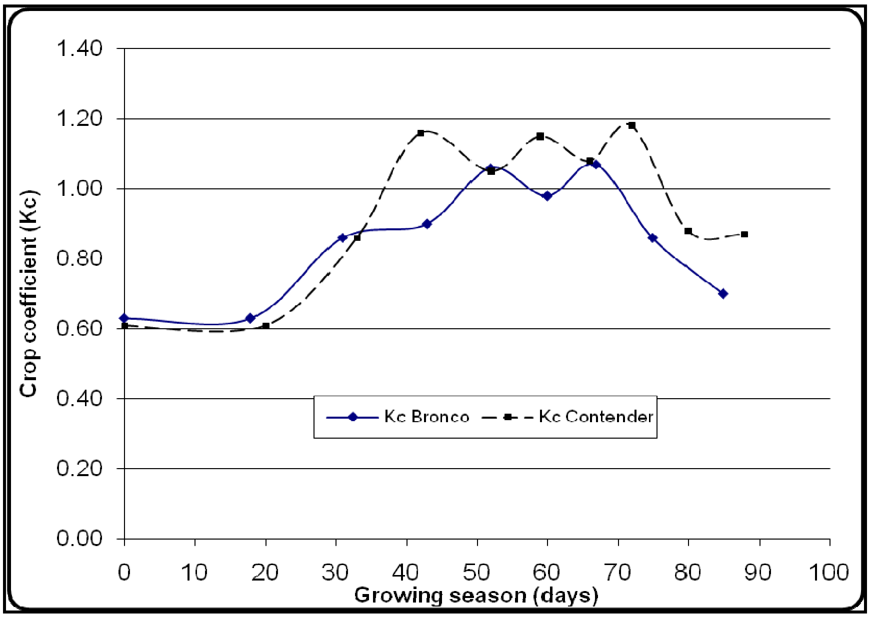

Figure (4): Crop coefficient along the growing season for the two varieties at 40 % of the available water under surface drip irrigation system.

Table (6): Crop coefficient of bean varieties under surface drip irrigation at 60 % of the available water along the growing season.

Bean Variety							
Bronco				Contender			
Irrigation duration (days)	**Crop evapotranspiration ETc (mm/day)**	**Reference evapotranspiration ETo (mm/day)**	**Crop coefficient (Kc)**	**Irrigation duration (days)**	**Crop evapotranspiration ETc (mm/day)**	**Reference evapotranspiration ETo (mm/day)**	**Crop coefficient (Kc)**
0				0			
12	1.62	2.65	0.61	13	1.49	2.43	0.61
13	1.49	2.45	0.61	12	1.62	2.39	0.68
11	1.76	2.72	0.65	9	2.16	2.73	0.79
8	2.43	2.65	0.92	8	2.43	2.71	0.89
7	2.77	2.94	0.94	7	2.77	2.60	1.07
5	3.88	3.64	1.07	5	3.88	3.30	1.18
5	3.88	3.76	1.03	5	3.88	3.68	1.05
6	3.23	3.93	0.82	4	4.85	3.83	1.27
6	3.23	4.07	0.80	4	4.85	3.93	1.24
6	3.23	4.17	0.78	6	3.23	4.02	0.80
6	3.23	4.20	0.77	6	3.23	4.22	0.77
				6	2.77	4.07	0.68

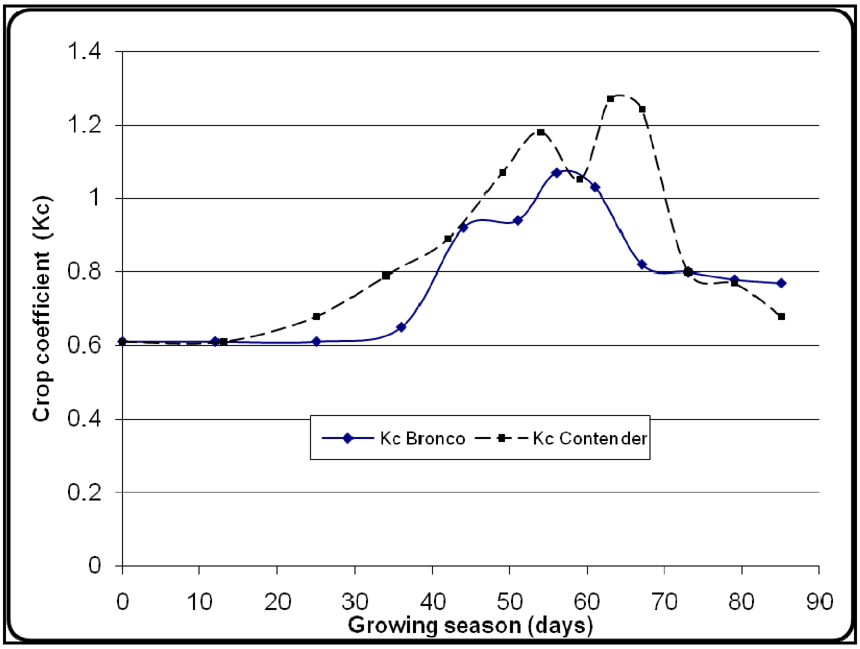

Figure (5) : Crop coefficient along the growing season for the two varieties at 60 % of the available water under surface drip irrigation system.

3.2.3 Crop coefficient at 80 % of the available water

The effect of level of water application (40%, 60% and 80%) became absolutely clear with the two drip irrigation systems. When moving from lower to higher level, the interval between irrigation events was closed and the trend of growing became more evident and can be simply derived. Application of 80% of the available water for the two bean varieties under surface drip irrigation system supported the above mentioned interpretation. Table (7) showed the calculated values of bean crop coefficient along the growing season for the two varieties at 80% of the available water. For the two varieties, at the beginning of the growing season, the bean crop coefficient was approximately similar and its value did not change greatly from duration to another. The peak value of crop coefficient for Bronco variety (1.29) was achieved after 58 days from planting. While it was (1.26) for Contender variety and was observed after 66 days from planting. At the end of the growing season it decreased gradually where, the length of growing season was 87 days for the two varieties.

3.3. Comparison between subsurface and surface drip irrigation systems

Tables (8) and (9) represent a comparison between subsurface and surface drip irrigation system for Bronco and contender bean varieties. The comparison was considered from the point of view of average crop coefficient and average percent of water consumption at each growing stage. Selected the higher average value of crop coefficient at each growing stage, it can be concluded that crop coefficient ranged between (0.59 - 0.64) for initial, (0.78 - 0.98) for development, (0.99 - 1.19) for midseason and (0.73-0.88) for harvesting stage. This did not depend on both irrigation system and level of water application. As for, the percent of water consumption it ranged between (6.88% - 11.29%) for initial stage, (37.19% - 43.23%)for development stage, (40.62% - 45.37%) for midseason and (18.32% - 26.61%) for harvesting stage.

Table (7): Crop coefficient of bean varieties under surface drip irrigation at 80 % of the available water.

Bean Variety							
Bronco				Contender			
Irrigation duration (days)	**Crop evapotranspiration ETc (mm/day)**	**Reference evapotranspiration ETo (mm/day)**	**Crop coefficient (Kc)**	**Irrigation duration (days)**	**Crop evapotranspiration ETc (mm/day)**	**Reference evapotranspiration ETo (mm/day)**	**Crop coefficient (Kc)**
0	1.39	2.46	0.56	0	1.21	2.36	0.51
7	1.39	2.43	0.57	8	1.39	2.43	0.57
7	1.39	2.47	0.56	7	1.39	2.46	0.56
7	1.39	2.16	0.64	7	1.62	2.50	0.65
7	1.62	2.87	0.56	6	1.94	2.70	0.72
6	1.62	2.63	0.61	5	1.94	2.78	0.70
6	1.62	2.68	0.60	5	1.94	2.74	0.71
6	1.94	2.96	0.66	5	1.94	2.58	0.75
5	2.43	3.48	0.70	5	2.43	3.10	0.78
4	3.23	3.77	0.86	4	3.23	3.40	0.95
3	3.23	3.77	0.86	3	3.23	3.77	0.86
3	3.23	3.87	0.84	3	3.23	3.70	0.87
3	4.85	4.05	1.20	3	3.23	3.90	0.83
2	4.85	3.75	1.29	3	4.85	3.85	1.26
2	4.85	4.50	1.08	2	4.85	3.90	1.24
2	4.85	3.85	1.26	2	4.85	4.15	1.17
2	3.23	4.17	0.78	2	4.85	4.10	1.18
3	3.23	4.27	0.76	2	4.85	4.15	1.17
3	3.23	4.07	0.80	2	3.23	4.00	0.81
3	3.23	4.17	0.78	3	3.23	4.27	0.76
3	3.23	4.23	0.76	3	2.43	4.10	0.59
3	1.39	2.46	0.56	4	1.21	2.36	0.51

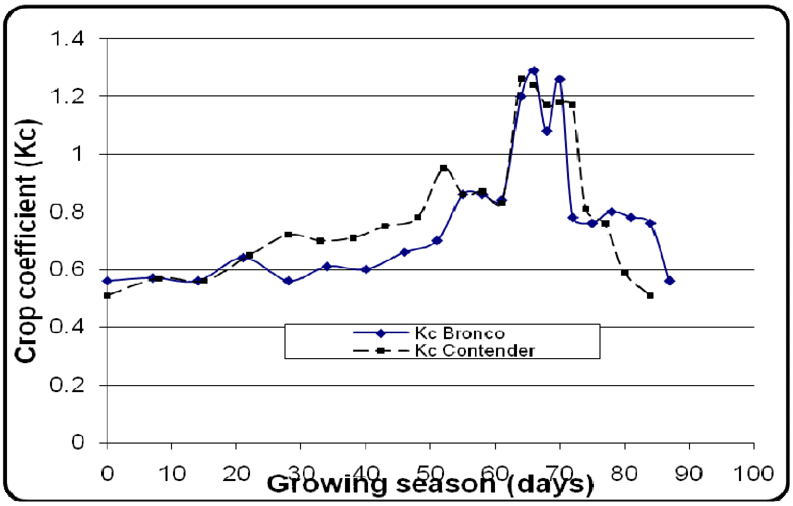

Figure (6): Crop coefficient along the growing season for the two varieties at 80 % of the available water under surface drip irrigation system.

Table (8): Average crop coefficient and percent of available water at each growth stage for Contender variety.

Growing stage	**Irrigation systems**											
	Subsurface drip irrigation system						**Surface drip irrigation system**					
	Average crop coefficient			**Percent of water consumption**			**Average crop coefficient**			**Percent of water consumption**		
	40%	**60%**	**80%**	**40%**	**60%**	**80%**	**40%**	**60%**	**80%**	**40%**	**60%**	**80%**
Initial	0.59	0.55	0.48	6.88	6.57	6.86	0.61	0.61	0.51	5.43	6.05	11.29
Development	0.78	0.76	0.78	43.23	33.98	35.48	0.98	0.79	0.70	31.52	31.53	33.19
Midseason	1.02	1.07	0.96	29.20	42.47	41.53	1.11	1.11	1.19	42.03	43.41	42.21
Harvesting	0.73	0.67	0.68	20.69	16.99	16.13	0.88	0.73	0.72	21.01	18.50	13.31

Table (9): Average crop coefficient and percent of available water at each growth stage for Bronco variety.

Growing stage	Irrigation system											
	Subsurface drip irrigation system						Surface drip irrigation system					
	Average crop coefficient			Percent of water consumption			Average crop coefficient			Percent of water consumption		
	40%	60%	80%	40%	60%	80%	40%	60%	80%	40%	60%	80%
Initial	0.61	0.64	0.51	6.88	8.50	10.66	0.63	0.61	0.56	6.70	8.70	11.29
Development	0.82	0.69	0.77	39.90	35.80	31.36	0.87	0.80	0.64	35.22	34.90	33.11
Midseason	0.97	0.99	0.94	26.61	37.13	40.62	1.01	0.91	0.97	40.39	42.30	45.37
Harvesting	0.80	0.73	0.81	26.61	18.56	17.36	0.74	0.77	0.94	18.32	14.20	10.22

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