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Water Requirement, Crop Coefficients of Peppermint (*Mentha piperita* L.) and Realizing of SIMDualKc Model

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ABSTRACT

Peppermint is one of the most important medicinal and industrial crops in the world, which due to the importance of water, it is necessary to determine its water requirements accurately. This study aimed to determine the water requirement, single and dual crop coefficients of Peppermint. For this purpose, 12 water balance drainable lysimeters were applied. Three lysimeters were used to determine grass and three were applied to estimate the evaporation of bare soil. In addition, in the 6 lysimeters, Peppermint was planted in two groups. The plants of group A and group B continued to grow until the end of flowering and appropriate extraction time, and the plants were harvested 3 times after reaching a height of 10-12 cm. The average water requirements of Peppermint for two lysimeters groups A and B were determined to be 646 and 532 mm, respectively. The single and base crop coefficients for lysimeters in group A were determined to be as 0.68, 1.07, 1.31 and 0.3, 0.88, 1.18 for the initial, development and middle growing stages. For lysimeters in group B, the average of single crop coefficients was determined to be 0.85, 0.92 and 0.95 respectively. Calibration and validation of the SIMDualKc model showed the model's capability and accuracy for proper irrigation planning and scheduling.

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1. Introduction

Peppermint (*Mentha piperita* L.) is a plant of the continuous dicotyledonous petals, which is the dark leader of mint and is an edible vegetable. It is a herbaceous plant with aerial roots and straight, rectangular and underground stems. Its fragrant stems and leaves are edible and medicinal and sometimes have colorful flowers. Its leaves are 3 to 5 cm long, opposite, lanceolate or spindle-shaped, its margin has deep incisions, its lateral incisions are sharp. The hairs of peppermint leaves are low. Green peppermint is commonly grown all over the world, this plant is the result of conversion and persistence of the perennial basil plant. This plant grows wild and cultivated in Iran. Red peppermint is a type of peppermint that grows on the banks of rivers and in soft and shallow waters, and because its leaves are red, it is called by this name (Darvishi *et al*., 2016).

The scarcity of water resources arising from different environmental phenomena including recurring drought events, continuing population growth, increased energy demands and drinking and industrial water use in different arid and semi-arid regions of the world continues to increase and become to be more problematic in the upcoming years. Therefore, food production for habitats in arid and semiarid regions requires to be treated with greater attention to applying different water resources more efficiently in order to meet environmental and agricultural demands. Moreover, the determination of evapotranspiration and crop coefficients of different plants are important factors to meet water resources and irrigation management objectives properly. In order to estimate water requirements in different crop growth

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stages, the values of crop coefficient should be necessarily determined. As suggested by (Allen *et al.*, 1998) and (Allen *et al.*, 2005) a dimensionless crop coefficient (Kc) is multiplied by ETo to compute ETc. In other words, the crop evapotranspiration (ETc) can be calculated by Kc, which is defined as the ratio of crop evapotranspiration to some reference evapotranspiration (ETo) which is, in its turn, defined by weather data.

Kc is affected by several factors such as crop type, the growth stage of the crop and the cropping pattern (Allen *et al.*, 1998). Jensen and Allen (2016) have recommended obtaining the crop coefficient values of each product through experiments based on the lysimeter data and the applicable local climate. Many researchers used drainable lysimeters to estimate Kc and they have reported different Kc values in their literature (Basiri *et al.*, 2019; Ghamarnia *et al.*, 2015a, 2015b; Majnooni-Heris *et al.*, 2012; Rahimikhoob *et al.*, 2020)

Different simulation models for irrigation schedules have been developed during recent decades. However, there have been few irrigation scheduling models that are based on the dual crop coefficient approach and its combination with hydrologic extensions for complete water balances. (Zhang *et al.*, 2013) reported that the SIMDualKc model developed and fully described by (Rosa *et al.*, 2012a) has the capability of estimating ETc daily while considering soil evaporation and crop transpiration components separately.

Ghamarnia et al. (2015a) estimated water requirement of basil, single and double plant coefficients were calculated based on the FAO56 method in Kermanshah, Iran. In this study, the SIMDualKc model was evaluated using the observed data, which showed a high correlation coefficient (0.83), low RMSE and MBE between the actual results and the model. In a similar study in southern Portugal, the evapotranspiration of sweet corn and sorghum was calculated using dual plant coefficients and the SIMDualKc model was evaluated (Rosa *et al.*, 2016). The results showed that the simulation of soil water content using this model has a regression coefficient close to 1, square mean error (RMSE) below 0.012 and modelling efficiency (EF) is above 0.80.The average crop evapotranpiration and crop coefficients of basil was determined by (Rahemikoob *et al.*, 2020) as 8.23 and 5.13 mm per day and 0.3,0.86 and 0.76 for initial, mid and end basil growing stage respectively. Evapotranspiration and different crop coefficient of coriander in a tropical environment reported by (Sousa *et al.*, 2018). They found that the mean values of coriander evapotranspiration and mean crop coefficient as 139.8 mm and 0.87.

Peppermint, basically known for its medical benefits, grows throughout North America, Asia, and Europe and is cultivated primarily for its oil, which is extracted from its leaves during its flowering stage. In different studies conducted so far some quantitative and qualitative characteristics of Peppermint (*Mentha piperita* L.) have been studied under different irrigation regimes (Akbarzadeh *et al.*, 2018; Basiri *et al.*, 2019; Hajmirzaie *et al.*, 2020). No different irrigation management parameters, such as water requirements and different crop coefficients, have been yet reported in the literature for Peppermint (*Mentha piperita* L.), especially for semi-arid climates. This medical crop has been supported by the local agricultural organization for more job creation and export to other neighbour countries recently.

The present study was conducted to determine different irrigation management parameters for Peppermint including (1) water requirements, (2) single crop coefficients and (3) dual crop coefficients in a semi-arid climate. Moreover, as reported by Rosa et al. (2012a) and (2012b) the two years of measured lysimetric data became available to the present study. The fourth purpose was to calibrate and validate the SIMDualKc model by comparing measured and simulated Dual Kc and evapotranspiration (ETc) values for Peppermint in a semi-arid climate. In order to show model capability for proper and accurate water resources management in medicinal crops. The study is the first one in the literature on the model application for medicinal crops.

2. Materials and methods

2.1. Experimental site, weather station, irrigation water and soil information

The lysimetric experiments were performed in a period of two years from 2015 to 2016 during April to July of each experimental year at the Irrigation and Water Resources Engineering Research Lysimetric Station No. 3 located at 47°9′E and 34°21′N, with an elevation of 1319 m (asl), as part of the Campus of Agriculture and Natural Resources of Razi University in Kermanshah, Iran. The region under study has a semi-arid climate and its daily meteorological data were obtained from the regional meteorological station located 100 m off the lysimetric station. Table 1 shows the average two-year meteorological data for the research region. The soil texture in the lysimeters was silty clay composed of different contributions of clay (52%), silt (44.30%), and sand (3.70%). Tables 2 and 3 show the chemical and physical properties of the soil and the chemical components of the irrigation water in the study. The pressure plate and sampling methods were used to determine θ (fc), θ (pwp) and bulk density determination in different lysimeters soil depths, respectively.

Table 1. Meteorological data for growing period 2015-2016

Year	Month	Mean temperature (C°)	Mean relative humidity (%)	Mean wind speed (m/s)	Mean monthly sunshine (h)	Total precipitation (mm)
2015	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
2016	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

Table 2. Physical and chemical properties of soil

Soil Texture	Sand (%)	Silt (%)	Clay (%)	Ec (ds/m)	Θ(Fc) (%)	Θ(PWP) (%)	pH	Bulk density (gr/cm^3)	Soil depth (cm)
				0.61			7.63	1.3	0-30
Silty	54	42.3	3.7	0.61	17.2	27.6	7.61		30-60
Clay				0.59			7.73		60-90
				0.58			7.73		90-120

Table 3. Physical and chemical properties of irrigation water

SO_2^- (Meq/L)	CL− (Meq/L)	HCO3$^-$ (Meq/L)	CO3^{2-} (Meq/L)	TDS (Meq/L)	pH	EC (dS/m)	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	0.61	9.30	3.1	1.15	5.05	9.30

2.2. Detail of drainable lysimeters

In this study, 12 drainable lysimeters were used, with an inner diameter of 1.20 m and a depth of 1.40 m. A 10-cm layer of gravel and a 10-cm layer of sand were placed at the bottom of each lysimeter. A pipe with a diameter of 2.50 cm and a control gate valve was installed at the bottom of each lysimeter to conduct drain water towards a graded container which measured excessive water from the lysimeters. The lysimeters conditions were similar to Oliviera et al. (1996).

According to Danielson and Sutherland (1986) and through applying Klute's method, the soil field moisture typical curves were developed.

2.3. Measurement of soil moisture

In order to soil moisture measurements, a TDR system (Trime-Fm with P2G probes) was used, in which the probes were 0.60 cm in diameter and 16 cm long and were installed in all lysimeters at 6 different depths of 20, 40, 60, 80, 100, and 120 cm. The irrigation was carried out in all lysimeters after 30% depletion of available soil moisture to avoid any water stress during the growing period (Nayak *et al*., 2016).

2.4. Actual and potential evapotranspiration

Three lysimeters were applied in the research for grass evapotranspiration, while three lysimeters were applied for bare soil evapotranspiration estimations. In six other lysimeters, peppermint was cultured in two groups including group A which continued to grow up to 70% of the flowering stage and suitable time for extraction, and group B, which was harvested three times after the plant reached a height of 10-12 cm. The actual evapotranspiration (ETc), bare soil evapotranspiration (Es) and potential evapotranspiration (ETo) calculated by (Eq.1) as follows:

$$ET_C = P + I - D - R + \Delta S \quad (1)$$

The details of this equation and how to calculate each of its components are described by Ghamernia et al. (2013).

2.5. Single and dual crop coefficient

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

$$K_C = \frac{ETc}{ET_O} \quad (2)$$

Where ETc = crop ET (mm); ETo = reference crop ET (mm); and Kc = crop coefficient.

The dual crop coefficients were measured only for lysimeters in groups A according to those proposed by (Allen *et al.*, 1998) in the FAO 56 and the following procedures were applied:

$$K_C = K_{Cbasal} + K_{Csoil-evaporation}, \quad K_{Cinitial} = K_{Cbasal-tabulated} \quad (3)$$

$$K_{Cbasal} = \left[K_{Cinitial} + 0.04(U_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3} \quad (4)$$

The details of (Eq.4) equation and how to calculate each of its components are described by Ghamernia et al. (2013).

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

$$K_{C\max} = \left(\left\{1.2 + \left[0.04(U_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3}\right\}, \left\{K_{Cb} + 0.05\right\}\right) \quad (5)$$

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

$$f_c = \left(\frac{K_{cb} - K_{c\min}}{K_{c\max} - K_{c\min}}\right)^{(1+0.5h)} \quad (6)$$

Where: fc = effective fraction of the soil surface covered by crop canopy and limited to [0–0.99], Kc_{min} = minimum Kc for bare soil with no ground cover (≈0.15), and h = mean plant height. The fraction of soil where it is exposed to solar radiation and air ventilation, and from which the majority of Es occurs, is expressed as (1−fc).

2.6. SIMDualKc model

The model was calibrated and validated for lysimetric data obtained in 2015 and 2016. The simulation procedures were carried out using soil, crop, irrigation, and weather data collected during both crop seasons. Soil data, which were collected at the experimental site, included basic soil hydraulic properties and soil water contents measured at different depths within effective rooting zones throughout crop seasons. Crop data included observed crop growth stage dates, crop cover parameters, crop heights and root depths from planting to harvesting phases. Climatic data requirements of SIMDualKc model to compute soil water balance also included reference evapotranspiration, (ETo) which was previously computed, daily precipitation, minimum relative humidity (RHmin) and wind speed at 2 meters height (u_2). Leaf area index (LAI) was measured during the study and every five days with a portable leaf area meter i.e., LAI-2000, USA. The values were used to estimate the grand cover fraction (fc). The calibration procedures required further adjustments to model parameters including depletion fraction (p), total evaporable water (TEW), readily evaporable water (REW), the thickness of the evaporation soil layer (Ze). The first set of the parameters was estimated following the standard values in the SIMDualKc model. Then, a trial and error procedure were initiated to select values until differences between observed and simulated values were approximately minimized, and then, stabilized. The model validation procedures began by using the calibrated values to simulate the lysimetric experiment. The statistical means were subsequently applied to assess the goodness fit of SIMDualKc model projections to the observations according to procedures as suggested by (Rosa *et al.*, 2012b, 2012a).

2.7. Model evaluation

SIMDualKc model was evaluated by comparing observed and simulated Dual Kc values over time for the area under study. The method suggested by (Jacovides, 1997) was used for the 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).

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

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

$$MBE = \sum_{i=1}^{n} \frac{d_i}{n} \qquad (9)$$

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

Where: x = the measurement value, $\bar{x}$ = the mean measurement value, y = the predicted value, $\bar{y}$ = the mean predict value, di = difference between i^{th} predicted and i^{th} measured values, n = number of data pairs i.

3. Results and discussion

3.1. Crop development stages

The growing season of the plant was divided into the initial, developing and middle stages. Tables 4 and 5 show the lengths of crop development stages for both groups A and B of lysimeters, respectively. The total duration of different Peppermint growing periods during 2015 and 2016, in two lysimeters groups A and B, are shown in Tables 4 and 5. The total growing periods of Peppermint were determined to be 112 and 103 days in 2015 and 2016, respectively.

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

Growth stages	2015		2016		Average duration (days)
	Date	Duration (days)	Date	Duration (days)	
Initial	10/04/2015 *To* 05/05/2015	26	10/04/2016 *To* 03/05/201	24	25
Development	06/05/2015 *To* 27/06/2015	53	04/05/2016 *To* 20/06/2016	49	51
Mid	28/06/2015 *To* 30/07/2015	33	21/06/2016 *To* 21/07/2016	30	31
Total growing period	112		103		107

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

Harvest times	2015		2016		Average duration (days)
	Date	Duration (days)	Date	Duration (days)	
first harvest	10/04/2015 *To* 30/05/2015	51	10/04/2016 *To* 29/05/2016	50	50
Second harvest	31/05/2015 *To* 03/07/2015	34	30/05/2016 *To* 27/06/2016	29	32
Third harvest	04/07/2015 *To* 30/07/2015	27	28/06/2016 *To* 21/07/2016	24	25
Total growing period	112		103		107

3.2. Actual and potential evapotranspiration and single crop coefficients

The lysimeters results over two years indicated that the daily reference evapotranspiration ranged from 2.7 to 8.5 mm per day. Tables 6 to 9 show the volume of water balance components consisting of mean monthly irrigation, precipitation, variation of soil water contents, drainage, and, finally, mean actual ET values during the experimental study for the two lysimeters groups A and B. The mean seasonal ETc of the cropping season for two lysimeters groups A and B in 2015 were slightly higher with ETc- GA = 664mm and ETc- GB = 566mm than 2016 with ETc-GA = 629 mm and ETc-GB = 496mm. The average water requirements of Peppermint in two lysimeters groups A and B were determined to be 611 and 498 mm, respectively. A summary of potential evapotranspiration (ETo), actual evapotranspiration (ETc), and Kc values for Peppermint for 10 days in 2015 and 2016 are given in Tables 10 and 11. As results in Table 12 indicate, during the initial, developing and middle growth stages, the single crop coefficients of Peppermint for lysimeters in group A were determined to be 0.69, 1.03 and 1.27 for 2015 and 0.66, 1.11 and 1.34 for 2016, while the average values for both years were determined to be 0.68, 1.07 and 1.31, respectively. Also, according to Table 13 during the first, second and third harvesting stages, the single crop coefficients of Peppermint for lysimeters in group B were determined to be 0.84, 0.92 and 0.96 for 2015 and 0.87, 0.92 and 0.93 for 2016, and the average values for both years were 0.85, 0.92 and 0.95, respectively. The actual daily crop coefficients and linear Kc values for Peppermint obtained from lysimetric data, for two lysimeters groups A and B during 2015 and 2016, are presented in Figs. 1 and 2, respectively.

Table 6. Volume balance components for lysimeters in group A, during 2015

Month	Mean irrigation (mm)	Precipitation (mm)	Variations of soil water content (mm)	Mean drainage (mm)	Actual evapotranspiration (mm)
From April 10	41.89	35.10	30.18	10.23	36.57
May	144.59	0.00	-21.90	35.06	131.42
June	254.04	0.00	-10.03	43.17	220.91
To July 30	316.81	0.00	-9.79	51.11	275.49

Table 7. Volume balance components for lysimeters in group B, during 2015

Month	Mean irrigation (mm)	Precipitation (mm)	Variations of soil water content (mm)	Mean drainage (mm)	Actual evapotranspiration (mm)
From April 10	46.47	35.10	31.31	9.87	40.39
May	141.55	0.00	-29.00	41.22	129.33
June	209.00	0.00	-11.89	39.15	181.74
To July 30	247.14	0.00	-21.94	54.18	214.90

Table 8. Volume balance components for lysimeters in group A, during 2016

Month	Mean irrigation (mm)	Precipitation (mm)	Variations of soil water content (mm)	Mean drainage (mm)	Actual evapotranspiration (mm)
From April 10	62.79	6.60	6.87	12.56	49.96
May	135.53	63.30	45.00	31.17	122.66
June	287.57	0.00	-13.93	60.39	241.11
To July 21	243.21	0.00	-18.53	46.21	215.53

Table 9. Volume balance components for lysimeters in group B, during 2016

Month	Mean irrigation (mm)	Precipitation (mm)	Variations of soil water content (mm)	Mean drainage (mm)	Actual evapotranspiration (mm)
From April 10	50.37	6.60	4.77	11.08	41.13
May	144.67	63.30	37.33	36.17	134.48
June	209.17	0.00	-12.03	39.74	181.46
To July 21	156.05	0.00	-18.97	35.89	139.13

Table 10. 10-Day Potential evapotranspiration, crop evapotranspiration, and average crop coefficient of Peppermint in lysimeters in group A, in 2015 and 2016

10 – day record	2015			2016			Average of both 2015 and 2016		
	ETc	ETo	Kc	ETc	ETo	Kc	ETc	ETo	Kc
1	14.58	23.68	0.66	20.01	37.46	0.53	17.29	30.57	0.57
2	19.37	29.87	0.66	26.39	35.59	0.74	22.88	32.73	0.70
3	30.57	38.62	0.80	30.76	38.25	0.80	30.67	38.43	0.80
4	40.54	49.67	0.85	43.14	42.57	1.01	41.84	46.12	0.92
5	52.44	49.03	1.08	40.53	41.59	0.99	46.48	45.31	1.03
6	61.34	63.48	0.97	68.69	54.02	1.28	65.02	58.75	1.11
7	73.23	64.98	1.13	77.26	61.79	1.25	75.25	63.38	1.18
8	80.16	67.71	1.22	88.90	66.24	1.34	84.53	66.98	1.27
9	82.42	68.44	1.23	96.59	73.62	1.31	89.50	71.03	1.27
10	90.35	72.34	1.28	103.75	76.82	1.35	97.05	74.58	1.31
11	98.09	80.92	1.24	34.24	25.03	1.37	51.38	58.40	1.12
12	21.29	15.88	1.34	-	-	-	-	-	-

Table 11. 10-Day potential evapotranspiration, crop evapotranspiration, and average crop coefficient of Peppermint in lysimeters in group B, in 2015 and 2016

10 – day record	2015			2016			Average of both 2015 and 2016		
	ETc	ETo	Kc	Etc	ETo	Kc	ETc	ETo	Kc
1	15.78	23.68	0.71	18.56	23.68	0.80	17.17	30.57	0.76
2	21.64	29.87	0.73	20.08	29.87	0.69	20.86	32.73	0.71
3	34.28	38.62	0.89	30.59	38.62	0.80	32.43	38.43	0.85
4	46.02	49.67	0.97	50.10	49.67	1.04	48.06	46.12	1.01
5	43.57	49.03	0.90	49.36	49.03	1.02	46.47	45.31	0.96
6	50.17	63.48	0.80	48.17	63.48	0.76	49.17	58.75	0.78
7	62.10	64.98	0.96	64.84	64.98	1.00	63.47	63.38	0.98
8	64.17	67.71	0.96	66.59	67.71	0.99	65.38	66.98	0.97
9	59.43	68.44	0.88	50.74	68.44	0.74	55.08	71.03	0.81
10	66.18	72.34	0.93	70.41	72.34	0.99	68.30	74.58	0.96
11	84.82	80.92	1.04	26.74	19.76	1.38	33.24	58.40	0.85
12	18.20	15.88	1.15	-	-	-	-	-	-

Table 12. Average Peppermint single crop coefficients in lysimeters in group A

Growth stage	2015	2016	Average
Initial	0.69	0.66	0.68
Development	1.03	1.11	1.07
Mid	1.27	1.34	1.31

Table 13. Average Peppermint single crop coefficients in lysimeters in group B

Harvest times	2015	2016	Average
First harvest	0.84	0.86	0.85
Second harvest	0.92	0.91	0.92
Third harvest	0.96	0.93	0.95

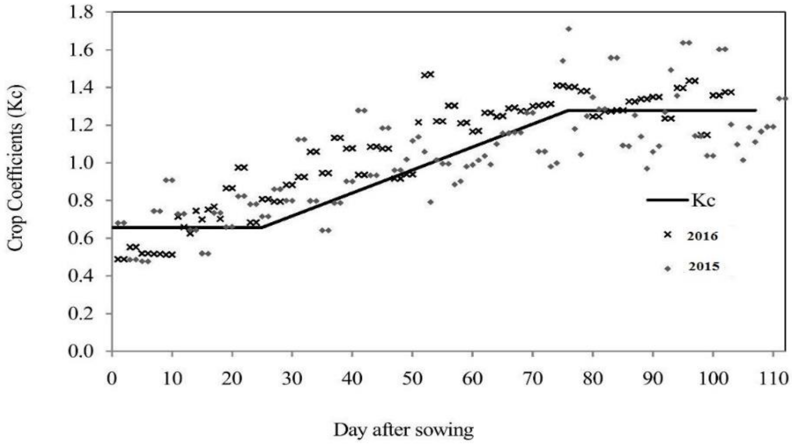

Figure 1. Actual daily crop coefficient and linear crop-specific coefficient (Kc) values for Peppermint stages in lysimeters in group A

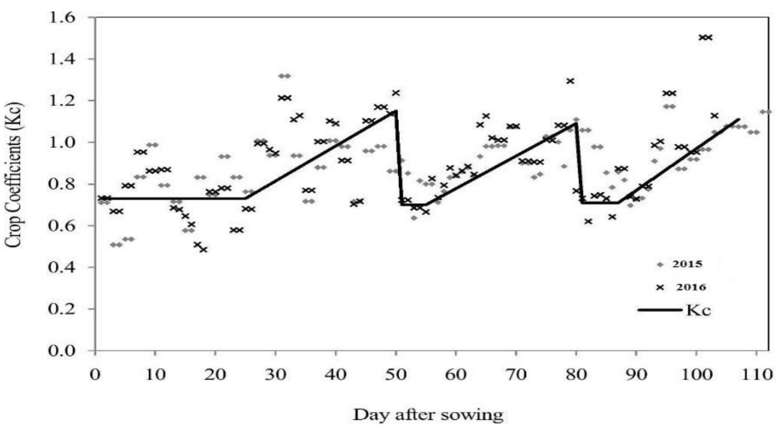

Figure 2. Actual daily crop coefficient and linear crop-specific coefficient (Kc) values for Peppermint stages in lysimeters in group B

3.3. Dual crop coefficient

During the years 2015 and 2016, 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 Peppermint for lysimeters in group A were obtained. Table 14 shows the values of basal crop coefficients during the Peppermint growing periods. The values of single and dual crop coefficient variations for 2015 and 2016 are presented in Figs. 3 and 4 respectively. As shown in Table 14 the average values of basal crop coefficients for initial, developing and middle stages were determined to be 0.30, 0.88 and 1.18 respectively.

Table 14. Average base crop coefficient of Peppermint during growth stages

Year	Initial	Developing	Middle
2015	0.29	0.86	1.17
2016	0.31	0.90	1.19
Average	0.30	0.88	1.18

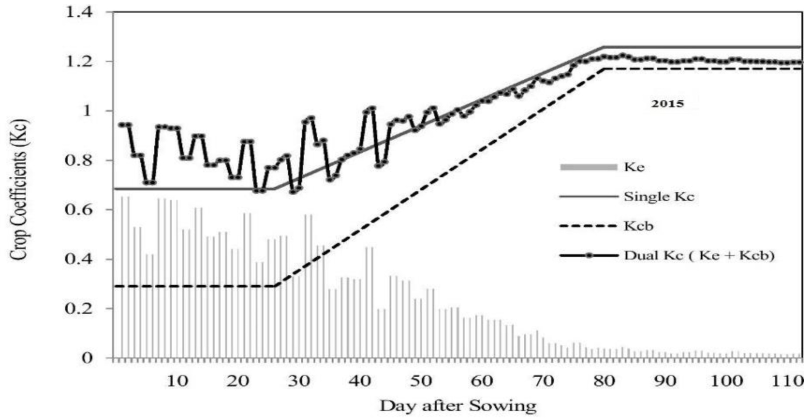

Figure 3. Single and dual Peppermint crop coefficient in 2015

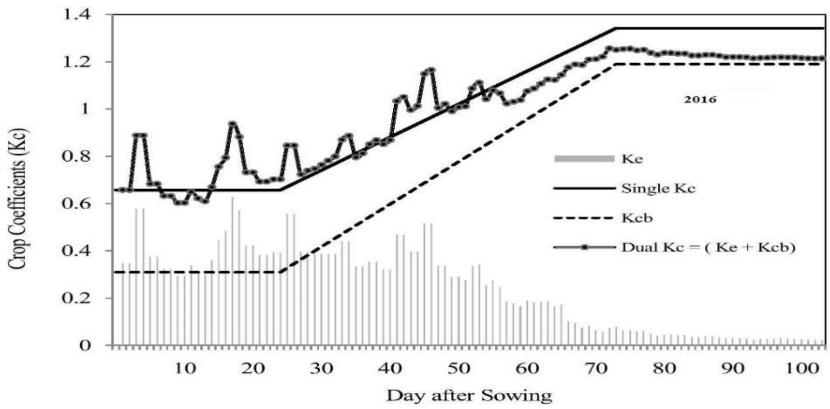

Figure 4. Single and dual Peppermint crop coefficient in 2016

3.4. Model comparison

The standard values for some parameters including TEW, REW and p are required to run the model after a calibration-validation procedure or trial and error similarly to (Rosa *et al.*, 2012b) The proper adjustments to the following values including REW, TEW and Ze with 10 mm and 35 mm, and Ze = 0.15 m were considered for simulations procedure, respectively. The initial depletion in the evaporable layer was set at 20% of TEW for both the 2015 and 2016 seasons. The R^2, RMSE, MBE and t-test (statistical methods) were used to compare the measured Dual Kc values with simulated values. The comparisons made between simulated and measured Dual Kc in the calibration (2015) and validation (2016) years are given in Table 15 and Fig. 5 Based on RMSE and MBE values in Table 5 the negative sign of the MBE indicates that the computed Dual Kc was lower than the Dual Kc measured by the lysimeter and the positive MBE shows overestimation of the lysimeter ETo values, while the absolute value was an indicator of method performance (Table 15). It can be seen that R^2 are between 0.88 and

0.91, the estimation errors RMSE and MBE ranging between (0.07-0.11) and (0.03-0.06), respectively. In addition, a comparison was made between model-simulated and ETC measured crop evapotranspiration's (ETc), the results of which are shown in Figs. 6 and 7 and Table 16. The results also suggest a good agreement between simulated and measured daily ETc values. The values of R^2 were between 0.90 and 0.96 and the results show a small overestimation of the model simulations during both years of the study. However, the estimated errors were acceptable with RMSE ranging between (0.69-1.07) mm/d, MBE ranging (-0.26-0.39 mm/d) and R/t ranging between (0.23-0.24), respectively.

Table 15. Correlation between the simulated Dual Kc and the measured values in 2015-2016

Year	RMSE	MBE	R^2	R/t
2015 (Calibration)	0.11	0.06	0.88	0.94
2016 (Validation)	0.07	0.03	0.91	0.21
Average	0.09	0.05	0.90	0.56

Table 16. Correlation between the simulated evapotranspiration and the measured values in 2015-2016

Year	RMSE	MBE	R^2	R/t
2015 (Calibration)	1.07	0.39	0.90	0.23
2016 (Validation)	0.69	-0.26	0.96	0.24
Average	0.88	0.07	0.93	0.24

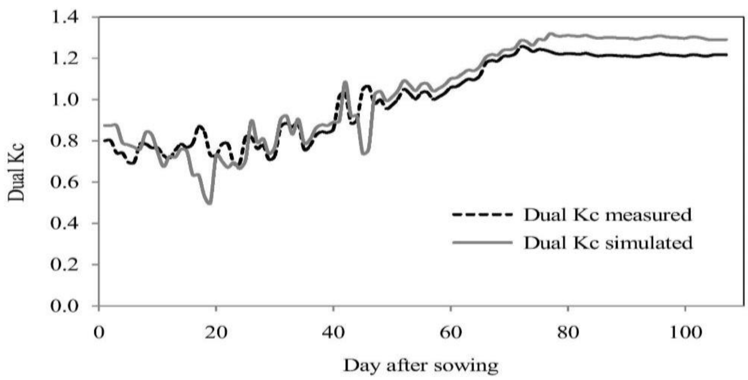

Figure 5. Comparison between simulated and measured Dual Kc

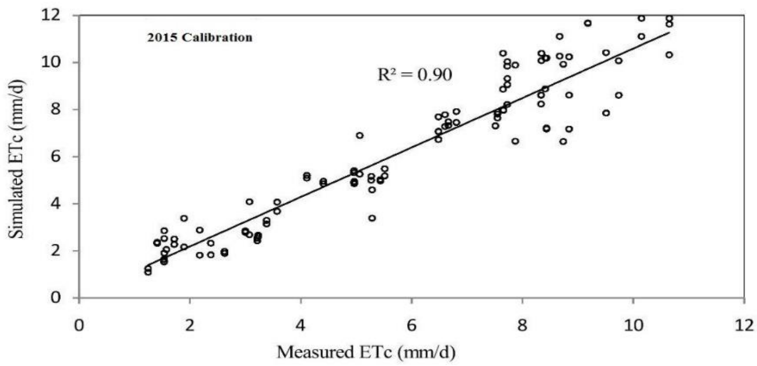

Figure 6. Comparison between simulated and measured evapotranspiration (ETc) in 2015

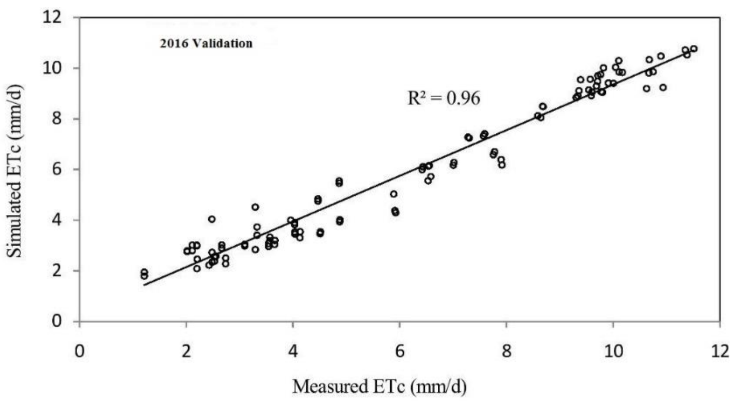

Figure7. Comparison between simulated and measured evapotranspiration (ETc) in 2016

By reviewing the results, it can be seen that the values of ETc and Kc in 2015 and 2016 throughout the third set of 10-day records were lower than the other decades (Table 10).

This is mainly due to the low canopy cover in the early stages of crop growth, where there are similar changes that can be seen in Table 11 after each harvest leading to low canopy cover of the crop in group A. Also, another important point that there are in the results is the difference between results obtained of the crop coefficient in a 2-year study conducted (Table 12 and 13), that the differences in crop coefficient values are probably due to daily water balance and climate conditions.

Also, according to the obtained results of dual crop coefficient (Table 14 and Figs. 3 and 4) can be seen that the values of the basal crop coefficient (i.e., transpiration values) gradually increased, and the highest values were obtained in the midseason stage. During the initial stage, when the plant green coverage was low, evaporation from the soil was the highest while during the stage of plant growth, it gradually decreased. Finally, the lowest values were obtained in the midseason of the growing period. In the initial stage, Es value was the predominant component of ETc, and Kcb, while single-Kc values were constant representing an average rate of Es from a dry soil surface. During crop development, both values of Kcb and single-Kc increased which was due to the development and expansion of leaf area. As the number and size of plant leave increased, the number of stomata increased as well while the increase of transpiration rate was directly related to Etc values (Allen *et al.*, 1998). At a mid-season stage, the full canopy cover grew and the transpiration rate was typically at a potential (i.e., maximum) rate. The dual-Kc is responsive to the surface wetness and increases whenever the soil surface was moist.

As already noted, another primary objective of the current study was calibrating and validate the SIMDualKc model by comparing measured and simulated Dual Kc and evapotranspiration (ETc) values for Peppermint. A few numbers of studies have been reported in the literature on SIMDualKc model simulation and validation (Paredes *et al.*, 2018; Ran *et al.*, 2017; Rosa *et al.*, 2016).

They suggested that the corresponding results showed a good agreement between the simulated and observed soil available water throughout the season, the regression coefficient was 0.99-1.02, and the root mean square error range was 2.0-3.3% of the total available water. No studies are now available in the literature on SIMDualKc model simulation and validation for Peppermint in a semi-arid climate for further comparison, albeit the results of the model simulation and validation found in the present study are in agreement with those reported by other researchers.

According to (Jacovides, 1997) the performance of each method in the present study was based on t values. Lower t-values showed a better performance of the method indicating that the differences between the measure and the 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 Table 15 Also, all indicators showed the capability of the model for accurate predictions of Dual Kc for Peppermint.

4. Conclusion

The results of two years investigation on Peppermint showed that the single and base crop coefficients for lysimeters in group A were determined to be as 0.68, 1.07, 1.31 and 0.3, 0.88, 1.18 for the initial, development and middle growing stages. For lysimeters in group B, the average of single crop coefficients was determined to be 0.85, 0.92 and 0.95 respectively. Those obtained values can be use by different researchers and consulting engineers for proper Peppermint water requirement and its irrigation scheduling. Moreover, calibration and validation of the SIMDualKc model showed the model's capability and accuracy for proper irrigation planning and scheduling.

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