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Model for Irrigation Management by Implementing the Two Crop Coefficient Approaches. 2. Model Validating on Some Oil Crops under Surface and Sub-surface Drip Irrigation

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Abstract
This paper is the second of a two-part series, with the first part describing the IMC-Model, an interactive **I**rrigation **M**anagement model for growing **C**rops that follows the two Kc approaches (dual-Kc and Single-Kc) for computing the actual ETc and then irrigation management parameters. The IMC-Model was validated by carrying out field experiments under surface (SDI) and sub-surface drip irrigation (SSDI) for two growing summer seasons of 2015 and 2016, respectively, in sandy soil at the National Research Centre (NRC) farm, El-Nubaria, Beheira, Egypt. The validated experiment included the following treatments: a) three approaches for computing ETc (single-Kc, dual-Kc, and control), b) two irrigation systems (SDI and SSDI), and c) two oil-seed crops (peanut and sesame). Results of the investigation indicated that the IMC-Model is a proper solution for providing appropriate information for irrigation management. In addition, the results revealed that the seasonal cumulative ETc computed by dual-Kc approach overestimated that estimated by single-Kc under SDI by 13.20 % for peanut and 21.90 % for sesame. However under SSDI, the dual-Kc overestimated the single-Kc by 4.42 % for peanut and 17.64 % for sesame. Maximum yield for peanut (2.23 ton fed^{-1}) and sesame (0.66 ton fed^{-1}) were obtained by the dual-kc under SSDI. Optimal water productivity for peanut (0.66 Kg m^{-3}) and sesame (0.23 Kg m^{-3}) were obtained by dual-kc under SSDI. It can be concluded that the IMC-Model is a proper solution for irrigation management. Additionally, the estimation of actual ETc using dual-Kc approach is more accurate compared with the single-Kc. It also could be maximize yield and improve water productivity by following the dual-kc approach under SSDI.

Keywords: Interactive model, crop evapotranspiration, dual crop coefficient, single crop coefficient, peanut, sesame, water productivity

1. Introduction

Efficient irrigation water management is extremely vital in maximizing the yield besides improving the water productivity as a result of increasing demands on limited water resources[1]. Drip irrigation, surface (SDI) and sub-surface (SSDI), can apply water both precisely and uniformly at a high frequency compared with irrigation methods[2]. However, achieving the actual benefits of drip irrigation, there is a need for accurate irrigation water management. The most fundamental requirement of irrigation management is the estimation of actual crop evapotranspiration (ETc)[3]. The direct methods of estimating ETc are expensive, difficult, and almost empirical for permanent use on a large scale[4]. Therefore, the ETc is commonly computed by the crop coefficient-reference evapotranspiration (Kc-ETo) procedure. In this procedure, the ETo is computed for a grass or alfalfa reference crop and is then multiplied by an empirical Kc to compute ETc under optimal growing conditions[5-7]. The FAO-56 Penman-Monteith ETo equation has been widely used because it gives satisfactory results under various climate conditions over the world[8,9]. The ETo represents nearly all effects of weather while the Kc varies predominantly with specific crop characteristics and have relatively lower effects of climate[10]. In addition, Kc also is affected by crop, water management, type of soil, and irrigation system (mainly by affecting Ke, the soil evaporation

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crop coefficient)[3]. The Kc is classified as single-Kc includes both evaporation from the soil surface and plant transpiration, while dual-Kc is expressed by the Ke and the basal crop coefficient (Kcb), separately[11]. The performance of the single-Kc or the dual-Kc depends on the precise selection of representative coefficient values for each of four crop growth stages (initial, crop development, mid-season, and late season), identification of the locally adjusted lengths of the growth stages, and precise estimation of ETo from weather parameters[12]. Peanut and sesame are very important cash crops for farmers in the world. This importance is due to the high nutritive value of their seeds which contain high amounts of edible oil, protein, and minerals[13]. According to Abou Kheira[14], optimum seed yield of peanut requires adequate water during all growth stages, but there are some critical periods that are very sensitive to soil water content in root zone by compared with early vegetative and late maturity[15]. Improper water during these critical periods reduces yield noticeably and fails to maximize water productivity[15]. In the same trend, sesame is sensitive to water deficit at seedling (low root expanding), flowering, and seed filling stages and can lead to yield loss[16]. Hence, it is necessary to compute the actual ETc and then the irrigation interval[13]. The IMC-Model was developed to provide an accurate, quick, and easy information about irrigation management for both experienced users and novice as farmers. Therefore, the objectives of this paper were: 1) validate The IMC-Model for computing daily actual ETc and then irrigation management parameters on some oil crops under surface and sub-surface drip irrigation; 2) Evaluate the precision of dual-Kc approach for estimating daily actual ETc and compare it with the single-Kc approach; and 3) Study the effect of the precise estimation of actual ETc on maximizing yield and improving water productivity.

2. Materials and methods
2.1. Site description
Two field experiments were conducted between May and October during 2014 and 2015, respectively, at the experimental farm of NRC, El-Nubaria, Beheira, Egypt (30.8667 N, 30.1667 E, and mean altitude 21-m above sea level) in order to validate the IMC-Model. Table 1 summarizes the average daily meteorological data for each month during the two growing seasons according to Central Laboratory for Agricultural Climate (CLAC). The soil texture is sandy and its samples were taken from 0 to 0.6 m during 2015 and 2016. The soil chemical and physical analysis are shown in Tables 2 and

3. Irrigation water was obtained from an irrigation channel, Nile water, going through the experimental site, with pH 7.3, and an electrical conductivity of 0.60 ds m^{-1}

Table 1: Average meteorological data at the experimental site during the months of validation (CLAC, from 2015-2016):

Month	T_{max}	T_{min}	RH_{mean}	u_2	R_a	P
	(℃)	(℃)	(%)	(m s^{-1})	(MJ m^{-2} d^{-1})	(mm)
May	32.8	26.5	60.2	1.7	41.3	0.3
June	34.8	28.2	62.6	2.3	41.6	0.0
July	36.8	32.2	67.5	1.7	40.7	0.4
August	35.3	31.8	61.6	2.1	38.4	0.6
September	32.4	27.3	66.4	1.8	33.9	0.2

T_{max} and T_{min}: maximum and minimum values of air temperature; R_{Hmean}: mean value of relative humidity; u_2: wind speed; R_a: extraterrestrial radiation; and P: precipitation.

Table 2: Some soil physical properties at the experimental site.

Depth	Particle Size distribution, %				Texture	θ_S % on weight basis			HC	B.D.	P
(cm)	C. San	F. Sand	Silt	Clay	Class	F.C.	P.W.P	A.W	(cm h^{-3})	(g cm^{-3})	(%)
0-15	8.4	77.6	8.5	5.5	Sand	12.0	4.1	7.9	6.68	1.69	36.23
15-30	8.6	77.7	8.3	5.4	Sand	12.0	4.1	7.9	6.84	1.69	36.23
30-45	8.5	77.5	8.8	5.2	Sand	12.0	4.1	7.9	6.91	1.69	36.23
45-60	8.8	76.7	8.6	5.9	Sand	12.0	4.1	7.9	6.17	1.67	36.98

F.C.: Field capacity; P.W.P.: Permanent wilting point (FC and PWP) were determined as a percentage (w/w); AW: Available water; HC: Hydraulic conductivity; B.D.: Bulk density and P: Porosity.

Table 3: Some soil chemical characteristics at the experimental site.

Depth,	pH	EC,		Soluble Cations, meq/L					Soluble Anions, meq/L		
(cm)	1:2.5	dS/m	Ca^{++}	Mg^{++}	Na^+	K^+	$CO3^{--}$	$HCO3^-$	$SO4^{--}$	Cl^-
0-15	8.3	0.35	0.50	0.42	1.05	0.23	0	0.11	0.82	1.27
15-30	8.2	0.36	0.51	0.43	1.04	0.24	0	0.13	0.86	1.23
30-45	8.3	0.34	0.55	0.41	1.05	0.23	0	0.12	0.85	1.27
45-60	8.4	0.73	0.57	0.43	1.06	0.25	0	0.17	0.86	1.28

2.2. Crop types
Two crops, peanut (*Arachis hypogaea L.*) cultivar Giza-6, and sesame (*Sesamum indicum L.*) cultivar Shandauil-3, had cultivated as oil-seed crops for the validation purposes of the IMC-Model. The peanut and sesame were grown in north-south rows with 0.2 m spacing between plants and 0.7 m between rows. All plots of peanut sesame had been applied with recommended fertilization and agronomic practices according to the recommendations of Agriculture Ministry in Egypt. The standard values of basal (Kcb), single (Kc) crop coefficients and other input data for computing the daily actual ETc and according dual-Kc and single-Kc approaches by The IMC-Model are tabulated in Table 4.

Table 4. Standard values of Lengths, the basal (Kcb) and single (Kc) crop coefficients, crop height (*h*), and root depth (Zr) for the four growth stages of peanut and sesame[17].

Stage	Period	days	Kc	Kcb	*h*, m	Zr, mm
I. Peanut						
Initial stage	25-May: 18-Jun	25	0.40	0.15	0.14*	0.20
Development stage	19-Jun: 24-Jul	35	0.77*	0.62*	0.26*	0.49*
Mid-season stage	25-Jul: 7-Sep	45	1.15	1.10	0.40	0.80
Late season stage	8-Sep : 2-Oct	25	0.90	0.8	0.40	0.80
II. Sesame						
Initial stage	25-May: 13-Jun	20	0.35	0.15	0.30*	0.10
Development stage	14-Jun: 13-Jul	30	0.75*	0.60*	0.64*	0.20*
Mid-season stage	14-Jul: 22-Aug	40	1.15	1.05	1.0	0.30
Late season stage	23-Aug : 11-Sep	20	0.74	0.66	1.0	0.30

* The average stagey values which were computed using the IMC-Model program.

2.3. Experimental design and irrigation system

The field experiment was a split-plot design. The main plots were devoted to irrigation system treatments (SDI and SSDI). On the other hand, the three approaches for estimating daily actual ETc, single-Kc; dual-Kc; and control treatment which was recommended by Ministry of Agriculture, occupied the sub-plots. Therefore, two field plots of size (28 × 11) m^2 with leaving 3 m between each other was selected for both peanut and sesame. Each plot was divided into two equal main plots of (12.5 × 11) m^2 for irrigation system treatments (SDI and SSDI) with leaving 1 m between these main plots as well as on both sides of the field. Each main plot of them was divided into three equal sub-plots of (3.5 × 11) m^2 for the estimating ETc approaches (single-Kc, dual-Kc, and control) with leaving 1 m between them An automatic irrigation system was installed to apply the accurate irrigation depth needed by plants and at the appropriate time. The irrigation network consists of a centrifugal pump with 100 m^3 h^{-1} discharge and control head (filters unit, pressure regulator, pressure gauges, flow-meter, and control valves). A PE venturi of 1 inch, the range of suction capacity 34-279 L h^{-1}, was used for fertilization purposes. The Mainline (110 mm diameter pipe-6 bar, PVC) was connected to sub-main pipes of (75 and 63 mm diameter-6 bar, PVC) to feed the manifold line which represents a treatment. Manifold lines (32 mm in diameter-6 bar, PVC) were connected to the sub-main line through a solenoid valve and discharge gauge for each sub-plot. The 12-solenoid valves were directly connected to a control panel. Lateral lines (16 mm in diameter-4 bar, PE) with built-in emitters (discharge of 4 L h^{-1} at 1 bar operating pressure and 0.30 m emitters spacing) were used for SDI and buried 0.15 m below the soil surface for SSDI. The distance between laterals was 0.70 m with 11 m long. The layout of the experiment is shown in Fig. 1.

2.4. Water productivity

Water productivity is a measure of the irrigation water productivity i.e., the yield produced by a unit volume of irrigation water. Water productivity (Kg m^{-3}) was estimating as following[3]:

$$\text{Water productivity} = \frac{Y}{4.2\ ETc}$$

Where, Y = seed yield (Kg fed.$^{-1}$), and ETc = actual crop evapotranspiration (mm).

2.5. Statistical analysis

The modeling output of seed yield for peanut and sesame crops obtained from the field experiments with the split-plot design were analyzed using CoStat-6.303 software, and the Duncan mean separation test procedure was applied. The treatments were compared according to LSD test at 5 % significance.
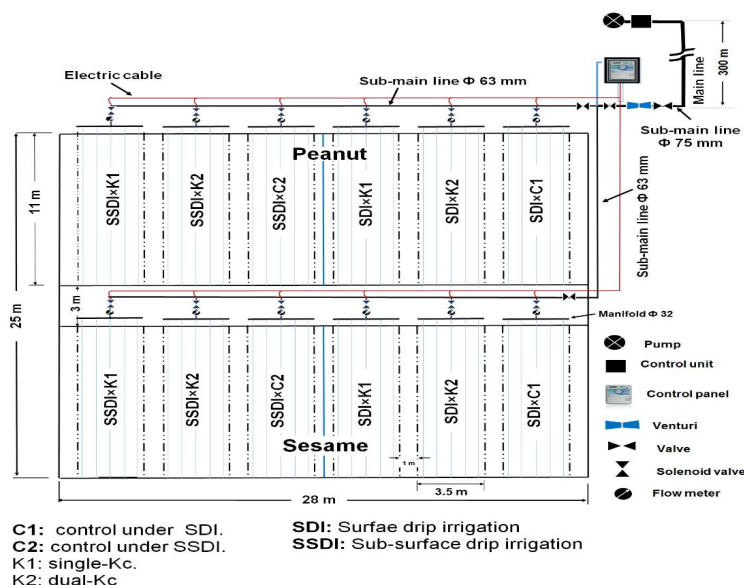

Fig. 1. Layout of the field experiment.

3. Results and discussion
3.1. The performance of the two Kc approaches
The dual-Kc curve during the whole season for peanut and sesame is described in Fig. 2. In the initial stage, the evaporation from the soil surface (Es) was the predominant component of ETc and the Kcb was constant. Whereas, at the crop development stage, the Kcb was increasing other than the Ke which was decreasing. This is due to the development and expansion of the leaf surface. As a result of increasing the canopy cover, the number of stomata increased and so was the Kcb. At the mid-season stage, the full canopy cover and transpiration rate were typically reached at a maximum rate. As the leaves mature and senescence set in, the number of leaves transpiring decreases and the crop curve decreases whenever the soil surface was moist, following rain or irrigation especially during the late season growth stages. This result is previously supported by Odhiambo and Irmak[12] and Parekh[18] as described earlier by Allen et al.[17]

Stage	Initial stage	Development stage	Mid-season	Late season
days	25	35	45	25

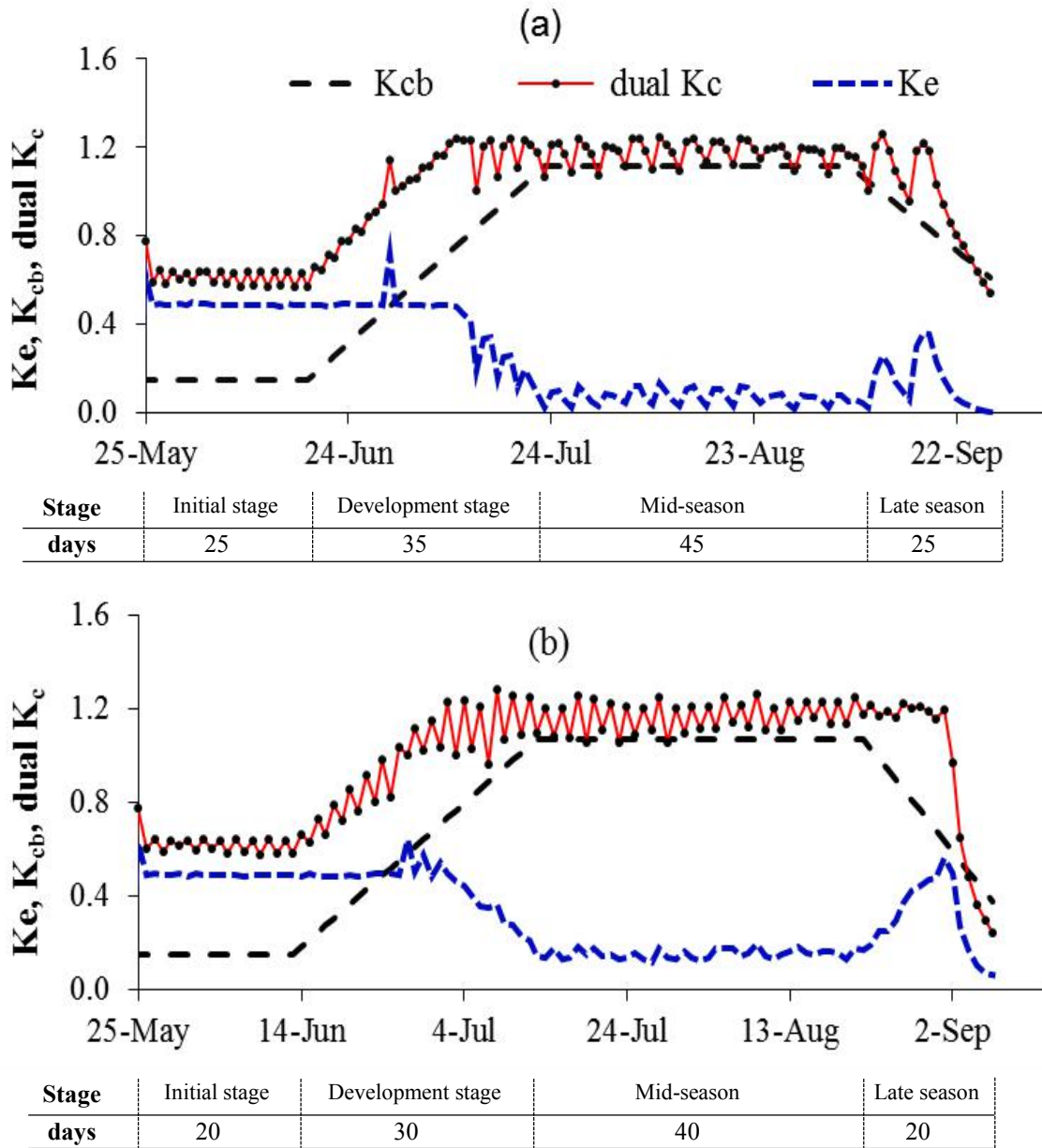| Stage	Initial stage	Development stage	Mid-season	Late season
days	20	30	40	20

Fig. 2: Ke, Kcb, and dual-Kc curves after irrigation during the whole season for (a) peanut and (b) sesame during 2015-2016.

Fig. 3 illustrates the differences between both dual-Kc and single-Kc curves during the growing season for peanut and sesame crops. In the initial period, it is noticed that the dual-Kc values were higher than single-Kc but the increasing rate was decreased gradually during the crop development stage and became unnoticed during both mid- and late season stages respectively as previously observed by Parekh[18] whose revealed that maximum differences between single-Kc and dual-Kc were observed at the initial stage. This is maybe because of the effect of the evaporation from the soil, which was taken in consideration in dual-Kc approach, was the prevailing component of ETc in the initial period. On the contrary, the Ke value was decreased gradually during crop development stage and became at the mid-season stage at a minimum rate. At the same time, the full canopy cover was reached at a maximum rate. Hence, the curves of dual-Kc and single-Kc were closer at the mid-season. This result is in agreement with that introduced by Odhiambo and Irmak[9].
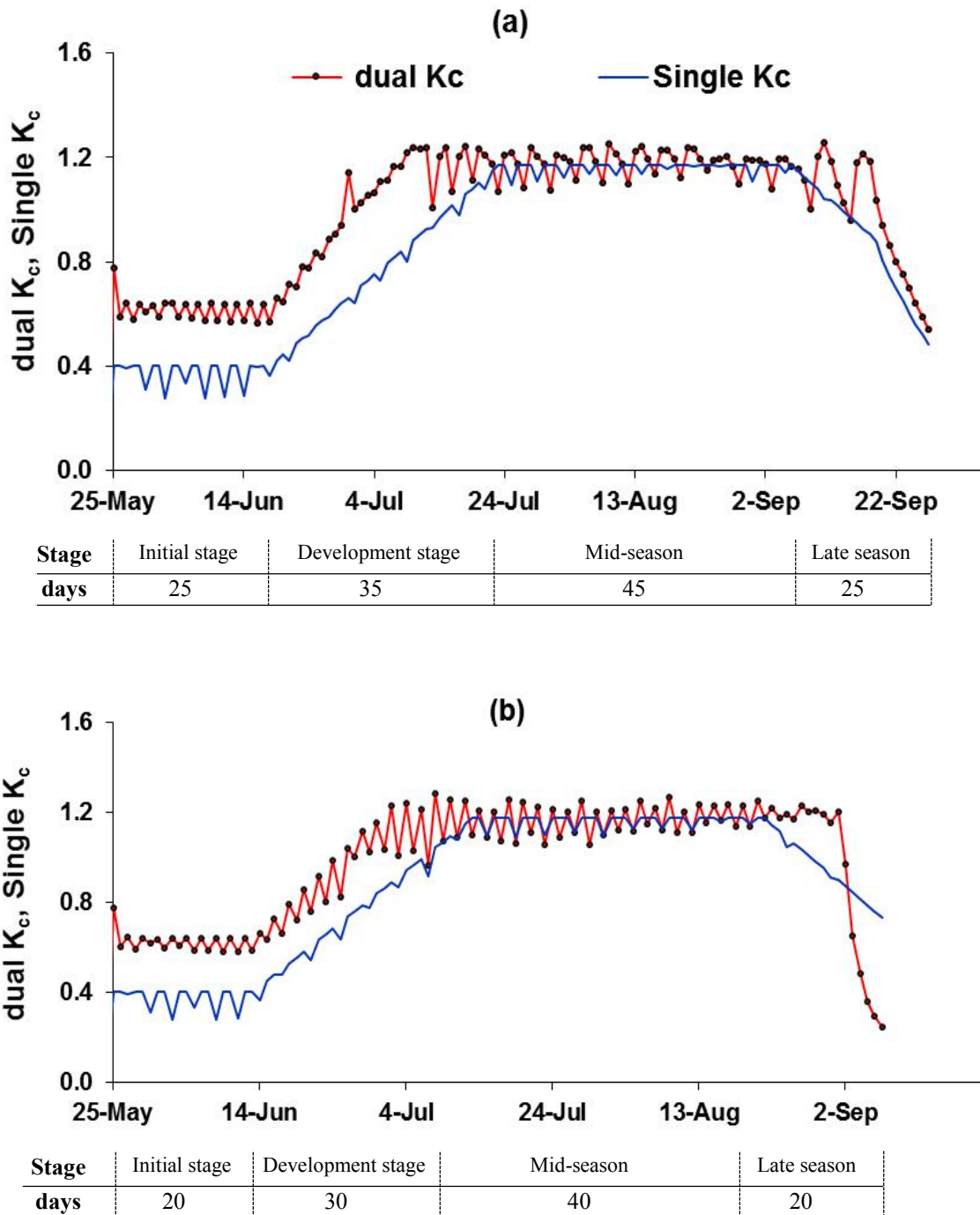
Fig. 3: Dual-Kc, and single-Kc curves after irrigation during the whole season for (a) peanut (b) sesame during 2015-2016.

3.2. Actual crop evapotranspiration

3.2.1. The cumulative ETc: The seasonal cumulative actual ETc computed by dual-Kc and single-Kc under SDI and SSDI for peanut and sesame are illustrated in both Fig. 4 and 5. The cumulative ETc estimated by single-Kc approach under SDI and SSDI were equal. On the contrary, the cumulative ETc estimated by dual-Kc under SDI overestimated it under SSDI for peanut and sesame crop. This result indicates that the cumulative ETc estimated by

single-Kc was not affected by the irrigation system. The dual-Kc approach overestimated the cumulative ETc estimated by single-Kc under SDI by 13.20 % for peanut and 21.90 % for sesame. while under SSDI, The dual-Kc overestimated the single-Kc by 4.42 % for peanut and 17.64 % for sesame. This result is in agreement with that mentioned by Odhiambo and Irmak[12], Silva *et al.*[19], and Paço *et al.*[20].
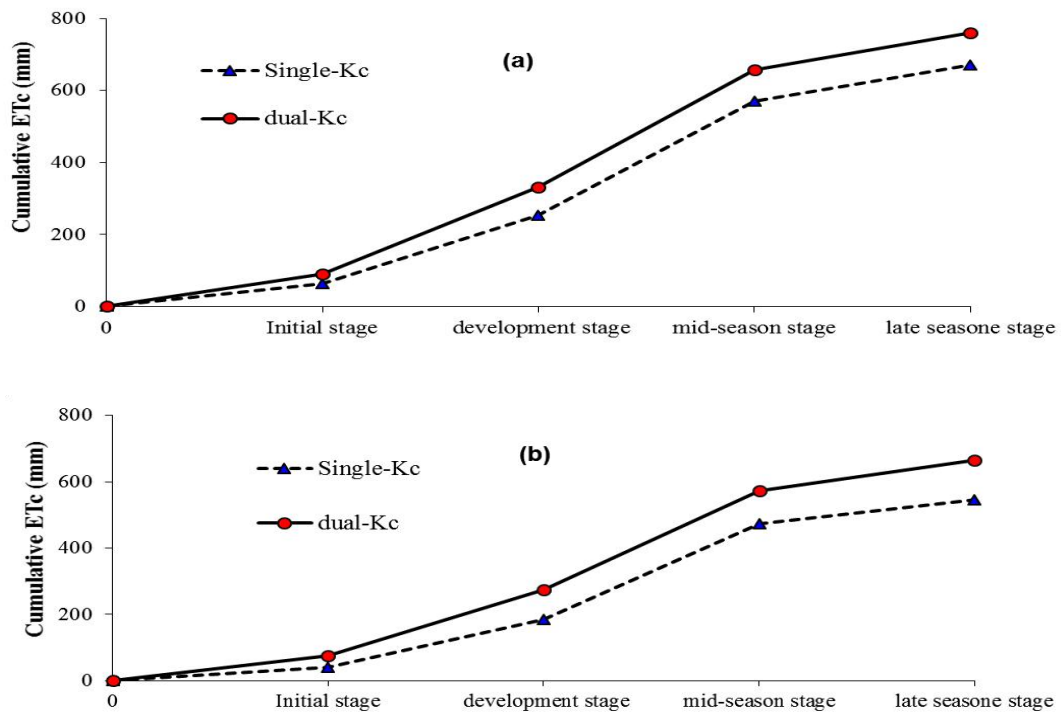
Fig. 4: Cumulative ETc estimated by single-Kc and dual-Kc approaches for (a) peanut and (b) sesame under SDI.
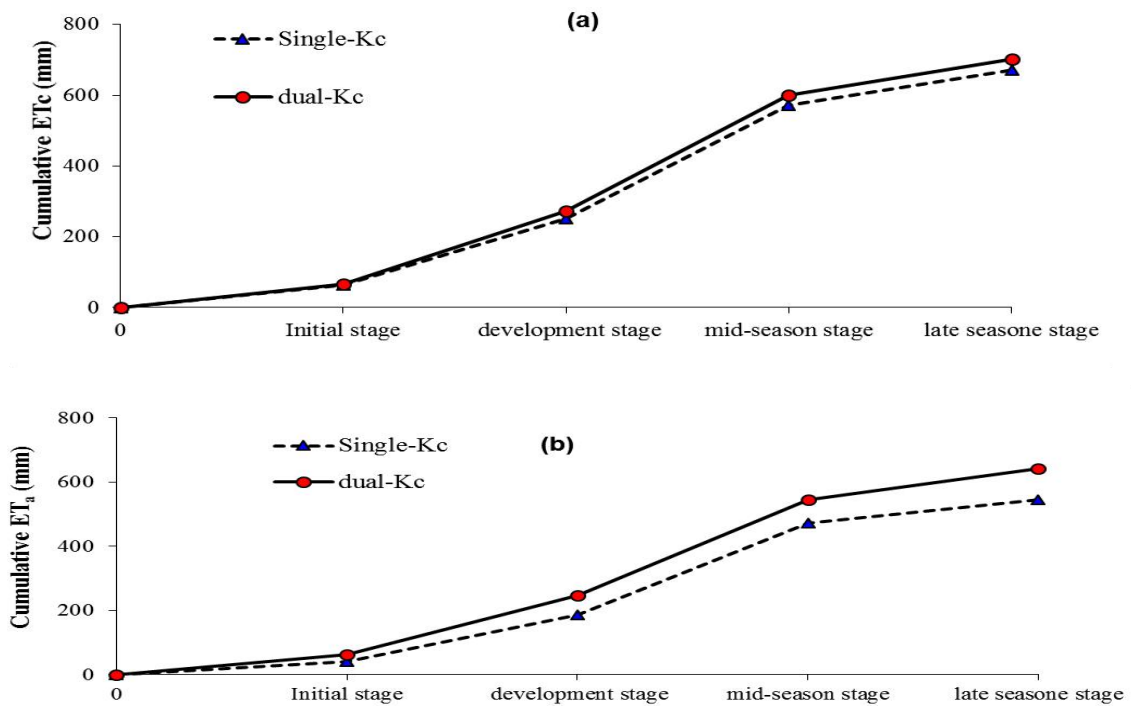

Fig. 5: Cumulative ETc estimated by single-Kc and dual-Kc approaches for (a) peanut and (b) sesame under SSDI.

3.2.2. The effect on seed yield and water productivity:
The estimation of actual ETc according to single-Kc and dual-Kc approaches were compared with the control treatment as presented in Table 6. It could be indicated that the obtained seed yield and the recorded water productivity for peanut and sesame from the single-Kc and dual-Kc approaches overestimated the control treatment. It can be also indicated that the seed yield according to dual-Kc overestimated those obtained from the single-Kc by 0.23 ton fed^{-1} (10.75 %) and 0.1 ton fed^{-1} (15.38 %) for peanut and sesame respectively. Meanwhile the recorded values of water productivity according to dual-Kc overestimated those recorded by single-Kc by 0.02 Kg m^{-3} (3.23 %) and 0.01 Kg m^{-3} (4.55 %) for peanut and sesame respectively.

Table 6: The effect of the three approaches for estimating ETc on seed yield for peanut and sesame.

Treatments	Yield (ton fed^{-1})		Water productivity (Kg m^{-3})	
	peanut	sesame	peanut	sesame
Control	1.72^c	0.51^c	0.43	0.14
single-Kc	1.91^b	0.55^b	0.60	0.21
dual-Kc	2.14^a	0.65^a	0.62	0.22
Average	1.92	0.57	0.55	0.18

3.3. Irrigation system (SDI and SSDI)

3.3.1. The effect on seed yield and water productivity: Data presented in Table 7 revealed that the obtained seed yield was significantly affected by irrigation system for both peanut and sesame crops. It is clear that the obtained seed yield for peanut and sesame under SSDI overestimated those under SDI by 0.12 ton fed^{-1} (6.06 %) and 0.04 ton fed^{-1} (6.78 %) respectively. This tendency is in harmony with those mentioned by Patel and Rajput[1]. In the same trend, the recorded values of water productivity for peanut and sesame under SSDI overestimated those under SDI by 0.06 Kg m^{-3} (10.35 %), and 0.02 Kg m^{-3} (10.53 %) respectively.

Table 7: The effect of irrigation system (SDI and SSDI) on seed yield and water productivity for peanut and sesame.

Treatments	Yield (ton fed^{-1})		Water productivity (Kg m^{-3})	
	peanut	sesame	peanut	sesame
SDI	1.86^b	0.55^b	0.52	0.17
SSDI	1.98^a	0.59^a	0.58	0.19
Average	1.92	0.57	0.55	0.18

SDI, SSDI: Surface, and Sub-surface drip irrigation system.

3.4. The interaction between actual ETc and irrigation system:

The effect on seed yield and water productivity: The obtained seed yield in response to the interaction between the irrigation system and the actual ETc computed by the two crop coefficient approaches (single-Kc and dual-Kc) were higher. According to the data presented in Table 8, the highest obtained values of seed yield for peanut (2.23 ton fed^{-1}) and sesame (0.66 ton fed^{-1}) were obtained from the interaction (SSDI × dual-Kc). While, the lowest values were obtained from the interaction (SDI × control) which were 1.68 ton fed^{-1}, 0.50 ton fed^{-1} for peanut and sesame respectively. Therefore, the effect of the interactions between the irrigation system and ETc estimated by single-Kc and dual-Kc approaches on seed yield for both peanut and sesame could be arranged as the following ascending orders: SDI × control < SSDI × control < SDI × single-Kc < SSDI × single-Kc < SDI × dual-Kc < SSDI × dual-Kc. In the same trend, the highest recorded values of water productivity for peanut (0.66 Kg m^{-3}) and sesame (0.23 Kg m^{-3}) were achieved with the interaction (SSDI × dual-Kc). On the contrary, the lowest values were recorded for the interaction (SDI × control) for peanut (0.41 Kg m^{-3}) and sesame (0.13 Kg m^{-3}) as presented in Table 8. Unlike seed yield, the effect of the interactions between the irrigation system and actual ETc estimated by single-Kc and dual-Kc approaches on water productivity for peanut and sesame could be arranged as the following ascending orders: SDI × control < SSDI × control < SDI × single-Kc < SDI × dual-Kc < SSDI × single-Kc < SSDI × dual-Kc.

Table 8: The effect of interaction between ETc and irrigation system (SDI and SSDI) on seed yield and water productivity for peanut and sesame.

Treatments	Yield (ton fed^{-1})		Water productivity (Kg m^{-3})	
	peanut	sesame	peanut	sesame
SDI × control	1.68^f	0.50^f	0.41	0.13
SDI × single-Kc	1.84^d	0.53^d	0.56	0.19
SDI × dual-Kc	2.05^b	0.64^b	0.58	0.20
SSDI × control	1.75^e	0.52^e	0.45	0.14
SDI × single-Kc	1.98^c	0.58^c	0.63	0.22
SSDI × dual-Kc	2.23^a	0.66^a	0.66	0.23
Average	1.92	0.57	0.55	0.18

SDI, SSDI: Surface, Sub-surface drip irrigation system.

4. Conclusion

It can be concluded that the IMC-Model is a proper solution for irrigation management. In addition, some of the observed results can be summarized as follows:

a) The estimation of actual ETc according to dual-Kc approach is more accurate compared with the single-Kc approach.

b) The seasonal cumulative ETc estimated by dual-Kc overestimated that estimated by single-Kc under SDI by 13.20 % for peanut and 21.90 % for sesame. While under SSDI, the dual-Kc overestimated the single-Kc by 4.42 % for peanut and 17.64 % for sesame.

c) Seed yield: The highest seed yield of peanut (2.23 ton fed^{-1}) and sesame (0.66 ton fed^{-1}) were obtained with the interaction (SSDI × dual-Kc) and the other interactions could be written as: SDI × control < SSDI × control < SDI × single-Kc < SSDI × single-Kc < SDI × dual-Kc. d) Water productivity: The optimal value of water productivity for peanut (0.66 Kg m^{-3}) and sesame (0.23 Kg m^{-3}) recorded with the interaction (SSDI × dual-Kc) and the other interactions could be arranged as: SDI × control < SSDI × control < SDI × single-Kc < SDI × dual-Kc < SSDI × single-Kc.

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