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Basil (*Ocimum basilicum* L.) Water Use, Crop Coefficients and SIMDualKc Model Implementing in a Semi-arid Climate

Houshang Ghamarnia[1*], Davod Amirkhani[1] and Issa Arji[2]

[1]Department of Water Resources Engineering, Campus of Agriculture and Natural Resource, Razi University, Kermanshah, Iran.
[2]Department of Soil and Water, Kermanshah Agricultural and Natural Resources Research Centre, Kermanshah, Iran.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The accurate estimation on crop evapotranspiration (ETc) and crop coefficients is of assistance infield proper irrigation and water management. In present study, experiments were carried through out two years (i.e., 2012 and 2013) to determine water requirements (single and dual crop coefficients of basil) by using a few drainable lysimeters in a semi-arid region in Iran. Three lysimeters were used for grass evapotranspiration while three others were used to estimate bare soil evapotranspiration. Also, basil seeds were planted in six lysimeters and two groups, including group A where plant grew continually until the end of flowering stage, and group B where the plant was harvested three times after it reached a height of 0.25-0.30 m. The average water requirements of basil in two lysimeters including groups A and B were determined to be 636.8and 849mm, respectively. Finally, single and base crop coefficients for lysimeters in group A for the initial development and middle stages of basil growth were determined to be as 0.71, 1.11, 1.39and 0.57, 0.97, 1.26, respectively. Moreover, SIMDualKc, a soil water balance and irrigation scheduling

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**Corresponding author: E-mail: hghamarnia@razi.ac.ir; hghamarnia@yahoo.co.uk;*

model, was developed by using dual crop coefficient approach for ETc estimation. The model was calibrated and validated by comparing the measured and simulated Dual Kc values for basil for a semi-arid climate. The results indicated with low RMSE and MBE and highR^2=0.83,the model was capable of accurate in proper irrigation, planning and scheduling in semi-arid climates.

Keywords: Water requirements; single and dual crop coefficient; drainable lysimeter.

1. INTRODUCTION

Water is an important resource in plant growth and food production. There has been a tense competition amongst the agricultural, industrial and municipal users to win a fair share of the available scarce water resources. The accurate estimation of irrigation water requirements plays a key role in water planning and management [1]. Water requirement is considered to be one of the key limiting factors in the development of agriculture, particularly in arid and semi-arid regions. The well-structured irrigation schedules can be devised by determining proper water requirements of the crop, which can lead to the increased crop yield, increased income and greater water savings [2]. The determination of crop coefficients is essential to estimate irrigation water requirements and have proper irrigation scheduling and water management [3]. Estimating crop coefficient (Kc) at different growth stages of a plant makes possible precise estimation of crop water requirement during the growing season.

The crop coefficient values need tobe obtainedempirically foreach crop based on lysimetric data and local climate [2]. Many researchers have reported different Kc values in literature. Kc values based on a modified Penman-Monteith equation developed [4]. They used drainage lysimeters to estimate Kc for these same plant in a semiarid region of Iran. The water requirements of onion reported by applying two single and dual crop coefficients [5]. They reported that the water requirements for both states, particularly in the double state, were less than the real values. The water requirements of saffron calculated to be 486 and 670 mm for periods of 1998–1999 and 1999–2000, respectively [6]. The results indicated saffron crop coefficients to be 0.22–0.24, 0.94–1.05 and 0.68–0.78 during initial, middle and final growth stages, respectively. A study was conducted to determine garlic plant coefficients in Hamedan located in the west of Iran, in which the actual crop coefficient values were found to be 0.5, 1.4, and 0.3 for initial, developing and final stages of plant growth, respectively [7]. Dual Kc is expressed by crop base coefficient (Keb) and soil evaporation coefficient (Ke), separately (FAO-56).Dual Kc of vetch, rye, phacelia and mustard showed that Kc in arid regions has produced reliable results [8]. Single and dual crop coefficients of coriander and black cumin determined using drainable lysimeter in a period from 2010 to 2011 [9,10].

Crop coefficients of different aromatic medical plants are yet unknown and have not been studied in different parts of the world. There is a lack of researches in determining irrigation management parameters for aromatic medicinal plants under different climates. Also, no crop water requirements and crop coefficients have been reported in literature for basil (*Ocimum basilicum* L.) in semi-arid regions. Basil is an annual plant originally growing in arid and semi-arid regions. In the present study, lysimetric experiments were conducted by using drainable lysimeters with the goals of determining [11] crop water requirements, [2] single crop coefficient values and [7] dual crop coefficient values under asemi-arid climate for basil (*Ocimum basilicum* L) in two planting conditions including: group A, where the plant grew continually until the end of flowering stage, and group B, where the plant was harvested three times after it reached the height of 0.25-0.30 m.

A variety of irrigation scheduling simulation models have been produced during recent decades. Also, as the forth objective of this study the SIMDualKc model were calibrated and validated for basil crop to determine its capability for proper and accurate water resources management. The study is the first on the model application for basil and no similar studies have been reported in the relevant literature.

2. MATERIAL AND METHODS

2.1 Experimental Site and Weather Station, Soil, and Irrigation Water Details

The experiments were performed at the Irrigation and Water Resources Engineering Research Lysimetric Station at 47°9′E and 34°21′N with an elevation of 1319 m asl, and the Agriculture and Natural Resources Campus of Razi University in

Kermanshah, west Iran. The experiments continued for 2 years, from 2012 to 2013and from the months of April to August of each year. The studied region has a semi-arid climate. All daily meteorological data were obtained from the regional meteorological station located 100 m away from the research station. (Table 1.) shows the average monthly meteorological data during the experiments for the study area. The soil texture in the lysimeters was silty clay. (Tables 2 and 3). indicate the properties of the soil and the chemical components of irrigation water used in this study. Pressure plate and sampling methods were used to determine field capacity (Fc), permanent wilting point (PWP) and bulk density in different lysimeters soil depths.

2.2 Detail of Drainable Lysimeters

Twelve drainable lysimeters were used with an internal diameter of 1.20 m and a depth of 1.40 m. Both inside and outside of each lysimeter were painted with epoxy to prevent rusting. Each lysimeter was completely isolated from outside with special tarry material. The bottom of each lysimeter was inclined towards the center to collect extra drainable water. Anintake screen of stainless steel with a mesh size of 0.2 mm was used to collect drain water at the bottom of each lysimeter. A 0.10 m layer of gravel and a 0.10 m layer of sand were placed at the bottom of each lysimeter. A pipe with a diameter of 25 mm and a control gate valve was placed at the bottom of each lysimeter to transfer drained water toa graded container. The collected water from lysimeters was measured by a graded container. Silty clay soil consisting of 54% clay, 42.3% silt and 3.7% sand was used in lysimeters. The soil was screened using a conventional 2-mm screened sieve. All lysimeters were filled with air-dried soil and the soil layer was manually compacted to reach a bulk density of 1300kg/m^3 according to [12] method. Soil field moisture characteristic curves were developed using method [13].

2.3 Soil Moisture Measurement

A Time Domain Reflectometer system (Trime-Fm with P2G probes) was used to measure soil moisture. TDR probes were 6mm in diameter and 160mm long. They were installed in all lysimeters at 6 different depths of 0.20, 0.40, 0.60, 0.80, 1.0 and 1.2 m. The irrigation was carried out in all lysimeters after 30% depletion of available soil moisture to avoid any water stresses during the growing period.

Table 1. Meteorological data for growing period 2012-2013

Year	Month	Mean temperature (C) °	Mean relative humidity(%)	Mean wind speed(m/s)	Mean monthly sunshine(h)	Total precipitation (mm)
2012	April	11.8	53.9	7.1	6.9	45.7
	May	18.4	36.5	7.7	8.3	0.0
	June	24.8	21.4	7.9	9.7	0.0
	July	28.1	19.6	7.6	10.2	0.0
	August	29.8	19.3	7.8	9.9	0.0
2013	April	13.4	42.5	7.3	7.3	10.7
	May	15.1	54.2	8.4	5.3	63.3
	June	23.3	27.4	7.4	9.2	0.0
	July	29.1	14.7	7.4	11.6	0.0
	August	30.8	14.8	8.3	11.4	0.0

Table 2. Physical and chemical properties of soil

Soil Texture	Sand (%)	Silt (%)	Clay (%)	Ec (dS/m)	Θ(Fc) (%)	Θ(PWP) (%)	pH	Buldensity (kg/m^3)	Soildepth (m)
Silty				0.61			7.63	1300	0-0.30
Clay	3.7	42.3	54	0.61	27.6	17.2	7.61		0.30-0.60
				0.59			7.73		0.60-0.90
				0.58			7.73		0.90-1.20

Table 3. Physical and chemical properties of Irrigation water

SO^{2-} (Meq/L)	CL^{-} (Meq/L)	HCO_3^{-} (Meq/L)	CO_3^{-2} (Meq/L)	TDS (Meq/L)	pH	Anions (Meq/L)	Mg^{2+} (Meq/L)	Na^{+} (Meq/L)	Ca^{2+} (Meq/L)	Cations (Meq/L)
1.25	1.90	6.15	0	390	7.2	9.30	3.1	1.15	5.05	9.30

2.4 Actual and Potential Evapotranspiration

Three lysimeters were used for grass evapotranspiration while three others were used to estimate bare soil evaporation. Basil was planted in other six lysimeters in two groups including group A (GA), whose growth continued to the end of flowering stage and group B (GB), which was harvested four times after reaching a height of 0.25-0.30m. Crop evapotranspiration (ETc), bare soil evaporation (Es) and reference evapotranspiration (ETo) were calculated separately by using Eq. (1) in their own lysimeters as follows:

$$ETc, ETo \text{ or } ES = P + I - D - R - \Delta s \qquad (1)$$

where P is precipitation (mm); I is irrigation (mm); D is drained water (mm); R is runoff (mm) and ΔS represents the changes in soil water storage during the period for which ETc, ETo or ES were computed (mm). The precipitation was measured with a rain gauge *in situ*. The irrigation (I), D and R were measured with a precession graded container and rain gauge. The changes in soil moisture were taken from soil moisture probe readings at different depths. Daily meteorological data including wind speed, sunshine hours, minimum and maximum temperatures and average relative humidity were collected from a local meteorological station.

2.5 Single and Basal Crop Coefficient

The single crop coefficient was calculated using measured crop evapotranspiration (ETc) with the calculated reference evapotranspiration values (ETo) in Eq. (2):

$$Kc = Et_c/ET_o \qquad (2)$$

where $ET_c$is crop ET (mm); $ET_o$is reference crop ET (mm) and $K_c$is crop coefficient.

The dual crop coefficients were measured only for lysimeters in group A, according to those proposed by Allen [2]as quoted in FAO 56. The following procedures were used:

$$Kc = Kc_{basal} + Kc_{soilevaporation} \qquad (3)$$

$$Kc_{initial} = Kc_{basal\ tabulated}$$

$$Kc_{basal} = Kc_{initial} + [0.04(U_2 - 2) - 0.004(RH_{min} - 45)]\,(h/3)^{0.3} \qquad (4)$$

Where $RH_{min}$is minimum relative air humidity (percentage); h is crop height (m) and $u_2$is wind speed at 2 m above ground surface (m s^{-1}).

The sum of Kcb and Ke (Kc soil evaporation) in Eq. (3) cannot exceed maximum value (Kc max) defining an upper limit on evaporation and transpiration from any cropped surface based on the available energy.

$$K_{cmax} \max\{[1.2 + [0.04(U_2 - 2) - 0.004(RH_{min} 45)](\frac{h}{3})^{0.3}](K_{cb} + 0.05)\} \qquad (5)$$

Where h is mean maximum plant height (m) and max indicates the selection of the maximum value within the brackets {}.

$$f_c = \left(\frac{K_{cb} - K_{cmin}}{K_{cmax} - K_{cmin}}\right)^{(1+.05h)} \qquad (6)$$

Where fc is the effective fraction of soil surface covered by crop canopy, Kc min is minimum Kc for bare soil with no ground cover (≈0.15), and h is mean plant height. Therefore, the fraction of soil exposed to solar radiations and air ventilation, and from which the majority of Es takes place, is expressed as (1−fc).

2.6 The Simdualkc Model

First, the model was calibrated and validated for lysimetric data obtained in 2012 and 2013. The simulation procedures were performed using crop, soil, irrigation and weather data collected during both crop seasons. Data were observed on dates of crop growth stage, crop cover parameters, crop heights and root depths from planting to harvesting stages. Also, the soil data collected at the experimental site included basic soil hydraulic properties and water contents measured at different depths within effective rooting zones throughout the crop seasons. Climate data required by SIMDualKc model to compute soil water balance included: reference evapotranspiration (ETo), which was previously computed, minimum relative humidity (RH_{min}), daily precipitation and wind speed at 2 meter height (U_2). Leaf area index (LAI) was measured during the study and at the5th day of plant growth with a portable leaf area meter LAI-2000, USA. The values were used to estimate grand cover fraction (fc). The calibration procedures consisted of adjustment of parameters including depletion fraction (p), total evaporable water (TEW), readily evaporable water (REW) and thickness of the evaporation soil layer (Ze). The first set of parameters was estimated according to standard values in SIMDualKc model. Then, a trial and error procedure was initiated to choose values until differences between observed and simulated values were approximately minimized. The validation of the model was performed using calibrated values to simulate lysimetric experiments. The statistical means were subsequently applied to assess the goodness fit of SIMDualKc model projections to the observations according to procedures as suggested by [14].

2.7 Model Comparison

The SIMDualKc model was evaluated by comparing observed and simulated Dual Kc values over time, for the studied region. The method suggested by [15] was used for statistical analyses. The following equations were used to compute the regression coefficients (r), root mean square error (RMSE), mean bias error (MBE) and t-statistic test (t):

$$r = \frac{\sum_{i=1}^{n}(x-\bar{x})(y-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x-\bar{x})^2 \sum_{i=1}^{n}(y-\bar{y})^2}} \tag{7}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}} \tag{8}$$

$$MBE = \sum_{i=1}^{n} \frac{d_i}{n} \tag{9}$$

$$t = \sqrt{\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}} \tag{10}$$

where x is the measurement value, $\bar{x}$ is the mean measurement value, y is the predicted value, $\bar{y}$ is the mean predicted value, d_i is the difference between i^{th} predictionand i^{th} measured values.andn isthe number of data pairs i.

3. RESULTS AND DISCUSSION

3.1 Crop Development Stages

The basil growing periods were divided into initial, developing, and middle growth stages. (Tables 4 and 5) show the lengths of crop development stages of two lysimeters groups including group A and group B, respectively, which were grown under irrigation. The initial stage was from seedling until 10% of plant growth. The crop development stage denotes the vegetative period of the crop covering from the end of initial stage to full canopy cover (canopy cover 70 – 80%). The mid-season stage indicates a period from full ground cover to the end of flowering stage. The total duration of different basil growing periods during 2012 and 2013 in two lysimeters groups (A and B) are shown in (Tables 4 and 5).

3.2 Actual and Potential Evapotranspiration and Single Crop Coefficients

The results of lysimeters for two years showed that the daily reference evapotranspiration ranged from 2.7 to 8.5mm per day. The volume of water balance components indicated of mean monthly irrigation, precipitations, variations of soil water contents, drainage and finally mean actual ET values during the experimental study for the two lysimeters in groups A and B, are given in (Tables 6 and 7). The mean seasonal ETc of the cropping season for 2lysimeter groups A and B in 2012 was slightly higher with ETc- GA = 763.19 mm and ETc- GB = 964.32mmin2013 with ETc- GA = 510.54 mm and ETc- GB = 733.72mm.The average water requirements of basil in 2 lysimeter groups A and B were determined to be 633.85 and 849.02 mm, respectively. A summary of potential Evapotranspiration (ETo), actual Evapotranspiration (ETc) and Kc values for basil over a 10-day period in years 2012 and 2013 is given in (Table 8), in which values of ETc and Kc in 2012 and 2013 during the third set of 10-day records are lower than the other ones. This indicates that ETc and Kc values have increased from the initial stage to the mid-season stage which can be attributed mainly to low canopy cover at early stage of crop growth. Similar changes can be seen in (Table 9) after each harvesting period leading to a lower canopy cover of crop in group A. During the initial, developing and middle growth stages, the single crop coefficients of basil for lysimeters in group A were determined to be 0.73, 1.13 and 1.39 for

2012 and 0.69, 1.09 and 1.40 for 2013 whereas the average values for both years were 0.71, 1.11 and 1.39, respectively(Table 10).During the first, second, third and fourth harvesting stages, the single crop coefficients of basil for lysimeters in group B, 0.74, 0.74, 0.72 and 0.72 for 2012 and 0.68, 0.73, 0.71 and 0.72 for 2013 and the average values for both years 0.71, 0.74, 0.71 and 0.72, were determined, respectively (Table 10). The differences in crop coefficient values are probably due to daily water balance and climate. The actual daily crop coefficient and linear Kc values for basil obtained from lysimetric data for the two lysimeters groups A and B during 2012 and 2013 are presented in (Figs. 1 and 2), respectively.

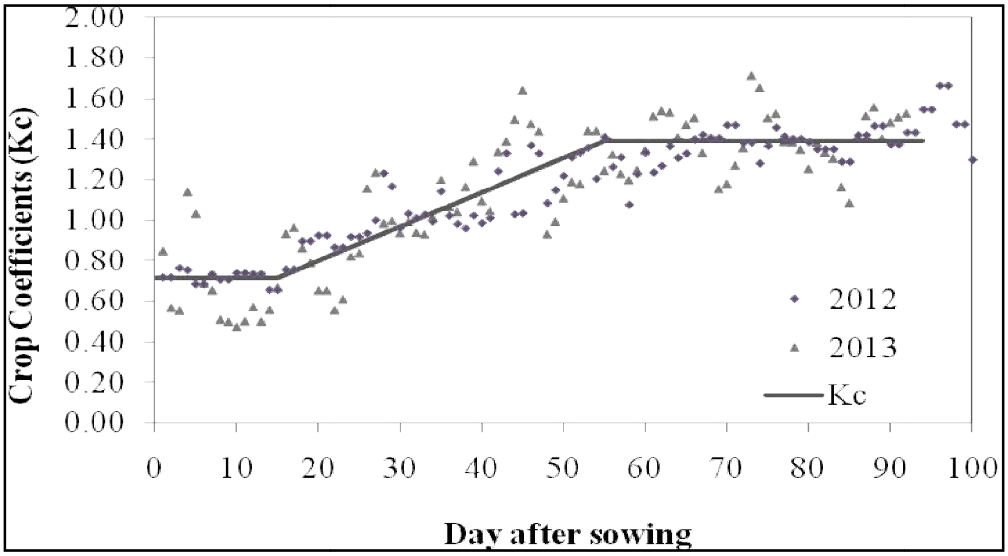

Fig. 1. Actual daily crop coefficient and linear crop-specific coefficient (Kc) values for Basil stages in lysimeters in group A

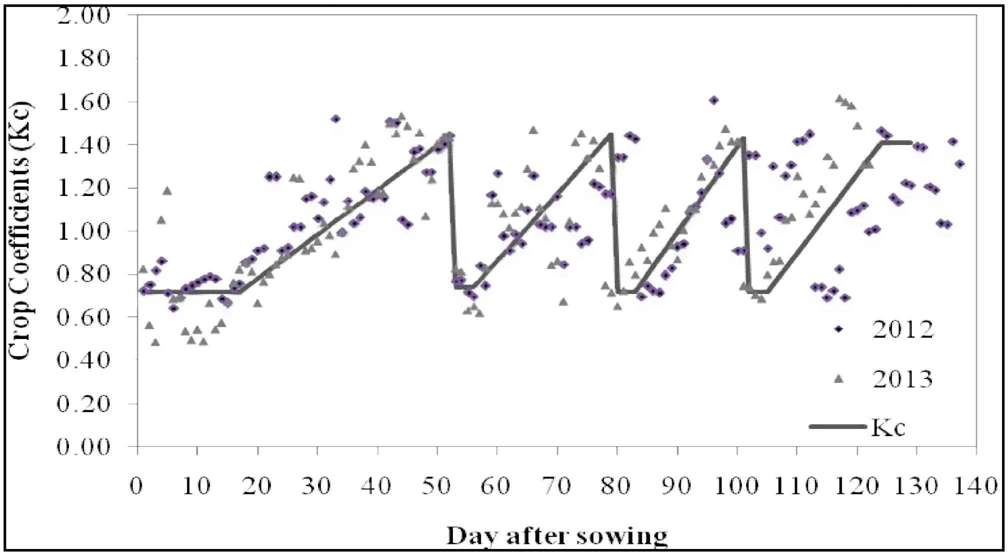

Fig. 2. Actual daily crop coefficient and linear crop-specific coefficient (Kc) values for Basil stages in lysimeters in group B

Table 4. Date and length of basil growth stages for lysimeters in group A

Year	**2012**		**2013**		
Growth stage	**Date**	**Duration (days)**	**Date**	**Duration (days)**	**Average duration (days)**
Initial	8-21/04/2012	14	9-25/04/2013	15	15
Development	22/04/2012To01/06/2012	40	26/04/2013 To 04/06/2013	40	40
Mid	02/06/2012 To 14/07/2012	44	05/06/2013 To 09/07/2013	35	39
Total growing period	98		90		94

Table 5. Date and length of basil growth stages for lysimeters in group B

year	**2012**		**2013**		
Harvest number	**Date**	**Duration(days)**	**Date**	**Duration(days)**	**Average duration(days)**
first harvest	08/04/2012 To 28/05/2012	51	08/04/2013 To 29/05/2013	52	52
Second harvest	29/05/2012 To 28/06/2012	30	30/05/2013 To 24/06/2013	25	27
Third harvest	29/06/2012 To 28/07/2012	30	25/06/2013 To 18/07/2013	24	27
Fourth harvest	29/07/2012 To 23/08/2012	25	19/07/2013 To 09/08/2013	21	23
Total growing period	136		122		129

Table 6. Volume balance components for lysimeters in group A and B, during 2012

Month	**Mean irrigation (mm)**		**Precipitation(mm)**		**Variations of soil water content (mm)**		**Mean drainage(mm)**		**Actual evapotranspiration (mm)**	
Lysimeteric group	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
From April 10	48.42	52.84	35.10	35.10	12.20	10.00	9.81	11.54	61.51	66.40
May	193.96	159.65	0.00	0.00	-11.03	-22.02	32.01	35.21	172.98	146.46
June	274.35	286.23	0.00	0.00	-18.73	-19.34	41.18	34.84	251.90	270.73
To July 14	293.29	-	0.00	-	-12.02	-	28.51	-	276.80	-
July	-	297.32	-	0.00	-	-12.90	-	46.21	-	264.01
To August 23	-	238.25	-	0.00	-	-5.97	-	27.50	-	216.72

Table 7. Volume balance components for lysimeters in group A and B, during 2013

Month	**Mean irrigation (mm)**		**Precipitation (mm)**		**Variations of soil water content (mm)**		**Mean drainage (mm)**		**Actual evapotranspiration (mm)**	
Lysimeteric group	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
From April 10	57.49	62.32	6.60	6.60	13.23	18.08	11.32	12.84	39.54	38.00
May	125.36	160.21	63.30	63.30	22.56	34.40	42.23	49.21	123.87	139.90
June	244.28	224.32	0.00	0.00	-6.64	-9.41	48.21	50.23	202.71	181.50
To July 09	164.32	-	0.00	-	-15.51	-	35.41	-	144.42	-
July	-	258.65	-	0.00	-	-14.93	-	47.30	-	226.28
To August 09	-	177.42	-	0.00	-	4.04	-	25.34	-	148.04

Table 8. 10-day potential evapotranspiration, crop evapotranspiration, and average crop coefficient of basil in lysimeters in group A, in 2012 and 2013

10 – day record	**2012**			**2013**			**Average of both 2012 and 2013**		
	ETc	**ETo**	**Kc**	**ETc**	**ETo**	**Kc**	**ETc**	**ETo**	**Kc**
1	16.41	22.98	0.71	23.51	36.02	0.65	19.96	29.50	0.68
2	31.70	35.59	0.89	23.92	34.95	0.68	27.81	35.27	0.78
3	44.85	42.60	1.05	32.36	37.75	0.86	38.60	40.51	0.95
4	56.14	52.01	1.08	44.47	41.50	1.07	50.30	46.75	1.08
5	64.26	50.86	1.26	50.64	40.74	1.24	57.45	45.80	1.25
6	86.55	67.53	1.28	67.21	52.66	1.28	76.88	60.09	1.28
7	96.68	69.12	1.40	82.82	59.76	1.38	89.75	64.44	1.39
8	89.20	65.19	1.37	94.32	66.16	1.43	91.76	65.67	1.40
9	102.28	69.97	1.46	98.04	71.92	1.36	100.16	70.94	1.41
10	108.93	74.79	1.46	-	-	-	-	-	-
11	54.08	52.65	1.03	-	-	-	-	-	-

Table 9. 10-day potential evapotranspiration, crop evapotranspiration, and average crop coefficient of basil in lysimeters in group B, in 2012 and 2013

10 – day record	2012			2013			Average of both 2012 and 2013		
	ETc	ETo	Kc	ETc	ETo	Kc	ETc	ETo	Kc
1	18.77	25.41	0.73	23.70	36.02	0.65	21.23	30.71	0.69
2	22.06	27.94	0.78	23.56	34.95	0.67	22.81	31.44	0.72
3	40.00	37.68	1.06	35.08	37.75	0.92	37.54	37.71	0.99
4	56.56	49.40	1.14	48.03	41.50	1.15	52.29	45.45	1.15
5	63.31	49.66	1.27	54.76	40.74	1.34	59.03	45.20	1.30
6	59.59	61.61	0.96	49.99	52.66	0.95	54.79	57.13	0.95
7	68.53	65.78	1.04	64.22	59.76	1.07	66.37	62.77	1.06
8	75.54	69.45	1.09	69.51	66.16	1.05	72.52	67.80	1.07
9	64.21	66.74	0.96	65.65	71.92	0.91	64.93	69.33	0.94
10	80.58	71.38	1.12	96.89	75.76	1.28	88.73	73.57	1.20
11	95.65	80.82	1.18	74.11	84.11	0.88	84.88	82.46	1.03
12	71.43	75.19	0.95	105.89	79.88	1.32	88.66	77.53	1.14
13	87.67	72.26	1.21	-	-	-	-	-	-
14	89.40	69.63	1.28	-	-	-	-	-	-
15	69.46	48.86	1.42	-	-	-	-	-	-

Table 10. Average basil single crop coefficients for lysimeters in group A and group B

Group A			
Growth stage	**2012**	**2013**	**Average**
Initial	0.73	0.69	0.71
Development	1.13	1.09	1.11
Mid	1.39	1.40	1.39
Group B			
Harvest times	**2012**	**2013**	**Average**
first harvest	0.74	0.68	0.71
Second harvest	0.74	0.73	0.74
Third harvest	0.72	0.71	0.71
Fourth harvest	0.72	0.72	0.72

3.3 Dual Crop Coefficient

The values of basal crop coefficients and evaporation from soil and dual daily crop coefficients for three growth stages (i.e., initial, crop development and mid-season growth) of basil for lysimeters in group A were obtained during the experimental years of this study (2012 and 2013), (Table 11) shows the values of basal crop coefficients during Basil growing periods. Also, the values of single and dual crop coefficient variations for 2012 and 2013 are presented in (Figs. 3 and 4), respectively. As shown in (Table 11) and (Figs. 3 and 4), the value of the basal crop coefficient (i.e., transpiration values) gradually increased and the highest values were obtained in midseason stage. During the initial stage, when the plant green coverage was lower, the evaporation from soil was the highest whereas during the stage of plant growth, it gradually decreased. Finally, the lowest values were obtained in mid-season, for the initial stage, Es is the predominant component of ETc and Kcb and single-Kc are constant representing the average rate of Es from a dry soil surface. Kcb and single-Kc continue to increase duringcrop developmental stage, which is due to the expansion of leafsurface. As the number and size of plant leaves increased, the number of stomata increased as well, while the increased transpiration rate was directly related to Etc values [2]. The full canopy cover was reached at mid-season while the transpiration rate was typically at its potential (i.e., maximum) rate. Dual-Kc is responsive to the surface wetness and increases whenever the soil surface was moist following rainfalls, especially during the initial growth stage of the plant. As shown in Table (11), the average values of basal crop coefficients for initial, developing and middle stages were determined to be 0.57, 0.97 and 1.26, respectively.

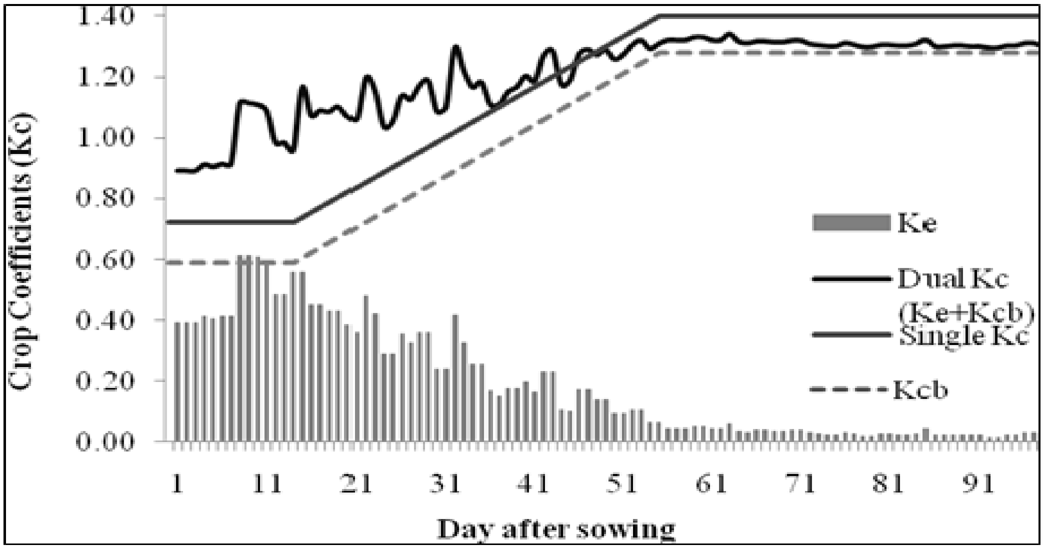

Fig. 3. Single and dual basil crop coefficient in 2012

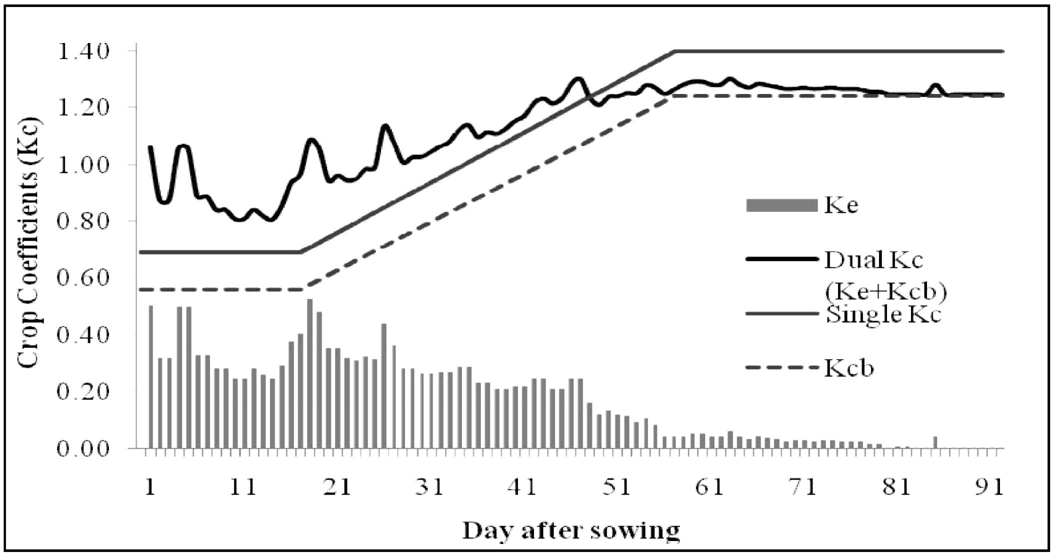

Fig. 4. Single and dual basil crop coefficient in 2013

Table 11. Average base crop coefficient of basil during growth stages

Year	Initial	Developing	Middle
2012	0.59	0.97	1.28
2013	0.56	0.98	1.24
Average	0.57	0.97	1.26

3.4 Model Comparison

The standard values for a number of parameters including TEW, REW and p are required to run model after a calibration-validation procedure or trial and error similarly proposed by [14]. The proper adjustments to the values including REW, TEW and Ze with 10 mm and 35 mm, and Ze = 0.15 m were considered for simulation procedures, respectively. The initial depletion in the evaporable layer was set at 20% of TEW for the seasons of both years 2012 and 2013. The R, RMSE, MBE and t-test statistical methods were used to compare the measured Dual Kc values with simulated values. The comparisons between simulated and measured Dual Kc in the calibration (2012) and validation (2013) years are given in (Table 12 and Fig. 5). Based on RMSE and MBE values presented in (Table12), the positive sign of the MBE indicates that the computed Dual Kc was higher than Dual Kc measured by lysimeter while the absolute value was an indicator of method performance (Table 12). The performance of each method in the present study was based on t values. The Lowest values show a better performance of the method indicating that the differences between the measured and lower estimated values are lower. (Fig. 5) shows a reasonable Dual Kc fitness between the measured and the model simulated values, as presented with different fitting indicators in (Table12). One can observe that R^2values are between 0.79 and 0.86while the estimation errors RMSE and MBE range between (0.15-0.18) and (0.09-0.12), respectively. All indicators showed that the model is technically capable of accurately predicting Dual Kc for basil. A few numbers of studies have been reported on SIMDualKc Model simulation and validation in literature. The model checked for citrus crop under micro irrigation systems [11]. The model has been validated and calibrated for wheat crop under sprinkle and surface irrigation systems [16-17]. The studies have reported good predictions of available soil water by the model. SIMDualKc Model is capable for simulating soil water balance and adopting dual Kc approach, and may be further used to develop improved irrigation schedules for winter wheat–summer maize crop sequence in North China as reported by [18]. The appropriateness of basal crop coefficients reported for maize through model calibration and validation using various treatments of maize irrigated with sprinkler and drip irrigation methods under full and deficit irrigation schemes and cropped with organic mulch [19]. They suggested that the corresponding results showed a good agreement between the simulated and observed results for available soil water throughout the season with regression coefficients of 0.99–1.02 and the root mean square error ranging from 2.0to3.3% of the total available water. No studies are yet available in literature on SIM Dual Kc Model simulation and validation for basil in a semi-arid climate for further comparison. The results of the model simulation and validation found in this study are in a good agreement with those reported by other researches.

Table 12. Correlation between the simulated Dual Kc and the measured values in 2012-2013

Year	RMSE	MBE	R^2	R/t
2012	0.18	0.12	0.79	0.18
2013	0.15	0.09	0.86	0.09
Average	0.17	0.10	0.83	0.13

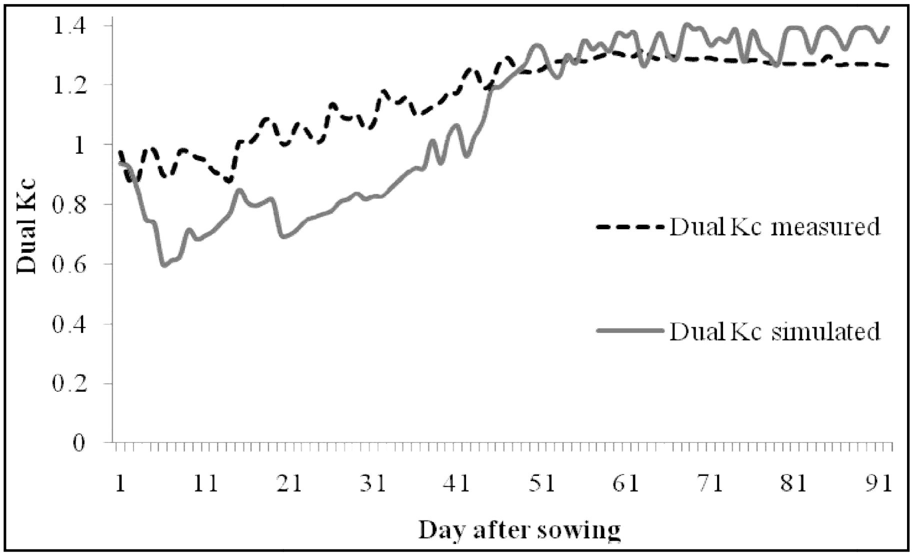

Fig. 5. Comparison between simulated and measured Dual Kc

4. CONCLUSION

The seasonal ETc of basil under two planting conditions including group A, during which the plant continued to grow to the end of flowering stage and group B, during which plant was harvested three times after reaching a height of 0.25-0.30 m, were studied in 2012 and 2013. The results showed that total water requirements in group A, single and dual crop coefficients for initial, developing and middle stage of basil were 636.8mm, 0.71, 1.11, 1.39 and 0.57, 0.97, 1.26,respectively. Also, total water requirements and single coefficients for initial stage in group B were determined to be 849 mm and 0.71, 0.74, 0.71 and 0.72,respectively. The model of SIMDualKc was calibrated and validated by lysimetric data which were obtained during the two years of this study. The results of all statistical parameters showed the capability of the model to accurately predict Dual Kc for basil in semi-arid climates. Therefore, the results can suggest that SIMDualKc model is sufficiently capable of estimating all irrigation management parameters with high accuracy and speed in semi-arid climates.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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