Sunflower Water Requirements Using Single and Dual Crop Coefficients

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ABSTRACT: A field experiment of drip-irrigated Sunflower (Helianthus annuus) was conducted at the Experimental Farm, Faculty of Agriculture (Saba-Basha), Alexandria University, Egypt during 2013 growing season to develop seasonal K_c values for drip irrigated sunflower. In this context the objectives were:

1. to analyze the ability of the FAO-56 single and dual crop coefficient models for assessment the regional evapotranspiration and water requirements, 2. to estimate an adequate water quantity needed for the sunflower.

The sunflower variety Sakha 53 was cultivated at 28th April and harvesting was done at 8 August, 2013. Seeds were sown at 4-5 seeds in each hill with a spacing of 0.3 m within each row and 0.6 spacing, then thinned to one plant after 2 weeks from sowing. After emergence, the plots were irrigated by the drip irrigation method. All field practices were done as usually recommended for sunflower cultivation. The irrigation treatments based on replenishment of soil water depletion according to reference evapotranspiration (ET_0). The irrigation treatments were; irrigation at 20, 40, 60, 80 and 100% of ET_0. The results indicated that seasonal sunflower evapotranspiration (mm) has higher value with field irrigation approach and the lower value was for standard FAO single approach. The seasonal evapotranspiration (single crop coefficient approach) was less than the seasonal evapotranspiration of dual crop coefficient approach. It appears that ETc estimation of sunflower crop is more accurate by dual crop coefficient approach than those produced by single crop coefficient approach because of using more parameters and taking the soil practices and crop characteristics in consideration. The basal crop coefficient values cannot be proposed for all climates and regions because of different climatic conditions and crop management practice under different regions. The present study recommended that for the present conditions and the same other conditions, the irrigation of sunflower crop must be done according to the dual crop coefficient approach because it is more accurate than single crop coefficient and close up to the field conditions.

Keywords: sunflower, water requirements, single crop coefficient, dual crop coefficient, FAO Penman- Monteith model

INTRODUCTION

Water scarcity in semi-arid or arid regions is one of the main factors limiting agricultural development. The impact of such water scarcity is amplified by inefficient irrigation practices. Therefore, the first step toward sound management of the scarce water resources in these regions requires an accurate estimation of the water needs and consumption of irrigated agriculture. Several models have been developed to simulate crop evapotranspiration (ET_c) and in some cases, its components (soil evaporation and plant transpiration). These models ranged from complex (Braud *et al.*, 1995) to more simple and conceptual ones (Olioso *et al.*, 1999). FAO-56 is based on the concepts of reference evapotranspiration ET_0 and crop coefficients K_c, which have been introduced to separate the climatic demand from the plant response (Allen *et al*., 1998). There are two approaches to estimate crop evapotranspiration: the single and the dual crop coefficients. In the FAO-56 single crop coefficient approach, the effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient, K_c, the FAO-56 dual crop coefficient approach describes the relationship between maximal evapotranspiration ET_c and reference evapotranspiration ET_0 by separating K_c into a basal crop (K_{cb}) and soil water evaporation (K_e) coefficients. In the semi-arid Mediterranean region of southern Morocco, Er-Raki *et al.* (2010) applied the single approach and found that the approach overestimates AET by about 18% when using the crop coefficient suggested by Allen (2000).

Knowledge of crop coefficient (K_c) is essential for the estimation of water use. It helps in determining the water requirement of the crops according to their growth stage and environmental factors. Studies have found that K_c for the same crop may vary from place to place based on factors such as climate and soil evaporation (Allen *et al*., 1998; Kang *et al*., 2003). Doorenboss and Pruitt (1977) and Kang *et al.* (2003) emphasized the need to develop regional K_c for accurate estimation of water use, under a specific climatic condition.

Numerous empirical methods have been developed to estimate evapotranspiration from different climatic variables. Examples of such methods include Penman-Monteith (Monteith, 1965) and Blaney-Criddle model (Blaney and Criddle, 1950). Blaney-Criddle model requires the temperature data while the FAO-Penman-Monteith requires additional parameters such as wind speed, humidity and solar radiation. The Blaney-Criddle method is used to calculate monthly K_c values as compared to daily and less data is needed for this method.

The Food and Agricultural Organization (FAO) recommended FAO-Penman Monteith (FAO-PM) method as the sole standard method for computation of ET_0 (Allen *et al*., 1998). FAO-PM can provide accurate ET_0 estimates for weekly or even hourly periods.

Accurate prediction of crop water use is the key to develop the efficient irrigation management practices making it imperative to develop K_c for a specific crop. Doorenbos and Pruitt (1977) prepared a comprehensive list of K_c for various crops under different climatic conditions by compiling results from different studies. A similar list of K_c was also given by Allen *et al.* (1998) and Doorenbos and Kassam (1979). However, K_c for a crop may vary from one place to another, depending on factors such as climate, soil, crop type, crop variety, irrigation methods (Kang *et al*., 2003). Thus, for an accurate estimation of the crop water use, it is imperative to use a regional K_c. Brouwe and Heibloem (1986) stated that the steps for development of K_c as: determination of the total growing period of the crop, identifying the length of different growth stages, and determination of K_c

values for each growth stage. However, K_c cannot be measured directly, but is estimated as a ratio (ET_C/ET_0). While ET_0 can be estimated using one of the several available methods, ET_c can be estimated by a lysimeter study as reported by Grattan *et al.* (1998). There are two approaches to estimate crop evapotranspiration: the single and the dual crop coefficients. The FAO-56 dual crop coefficient approach (Allen *et al*., 1998) describes the relationship between crop evapotranspiration, ET_c and reference evapotranspiration, ET_0 by separating the single K_c into the basal crop K_{cb} and soil water evaporation K_e coefficients, while in the FAO-56 single crop coefficient approach, the effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient. Many studies have focused on the application of the single approach for determining olive water requirement within Mediterranean regions (Palomo *et al*., 2002; AbidKarray *et al*., 2008; Martinez-Cob and Faci, 2010). In the semi-arid Mediterranean region of southern Morocco, Er-Raki *et al*. (2008) applied also the single approach over the same study site of this work, and they found that the approach overestimates AET by about 18% when using the crop coefficient suggested by Allen *et al*. (1998). Recently, several studies used the FAO-56 dual crop coefficient for estimating water consumptions of different crops (Hunsaker *et al*., 2003, 2005; Allen *et al*., 2005 a, b; Paço *et al*., 2006; Er-Raki *et al*., 2007). Some of these studies adopted the FAO-56 dual approach to use satellite-based vegetation index (Hunsaker *et al*., 2003, 2005; Er-Raki *et al*., 2007; González-Dugo and Mateo, 2008; Er-Raki *et al*., 2010). The results show that relating the basal crop coefficient K_{cb} to remotely sensed vegetation index greatly improves the performance of the FAO-56 method. However, Er-Raki *et al*. (2006) showed that the performance of the FAO-56 method has some limitations when there is high soil evaporation or when stress occurs. To overcome this problem and then enhance the FAO-56 performances, ET derived from thermal infrared (TIR) observations was assimilated into FAO-56 single source model (Er-Raki *et al*., 2008) in order to estimate accurately the water consumption of olive orchards in the semi-arid region of the Ten sift basin (central of Morocco).

The goal of this study was to develop seasonal and growth stages K_c values for drip irrigated sunflower. In this context the objectives of this study were:
1. to analyze the ability of the FAO-56 dual crop coefficient model for assessment the regional evapotranspiration and water requirements.
2. to estimate an adequate water quantity needed for the sunflower and to determine the best quantity of irrigation by using the FAO- single and dual crop coefficient approaches.

MATERIALS AND METHODS

1. Experimental site and conditions

This study was conducted during the 2013 summer season at the Experimental Farm, Faculty of Agriculture (Saba-Basha), Alexandria University, Egypt. The farm is located at Abees region located at 31˚ 10.102′ N and 29˚ 58.085′ E with an altitude of (-5 m) under sea level. The site was planted with corn crop in the previous season. This area is characterized by a semi-arid climate, the weather is hot and dry from May to August where temperatures ranged from 25 to 30 ºC. On the other hand, the average values of rainfall were 186.2 mm per year. Wind speed average was 13.5 km/day and relative humidity average was about 69.5 %. Some climatologically data on the experimental site were taken from Nouzha Weather Station and are given in Table (1).

2. Soil of the experimental site

Soil samples were collected from the experimental soil for both surface (0-30 cm) and subsurface (30-60 cm) layers. Some physical and chemical properties of the experimental field soil are presented in Table (2). The soil properties were performed according to the methods outlined in Carter and Gregorich (2008). The soil of the experimental site is clayey texture with water table level of 1 m down the soil surface, the groundwater is moderately saline (2.5 dS/m) and the contribution of water table to plant water requirements is low in the site of experiment.

3. Sunflower cultivation

Sunflower (*Helianthus annuus*) variety Sakha 53 early variety (100 days' crop age) was selected for the study at 2013 summer season. Plant sowing date was at 28 April, 2013. Seeds were sown (4-5 seeds) in each hill with spacing of 0.3 m within each row. Thinning to one plant per hill was carried out after 15 days from sowing to obtain a final plant population of 55500 plants/ha. After emergence, the plots were irrigated by the drip irrigation method, Table (3) shows the chemical analysis of irrigation water. Irrigation was terminated at 5 August, complete canopy and initial blooming date was at 13 June, and harvesting data was at 9 August. All field practices were done as usually recommended for sunflower cultivation. Phosphorus fertilizer as calcium superphosphate (15.5% P_2O_5) was fully added to the soil during seed preparation at 336 kg P_2O_5 ha^{-1}. Ammonium Nitrate (33.5% N) at the rate of 168 kg ha^{-1} were applied at two equal doses, one after sowing and the second after one month later. Potassium Sulfate (48% K_2O) at the rate of 67 kg ha^{-1} were added at two equal doses, one after sowing and the second after one month later.

Table (1). Daily maximum, minimum and average temperature, wind speed, solar radiation for the experimental Site during the experimental period

Months	Average minimum daily temperature T_{min} (°C)	Average maximum daily temperature T_{max} (°C)	Average daily temperature T_m (°C)	Average daily wind speed U_2 (m/s)	Average relative humidity %	Average atmospheric pressure mb	Average precipitation mm/month	Average daily solar radiation (MJ/m^2/day)
April 2013	14.8	24.6	19.4	11.18	62.9	1014.8	0	34.12
May 2013	18.8	28.7	23.5	9.79	68.0	1012.4	3.1	35.90
June 2013	21.7	30.3	25.6	10.83	68.4	1011.1	0	37.41
July 2013	23.4	30.2	26.6	11.66	71.4	1008.1	0	36.64
August 2013	23.9	31.7	27.8	9.58	72.1	1008.9	0	34.99

Table (2). Some physical and chemical properties of the experimental site

Soil parameters	0-10cm depth	10-20cm depth	20-40cm depth	Unit
Particle size distribution(%)				
Sand	29.7	29.7	32.2	%
Silt	15.0	17.5	15.0	%
Clay	55.3	52.8	52.8	%
Textural class	Clay	Clay	Clay	-
Soil bulk density	1.240	1.245	1.248	Mg/ m^{-3}
Soil moisture content at field capacity (θ_{fc})	0.3513	0.3613	0.3687	m^3m^{-3}
Soil moisture content at permanent wilting point (θ_{wp})	0.1221	0.1281	0.1295	m^3m^{-3}
Plant available water content (PAW)	0.2292	0.2332	0.2392	m^3m^{-3}
Organic matter content	2.87	2.87	2.15	%
Total calcium carbonate	18.12	18.12	15.78	%
Electrical Conductivity (EC_w), (1:1, soil: water extract) dS/m	6.98	6.29	5.94	ds/m
pH (1:1, soil : water suspension)	8.05	8.15	8.25	-
Soluble Cations				
Ca^{2+}	2.38	1.69	1.42	meq/
Mg^{2+}	7.85	6.05	4.50	meq/
Na^{+}	58.15	54.13	52.13	meq/
K^{+}	1.35	1.12	1.12	meq/
Soluble Anions				
$CO^{=}_{3+}$ HCO^{-3}	10.20	9.92	2.12	meq/
Cl^{-}	44.00	44.39	41.00	meq/
$SO^{=}_{4}$	14.03	7.70	12.54	meq/

Table (3). Chemical analysis of irrigation water used in the field experiment

Parameters	Value	unit
pH	7.35	-
EC_{iw}	0.60	dSm^{-1}
Soluble Cations		
Ca^{+2}	1.89	$meql^{-1}$
Mg^{+2}	0.81	$meql^{-1}$
K^{+}	2.74	$meql^{-1}$
Na^{+}	0.46	$meql^{-1}$
Soluble Anions		
$CO^{=}_{3}$ + HCO^{-}_{3}	1.98	$meql^{-1}$
Cl^{-}	0.810	$meql^{-1}$
SO_4^{-2}	3.14	$meql^{-1}$

At harvest, the sample of plants (1 m of the row × 0.60 m width of the row = 0.60 m^2) of the two central ridge were chosen to determine the sunflower yield and the total yield per ha^{-1} was calculated.

4. Irrigation regime

The irrigation treatments were based on replenishment of soil water depletion according to the reference evapotranspiration (ET_0). The irrigation treatments were:

I1 irrigation at 20% of ET_0,
I2 irrigation at 40% of ET_0,
I3 irrigation at 60% of ET_0,
I4 irrigation at 80% of ET_0, and
I5 irrigation at 100% of ET_0

Irrigation water in drip irrigation system was taken by a water pump. Distribution lines consisted of PVC pipe manifolds for each plot. The diameter of the polyethylene laterals was 16 mm and each lateral irrigated one plant row. The inline emitter discharge rate was 4 l h^{-1} at 100 kPa operating pressure. The actual emitter discharge rate was calibrated before starting the experiment. The drip network calibration was performed and the actual rate of emitter was 3.43 l h^{-1}.

Soil water content was measured by sampling a soil from each row with soil tube 0.025 m diameter at three depths i.e. 0-10, 10-20 and 20-60 cm below soil surface then determined by gravimetric method. Soil water contents were monitored prior each irrigation and after irrigation at surface and subsurface depths through electronic pressure transducer (electronic tensimeter).

5. Crop Evapotranspiration

The irrigation requirements were calculated according to the Penman-Monteith equation (Allen *et al.*, 1998) according the following equation:

$$ET_{crop} = \frac{ET_{drip}}{E_a(1\text{-}LR)} \qquad (2)$$

Where:

ET_{crop} is the crop evapotranspiration, mm/day
ET_{drip} is the crop evapotranspiration under drip irrigation system, mm/day
E_a is the efficiency of irrigation system (assumed as 95 % for drip irrigation system under the present conditions).
LR is the Leaching Requirements required for salt leaching in the root zone depth (assumed as 15 %). and

$$ET_{drip} = K_r \times K_c \times ET_0 \qquad (3)$$

K_r is the reduction factor that reflects the percent of soil covering by crop canopy and can be calculated by the equation described in Karmeli and Keller (1975):

$$K_r = \frac{GC}{0.85} \quad (4)$$

Where, GC is the ground cover fraction (plant canopy area divided by soil area occupied by one plant, assumed as 0.6).

K_c is the crop coefficient ranging from 0.35 (for initial stage) to 1.15 (for development stage) for sunflower (Allen *et al*., 1998). We need the length and crop coefficient (K_c) for each of the 4 growth stages: initial, crop development, mid-season and late season stages. The crop coefficients (K_c and K_{cb}) were collected from FAO (Allen *et al*., 1998) and are presented in Table (4).

Table (4). Crop coefficient (K_c) and development stages period for sunflower

Growth stages	K_c Single crop coefficient	K_{cb} Basal Crop Coefficient	Stage period, days
Initial	0.35	0.15	20
Crop development	0.35 - 1.15	0.15 - 1.05	25
Mid-season	1.15	1.05	38
Late-season	1.15 - 0.35	1.05 – 0.2	20

ET_0 is the reference evapotranspiration calculated with FAO Penman-Monteith equation (Allen *et al*., 1998) using the climatic data collected from the Nouzha Weather Station as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)} \quad (5)$$

Where:

ET_0 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}, Generally very small and assumed to be zero).
T Mean daily air temperature at 2.0 m height, °C,
U_2 Wind speed at 2 m height, m s^{-1} ,
e_s Saturation vapor pressure at 1.5 to 2.5-m height, kPa,
e_a Actual vapor pressure at 1.5 to 2.5-m height, kPa,
e_s - e_a Saturation vapor pressure deficit, KPa,
Δ Slope vapor pressure curve, kPa°C^{-1},
γ Psychometric constant, kPa°C^{-1}.

The effect of soil water stress on crop ET is accounted by multiplying the crop coefficient by the water stress coefficient (K_s), which is given by the following equation:

$$K_s = \frac{TAW\text{-}D_r}{TAW\text{-}RAW} = \frac{TAW\text{-}D_r}{(1\text{-}p)TAW} \quad (6)$$

Where:
TAW is the total available water in the root zone depth (mm),
RAW is the readily available water in the root zone (mm), RAW=p*TAW,
p is the fraction of TAW that a crop can extract from the root zone without water stress (assumed as 0.45) and
D_r is the root zone depletion in the root zone (mm)

The total available water in the root zone is estimated as follows:

$$TAW=1000(\theta_{FC}\text{-}\theta_{WP})Z_r \quad (7)$$

Where:
θ_{FC} is the field capacity (m^3/m^3),
θ_{WP} is the permanent wilting point (m^3/m^3) and
Z_r is the effective rooting depth (m)
The adjusted K_c due to water stress is:

$$K_{c\text{-}adj}=K_s \times K_c \quad \text{for single crop coefficient} \quad (8)$$

$$K_{c\text{-}adj}=K_s \times K_{cb}+K_e \quad \text{for dual crop coefficient}$$

(9)

The field crop evapotranspiration (ET_C) was calculated using the following equation (10):

$$ET_C=P+I\text{-}D\text{-}R\pm\Delta S \quad (10)$$

Where ET_C is the crop evapotranspiration (mm), P is precipitation (mm), I is irrigation (mm), D is the water drained (mm), R is the runoff (mm) and ΔS represents the changes in soil water storage during the growth period. D and R were considered as zero because of control irrigation. The changes in soil moisture were estimated with soil moisture measurements at different depths.

6. Development of Crop Coefficient

The K_c values were developed for sunflower crop using ET_0 estimates from FAO-PM method. To compute K_c based on crop development stage, it is important to establish the length of different crop growth stages (Table 4). Allen *et al.* (1998) divided the crop cycle into four stages: initial stage (marked with about 10% of plant cover), development stage (marked with the growth of plant 10% ground cover to effective cover i.e., flowering), mid-season stage (effective cover to start maturity) and late season stage (Start of maturity to harvest).

7. Sunflower crop coefficient (K_c)

The crop coefficients of the sunflower during the different growth stages according to the standard FAO methodology were presented in Table (5).

Table(5). Sunflower crop coefficient at growing periods (Doorenbose and Kassam, 1986)

Growth stages	Period length (days)	K_c value
Initial	20	0.35
Development	25	0.75
Midseason	38	1.10
Late season	20	0.35

Crop coefficient obtained for four growth stages of crop growing periods. The four growth stages of crop growing periods are as follows:

1. Initial period (planting to 10% ground cover)
2. Crop development (10% ground cover to effective cover i.e., flowering)
3. Mid-season (Effective cover to start maturity)
4. Late-season (Start of maturity to harvest)

The calculation procedure for crop evapotranspiration (ETc) consists of:

1. identifying the crop growth stages, determining their lengths, and selecting the corresponding K_c coefficients;
2. adjusting the selected K_c coefficients for frequency of wetting or climatic conditions during the stage;
3. constructing the crop coefficient curve (allowing one to determine K_c values for any period during the growing period); and
4. calculating ET_c as the product of ET_o and K_c.

8. Crop coefficient (field approach)

The single crop coefficient (K_c single) was defined as the ratio of the measured ET_c by field soil moisture measurement to the ET_0 estimated by the FAO Penman –Monteith equation (Allen *et al.*, 1998) under standard condition as follows:

$$K_{c\text{-single}} = \frac{ET_c}{ET_0} \tag{11}$$

The dual crop coefficient under standard conditions can be presented as:

$$K_{c\text{-dual}} = \frac{ET_c}{ET_0} = K_{cb} + K_e \tag{12}$$

Where:
K_{cb} is the basal crop coefficient and K_e is the soil evaporation coefficient.

Therefore, crop development and its characteristics were recorded during the growing season to separate the individual growing stages of sunflower being the initial, development, mid and end stages.

9. Crop coefficient (FAO approach)
1. Single crop coefficient

The values for large number of crops are presented in Allen *et al.* (1998). They are based on average conditions in sub-humid climate. FAO has presented a correction equation to normalize the K_c value for other places with different climatological and soil conditions.

The value of $K_{c\ ini}$ can be estimated from Figures 29 and 30 (Allen *et al.*, 1998) as follows:

$$K_{c\ ini} = K_{c ini}(\text{Fig. } 29) + \frac{(\text{I-10})}{(40\text{-}10)}\left[K_{c ini}(\text{Fig } 30)\text{-}K_{c ini}(\text{Fig } 29)\right] \qquad (13)$$

Where:
$K_{c\ ini}$ is the value for $K_{c\ ini}$ from Figure 29 (Allen *et al.*, 1998)
$K_{c\ ini}$ is the value for $K_{c\ ini}$ from Figure 30 (Allen *et al.*, 1998)
I is the average infiltration depth (mm)

The values 10 and 40 in Equation are the average depths of infiltration(mm) upon which Figures 29 and 30 (Allen *et al.*, 1998) are based.

Drip irrigation wet only a fraction of the soil surface, the fraction of the surface wetted, f_w ranged from 0.3 to 0.4. The Kc_{ini} can be calculated from the following equation:

$$K_{c ini} = f_w \times K_{c ini}(\text{Tab, Fig}) \qquad (14)$$

Where:
f_w is the fraction of surface wetted by irrigation (0 – 1), 0.3 for drip irrigation
$K_{c\ ini}$ (Tab, Fig) is the value of $K_{c\ ini}$ from Table 12 or Figure 29 or 30 (Allen *et al.*, 1998).

The value of $K_{c\ mid}$, specific adjustment in climate where RH_{min} differ from 45% or where U_2 is larger or smaller than 2.0 m/s was used. The value of $K_{c\ mid}$ is adjusted as:

$$K_{c\text{-}mid} = K_{c\text{-}mid}\ (\text{Tab}) + \left[0.04(U_2\text{-}2)\text{-}0.004(RH_{min}\text{-}45)\right]\left[\frac{h}{3}\right]^{0.3} \qquad (15)$$

Where:
$K_{c\ mid}$ (Tab) is the value of Kc mid taken from FAO Table (12), Allen *et al.* (1998)

U_2 is the mean value of daily wind speed at 2 m height over the soil surface during the mid- season growth stage (m/s) for 1 m/s <= U_2 <= 6 m/s.
RH_{min} is the mean value for daily minimum relative humidity during the mid-season growth stage 9%), for 20% <= RH_{min}<=80%.
h is the mean plant height during the mid-season growth stage (m) for 0.1 m<h< 10 m.

The value of $K_{c\ end}$ is adjusted as:

$$K_{c\text{-}end}=K_{c\text{-}end}\ (Tab)+\left[0.04(U_2\text{-}2)\text{-}0.004(RH_{min}\text{-}45)\right]\left[\frac{h}{3}\right]^{0.3} \quad (16)$$

2. Dual crop coefficient

The crop coefficient is divided into two parts (Equation). The first part is the basal crop coefficient (K_{cb}) that refers to the crop transpiration component of ET_c when the soil surface is dry but transpiration is occurring at a potential rate, i.e., water is not limiting transpiration (Allen *et al*., 1998). The second part is the soil evaporation coefficient K_e that describes the soil evaporation component of ET_c.

Similar to the single crop coefficient approach, a correction equation is used to determine K_{cb} in mid- and end-season stages of sunflower through the following equations:

$$K_{cb\text{-}mid}=K_{cb\text{-}mid}\ (Tab)+\left[0.04(U_2\text{-}2)\text{-}0.004(RH_{min}\text{-}45)\right]\left[\frac{h}{3}\right]^{0.3} \quad (17)$$

$$K_{cb\text{-}end}=K_{cb\text{-}end}\ (Tab)+\left[0.04(U_2\text{-}2)\text{-}0.004(RH_{min}\text{-}45)\right]\left[\frac{h}{3}\right]^{0.3} \quad (18)$$

The soil evaporation coefficient (K_e) depends on several parameters such as the irrigation period, irrigation depth, soil properties, wetting area, and crop development.

When the soil is wet, evaporation from the soil surface occurs at maximum rate. Therefore, the dual crop coefficient can never exceed a maximum value, $K_{c\ max}$. The K_e can be determined as:

$$K_e = K_r(K_{c\ max}\text{-}K_{cb}) <= f_{ew}\ K_{c\ max} \quad (19)$$

Where:
K_e is the soil evaporation coefficient (-)
K_{cb} is the basal crop coefficient,
$K_{c\ max}$ is the maximum value of Kc following irrigation,
K_r is the evaporation reduction coefficient depends on the cumulative depth of water depleted from the topsoil,
f_{ew} is the fraction of the soil that is both exposed and wetted
The $K_{c\ max}$ range from 1.05 to 1.30 and can be expressed as:

$$K_{c\,max} = \max\left\langle\left[1.2+(0.04(U_2-2)-0.004(RH_{min}-45))(\frac{h}{3})^{0.3}\right]\right\rangle,\{K_{cb}+0.05)\} \quad (20)$$

$$K_r = \frac{TEW\text{-}Di}{TEW\text{-}REW} \quad (21)$$

Where:

TEW is the maximum cumulative depth of evaporation (depletion) from the soil surface layer

REW is the readily evaporable water (mm)

Di is the cumulative depth of evaporation (depletion) from the soil surface layer.

$$f_{ew} = \min(1\text{-}f_c, f_w) \quad (22)$$

$1\text{-}f_c$ is the average exposed soil fraction not covered by vegetation (0.01-1), Table (6)

f_{ew} is the average fraction of soil surface wetted by irrigation (0.01-1)

Table (6). Common values of fractions covered by vegetation (fc) and exposed sunlight(1-f_c), Allen *et al.* (1998).

Crop growth stage	f_c	$1\text{-}f_c$
Initial stage (I)	0.0-0.1	1.0-0.9
Crop development stage (II)	0.1-0.8	0.9-0.2
Mid-season stage (III)	0.8-1.0	0.2-0.0
Late (end) season stage (IV)	0.8-0.2	0.2-0.8

10. Experimental design

A randomized complete block design (RCBD) with five treatments. Irrigation treatments were conducted using a drip irrigation system. The drip irrigation system was divided into three plots (replicates), and each plot had one valve.

11. Statistical analysis

Seed and oil yields were analyzed using a single-factor analysis of variance (ANOVA), and multiple comparisons were done for significant effects among treatment with the least significant difference (LSD) test by SPSS (Windows V18). The analysis was performed at 0.05 probability level of significant. The Duncan's Multiple Range Test was used for comparisons among different sources of variance.

RESULTS AND DISCUSSION

The sunflower growing periods were divided to four stages; initial, development, mid- and late growing stages. The sunflower planting period started on 28 April and was finished on 8 August. Table (7) illustrates the length of growing stages, crop coefficient (K_c) and reference evapotranspiration (ET_0).

Table (7). Growth period, crop coefficient and reference evapotranspiration of sunflower

Growth stage	Period length (days)	K_c value	ET_0 (mm)
Initial stage (I)	20	0.35	87.2
Crop development stage (II)	25	0.75	142.7
Mid-season stage (III)	38	1.15	182.0
Late (end) season stage (IV)	20	0.35	93.5
Total	103		505.4

1. Reference Evapotranspiration (ET_0)

The daily ET_0 was calculated according to the FAO Penman-Monteith equation (Allen *et al*., 1998). During the sunflower growing season, the daily ET_0 varied from 3.21 to 9.97 mm/day with an average of 4.91 mm/day and total value of 505.4 mm/season. The variation of ET_0 during the growing period is illustrated in Figure (1).

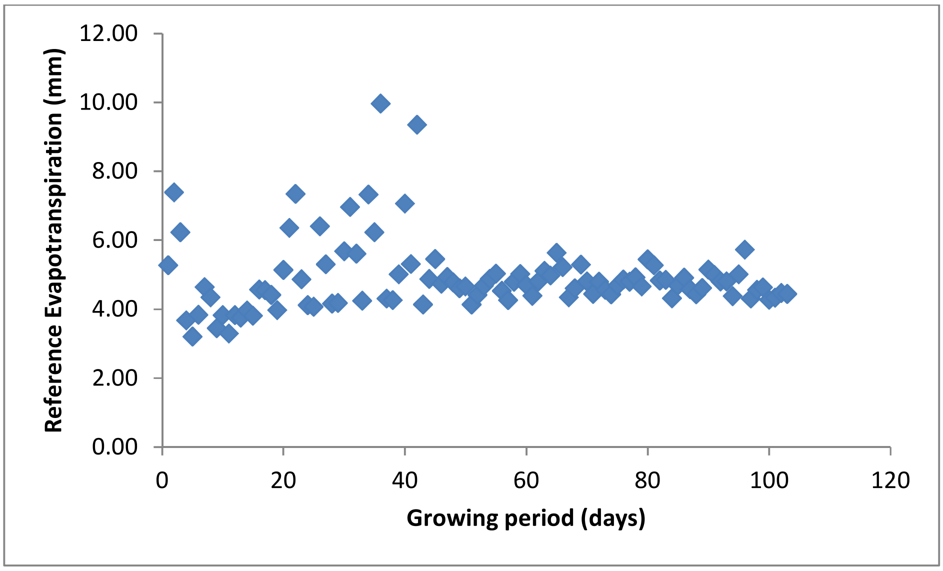

Fig. (1). Daily variation of reference evapotranspiration during growing period of sunflower

2. Crop evapotranspiration (ET_c) of sunflower
1. FAO single crop coefficient (K_c)

The daily sunflower evapotranspiration (ET_c) using standard single crop coefficient is illustrated in Figure (2).

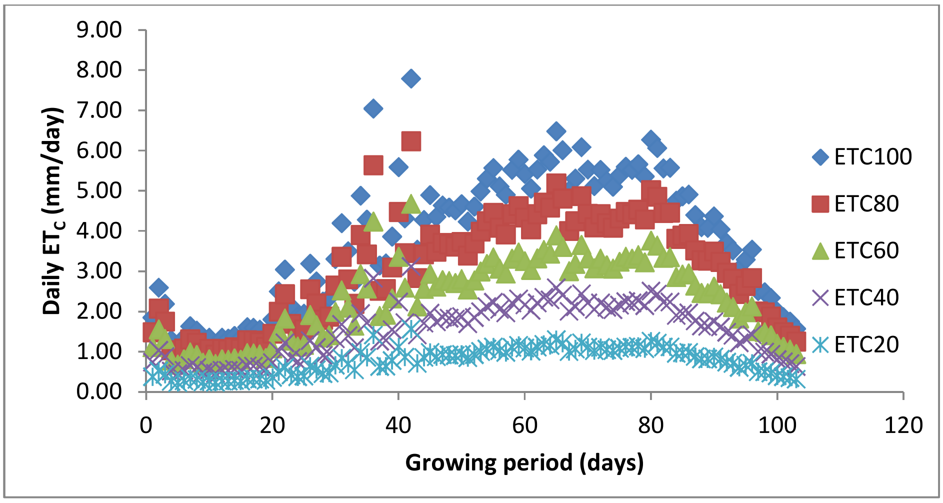

Figure (2). Daily variation of sunflower crop evapotranspiration (ET_c) with irrigation regimes using single crop coefficient.

Table (8) shows the sunflower crop evapotranspiration during initial, development, mid- and late growth stages according FAO standard approach. The crop evapotranspiration was decreased as water regime (% of ET_0) decreased. The crop coefficient was 0.35, 1.15 and 0.35 for initial, mid- and late growth stages as mentioned by Allen *et al.* (1998).

Table (8). Sunflower crop evapotranspiration(mm/ha) of growth stages with irrigation regimes (Single crop coefficient standard FAO approach)

Growth stage	K_c value (standard FAO K_c)	ET_0 (mm)	100% ET_0 (mm)	80% ET_0 (mm)	60% ET_0 (mm)	40% ET_0 (mm)	20% ET_0 (mm)
Initial stage (I)	0.35	87.2	30.5	24.4	18.3	12.2	6.1
Crop development stage (II)	0.75	142.7	110.2	88.2	66.1	44.1	22.0
Mid-season stage (III)	1.15	182.0	209.3	167.4	125.6	83.7	41.9
Late (end) season stage (IV)	0.35	93.5	68.5	54.8	41.1	27.4	13.7
Total (mm)		505.4	418.5	334.8	251.1	167.4	83.7

The seasonal sunflower crop evapotranspiration (ET_c) according to standard FAO methodology were 418.5, 344.8, 251.1, 167.4 and 83.7 mm for 100, 80, 60, 40 and 20% ET_0 irrigation regimes, respectively (Table 8).

The seasonal crop evapotranspiration (ET_c) of sunflower according to single crop coefficient field approach were 466.2, 372.9, 279.9, 186.5 and 93.2 mm for 100, 80, 60, 40 and 20% ET_0 irrigation regimes, respectively (Table 9). The single crop coefficient was 0.58, 0.89, 1.19 and 0.35 for initial, development, mid- and late growth stages under field conditions.

There are little differences between standard and field approach of crop coefficient, but the initial crop coefficient ($K_{C\ ini}$) is larger in field approach because of field conditions of the present experiment. Generally, crop coefficient depends on weather conditions, growth characteristics and ground cover of sunflower under field conditions.

Table (9). Sunflower actual crop evapotranspiration (mm) of growth stages with irrigation regimes (single crop coefficient field approach)

Growth stage	K_c value (Field approach)	ET_0 (mm)	100% ET_0 (mm)	80% ET_0 (mm)	60% ET_0 (mm)	40% ET_0 (mm)	20% ET_0 (mm)
Initial stage (I)	0.58	87.2	50.6	40.5	30.4	20.2	10.1
Crop development stage (II)	0.89	142.7	128.7	103.0	77.2	51.5	25.7
Mid-season stage (III)	1.19	182.0	216.6	173.3	129.9	86.6	43.3
Late (end) season stage (IV)	0.35	93.5	70.3	56.3	42.2	28.1	14.1
Total (mm)		505.4	466.2	372.9	279.7	186.5	93.2

2. Basal crop coefficient (K_{cb})

The crop coefficient, soil evaporation and dual daily crop coefficient of sunflower crop were obtained during the growing period. The values of basal crop coefficient during sunflower growing period are shown in Table (10). The values were 0.32, 0.69, 1.05 and 0.25 for initial, development, mid- and late growth stages according to FAO standard approach (Table 10).The basal crop coefficient (i.e., transpiration component) gradually increased as the highest value was obtained in the development growth stage. Thus, the transpiration value was decreased during late growing stage. The soil evaporation was differed according to the water regime, it reached 0.61, 0.55, 0.51, 0.43 and 0.34 for 100, 80, 60, 40 and 20% of ET_0. The seasonal crop evapotranspiration (ET_c) of sunflower according to dual crop coefficient standard approach were 484.7, 377.7, 291.0, 184.4 and 99.0 mm for 100, 80, 60, 40 and 20% ET_0 irrigation regimes, respectively (Table 10).

Table (10). Sunflower crop evapotranspiration (mm) of growth stages with irrigation regimes (dual crop coefficient standard FAO approach)

Growth stage	K_{cb} value (standard approach)	ET_0 (mm)	100% ET_0 (mm)	80% ET_0 (mm)	60% ET_0 (mm)	40% ET_0 (mm)	20% ET_0 (mm)
Initial stage (I)	0.32	87.2	58.4	45.7	36.7	24.3	14.1
Crop development stage (II)	0.69	142.7	135.1	103.3	79.9	50.8	27.5
Mid-season stage (III)	1.05	182.0	217.5	164.4	124.5	77.3	40.0
Late (end) season stage (IV)	0.25	93.5	83.7	64.2	49.9	31.9	17.4
Total (mm)		505.4	484.7	377.7	291.0	184.4	99.0

The seasonal crop evapotranspiration (ET_c) of sunflower according to dual crop coefficient field approach were 496.1, 388.9, 288.8, 188.7 and 100.8 mm for 100, 80, 60, 40 and 20% ET_0 irrigation regimes, respectively (Table 10). The dual crop coefficient (field approach) was 0.35, 0.69, 1.09 and 0.35 for initial, development, mid- and late growth stages (Table 11).

Table (11). Sunflower crop evapotranspiration (mm) of growth stages with irrigation regimes (dual crop coefficient field approach)

Growth stage	K_{cb} value (field approach)	ET_0 (mm)	100% ET_0 (mm)	80% ET_0 (mm)	60% ET_0 (mm)	40% ET_0 (mm)	20% ET_0 (mm)
Initial stage (I)	0.35	87.2	58.6	47.1	37.7	24.9	14.3
Crop development stage (II)	0.69	142.7	134.9	106.0	81.7	51.8	27.9
Mid-season stage (III)	1.09	182.0	216.6	168.2	127.1	78.8	40.6
Late (end) season stage (IV)	0.35	93.5	86.0	67.7	52.3	33.3	18.0
Total (mm)		505.4	496.1	388.9	298.8	188.7	100.8

The seasonal crop evapotranspiration (ET_c) of sunflower according to Irrigation field approach was 496.0, 398.1, 299.6, 200.1 and 103.3 mm for 100, 80, 60, 40 and 20% ET_0 irrigation regimes, respectively (Table 12). The crop coefficient was 0.51, 0.90, 1.50 and 0.54 for initial, development, mid- and late growth stages under field conditions.

Table (12). Sunflower crop evapotranspiration (mm) of growth stages with irrigation regimes (Field Irrigation approach)

Growth stage	K_c value (field approach)	ET_0 (mm)	100% ET_0 (mm)	80% ET_0 (mm)	60% ET_0 (mm)	40% ET_0 (mm)	20% ET_0 (mm)
Initial stage (I)	0.51	87.2	44.2	38.4	35.7	28.4	19.5
Crop development stage (II)	0.90	142.7	128.4	104.0	75.3	50.3	22.5
Mid-season stage (III)	1.50	182.0	272.5	217.0	162.8	106.3	53.2
Late (end) season stage (IV)	0.54	93.5	50.9	38.7	25.9	15.1	8.1
Total		505.4	496.0	398.1	299.6	200.1	103.3

The daily sunflower crop coefficient can be calculated by the best fitted polynomial equation (Table 13):

K_c-single(standard) =7.0E-08DAP^4-2.0E-05DAP^3+0.0015DAP^2-0.0184DAP+0.3783 (R^2=0.9700)

K_c-single(field) =3.0E-08DAP^4-1.0E-05DAP^3+0.001DAP^2-0.0113DAP+0.5913 (R^2=0.9688)

K_{cb}-dual(standard)=5.0E-08DAP^4-2.0E-05DAP^3+0.0013DAP^2-0.0159DAP+0.3427 (R^2=0.9695)

K_{cb}-dual(field)=6.0E-08DAP^4-2.0E-05DAP^3+0.0014DAP^2-0.017DAP+0.3762 (R^2=0.9695)

K_c(field irrigation)=8.0E-08DAP^4-2.0E-05DAP^3+0.0017DAP^2-0.0185DAP+0.5215 (R^2=0.9671)

Where DAP is the days after planting

Table (13). Crop coefficient during growth stages according to different approaches

Methods	Initial	Mid-	Late
Single crop coefficient standard approach(K_c)	0.35	1.15	0.35
Single crop coefficient field approach ($K_{c\ adj}$)	0.58	1.19	0.35
Basal crop coefficient standard approach (K_{cb})	0.32	1.05	0.25
Basal crop coefficient field($K_{cb\ adj}$)	0.35	1.09	0.35
Field irrigation approach (K_c)	0.51	1.50	0.54

The results indicated that seasonal sunflower evapotranspiration (mm) has higher value with field irrigation approach and the lower value was for standard FAO single approach. The seasonal evapotranspiration (single crop coefficient approach) was less value than the seasonal evapotranspiration of dual crop coefficient approach.

The seasonal water requirements for sunflower crop with considering the irrigation and soil practices are illustrated in Table (14). The results indicated that water requirements of sunflower growing season were higher with irrigation approach and lower with single crop coefficient approach.

Comparison of the measured single crop coefficient with standard values of FAO showed that, the measured K_c value at the initial stage was higher than the FAO standard value (by about 74.3% higher). The K_{c-ini} greatly depends on the evaporating power of the atmosphere (ET_0), the water supply during a wetting event and the time interval between wetting events. Consequently, the K_{c-ini} is influenced by the different irrigation strategies and soil practices.

Therefore, field management in the present study may not similar to the FAO-56 conditions. The FAO's predicted K_c may not predict the evapotranspiration that occurs in the initial growing stage. The measured value of late stage (K_{c-end}) is larger than proposed value of FAO-56 by about 11.42% (Table 15).

Table (14). Sunflower water requirements (m^3/ha) with irrigation regimes

Growth stage	100% ET_0(m^3/ha)	80% ET_0(m^3/ha)	60% ET_0(m^3/ha)	40% ET_0(m^3/ha)	20% ET_0(m^3/ha)
single crop coefficient standard FAO approach					
Initial stage (I)	378.1	302.5	226.9	151.2	75.6
Crop development stage (II)	1364.7	1091.8	818.8	545.9	272.9
Mid-season stage (III)	2591.8	2073.4	1555.1	1036.7	518.4
Late (end) season stage (IV)	848.6	678.9	509.2	339.5	169.7
Total water requirements	5183.3	4146.6	3110.0	2073.3	1036.7
single crop coefficient field approach					
Initial stage (I)	626.6	501.3	376.0	250.6	125.3
Crop development stage (II)	1593.8	1275.1	956.3	637.5	318.8
Mid-season stage (III)	2682.0	2145.6	1609.2	1072.8	536.4
Late (end) season stage (IV)	870.8	696.7	522.5	348.3	174.2
Total water requirements	5773.2	4618.6	3463.9	2309.3	1154.6
dual crop coefficient standard approach					
Initial stage (I)	723.4	566.0	455.0	301.4	174.6
Crop development stage (II)	1673.4	1279.8	989.3	629.1	340.0
Mid-season stage (III)	2693.7	2036.3	1541.6	957.8	495.8
Late (end) season stage (IV)	1036.1	795.0	618.1	395.5	216.1
Total water requirements	6126.6	4677.0	3604.0	2283.9	1226.5
(dual crop coefficient field approach					
Initial stage (I)	726.0	582.9	466.7	307.9	177.2
Crop development stage (II)	1670.5	1312.2	1011.8	641.6	345.0
Mid-season stage (III)	2682.0	2083.1	1574.0	975.9	503.0
Late (end) season stage (IV)	1065.1	837.9	647.8	412.0	222.7
Total water requirements	6143.6	4816.0	3700.3	2337.4	1247.9
field irrigation approach					
Initial stage (I)	547.7	475.2	441.9	351.7	241.5
Crop development stage (II)	1590.1	1287.9	932.5	622.9	278.6
Mid-season stage (III)	3374.6	2687.3	2016.1	1316.4	658.8
Late (end) season stage (IV)	630.3	479.6	320.2	187.2	100.3
Total water requirements	6142.7	4930.1	3710.7	2478.3	1279.3

Table (15). Seasonal water requirements of sunflower (%) as related to single crop coefficient (FAO standard)

Methods	$100\%ET_0$	$80\%ET_0$	$60\%ET_0$	$40\%ET_0$	$20\%ET_0$
Single standard	100.00	100.00	100.00	100.00	100.00
Single field	111.38	111.38	111.38	111.38	111.38
Dual standard	118.20	112.79	115.89	110.16	118.31
Dual field	115.80	112.80	115.88	110.14	118.27
Irrigation	118.51	118.89	119.32	119.53	123.40

According to FAO-56 method corrected by equation (16 and 17), the sunflower K_{cb} values were 0.32, 1.05 and 0.25 for initial, mid- and late-season stages, respectively. Actually, the measured values of K_{cb} (0.35, 1.09 and 0.35, respectively) were similar to the standard FAO method values. The K_{cb} values are correlated with crop variety, cultivation pattern, crop coverage, soil practices and also the final crop yield. Different field treatments especially short irrigation intervals may keep the soil water content at optimum or higher value may lead to more or less evaporation occurring that affect the K_e and K_{cb} values. The field measurement to predict soil evaporation needs some practices to be more accurate to reduce the measured error.

The soil evaporation, K_c and K_{cb} coefficients are greatly affected by irrigation strategy, canopy coverage, local weather conditions, soil practices and irrigation system, therefore more investigation must be considering in determination of these parameters.

The higher values of sunflower water requirements for dual than single crop coefficients by about 3.1% may be due to more parameters affected the determination of dual K_{cb} than single K_c. Therefore, the values of K_c must be determined for different regions and different agricultural parameters, then local determination of crop coefficient has been recommended. The water requirements of sunflower with field irrigation approach were more than the dual crop coefficient approach by about 3.48% as mean of all water regimes.

The use of crop coefficients presented by FAO-56 (Allen *et al.*, 1998) is common for use with crop water requirements estimation around the world. The present study showed that dual crop coefficient approach is located between the single crop coefficient and field irrigation approaches ($\mp$3.2%). Therefore, dual crop coefficient is the more precise estimation of crop water requirements of sunflower than single coefficient and field irrigation approaches. The presented values of single and dual K_c will be useful in estimating sunflower water requirements of different crop growth stages and irrigation scheduling under semi-arid regions such as the present experimental conditions.

It appears that ET_c estimation of sunflower crop is more accurate by dual crop coefficient approach than those produced by single crop coefficient approach because of using more parameters and taking the soil practices and crop characteristics in consideration. The basal crop coefficient values cannot be proposed for all climates and regions because of different climatic conditions and crop management practice under different regions.

The present study recommended that under the same conditions, the irrigation of sunflower crop must be done according to the dual crop coefficient approach because it is more accurate than single crop coefficient and close up to the field irrigation conditions. Also, the field measurement to predict soil evaporation needs some practices to be more accurate to reduce the measured error.

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الملخص العربي

الاحتياجات المائية لزهرة الشمس باستخدام معاملات المحصول المفرد والمزدوج

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أجريت تجربة حقلية لمحصول زهرة الشمس تحت نظام الري بالتنقيط فى المزرعة البحثية لمحطة التجارب الزراعية لكلية الزراعة (سابا باشا) – جامعة الاسكندرية في منطقة أبيس – مصر خلال موسم الصيف ٢٠١٣م . وكان الهدف من الدراسة هو ايجاد معامل المحصول لمحصول زهرة الشمس تحت نظام الرى بالتنقيط – لتحقيق هذا الهدف تم ما يلي: ١- تحليل قدرة معامل المحصول المفرد والمزدوج المقترح من قبل الفاو لتقييم البخر-نتح والاحتياجات المائية المحلية. ٢- تقدير كمية مياه الرى المطلوبة لمحصول زهرة الشمس تحت نظم الحساب المختلفة. وقد تم زراعة محصول زهرة الشمس صنف سخا ٥٣ فى ٢٨ ابريل وتم الحصاد فى ٨ اغسطس ٢٠١٣ – وقد تم زراعة بذور زهرة الشمس (٥-٤ بذور) فى جور على ابعاد ٠.٣ متر داخل الخط و٠.٦ متر بين الخطوط وقد تم خفها بعد اسبوعين من الزراعة الى نبات واحد فى الجورة. بعد الانبات تم رى التجربة بخمس معاملات للري هى ٢٠، ٤٠، ٦٠، ٨٠ و ١٠٠% من البخر نتح المرجعي· وتوضح النتائج ان البخر-نتح الموسمي كان اعلى قيمة مع برنامج الرى الحقلي طبقا لحالة الرطوبة فى التربة وأقل قيمة مع برنامج معامل المحصول المفرد القياسي تبعا لمقترح الفاو. وقد كانت قيم الاستهلاك المائي الموسمي بطريقة معامل المحصول المفرد القياسي أقل من قيمة الاستهلاك المائي الموسمى مع معامل المحصول المزدوج القياسي. ويظهر من النتائج ان البخر-نتح من محصول زهرة الشمس أكثر دقة باستخدام معامل المحصول

المزدوج عن استخدام معامل المحصول المفرد وذلك بسبب ارتباطه مع عوامل متعددة تأخذ فى الاعتبار خدمة التربة وخواص المحصول. قيم معامل المحصول الاساسي (K_{cb}) لايمكن تعميمها لكل المناطق والنطاقات المناخية لاختلاف الظروف المناخية وادارة المحصول تحت ظروف المناطق المختلفة. وتوصى هذه الدراسة بانه فى مثل الظروف الحالية او الظروف المشابهة فان رى محصول زهرة الشمس يجب ان يتم باستخدام معامل المحصول المزدوج لانه اكثر دقة عن معامل المحصول المفرد وقريب من الظروف الحقلية.