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Estimation of Crop Coefficient and Irrigation Water Requirements of Cucumber Using the Accumulated Heat Units (Hus) in Open Field and Greenhouse Conditions

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ABSTRACT

The present study was conducted to compare the reference evapotranspiration (ETo), crop coefficient (k_c), applied irrigation water (AIW) and water productivity (*WP*) under the open field and greenhouse conditions for cucumber crops. Precise estimation of ETo, k_c, ET_c daily is important to apply water through a drip system in the open field and greenhouse. The ETo was estimated in the open field using "FAO-56 Penman-Monteith method" whereas, inside the greenhouse ETo was estimated using "Makkink FAO-24". The k_c value represents crop specific water use and it is a requirement for accurate estimation of irrigation requirements for cucumber crops. The accumulated heat units (HUs) were used to determine the k_c daily for each growing stage. The results revealed that the monthly ETo values under greenhouse were less than those under open field for all months. Mean values of k_c in the open field during the Four growth stage (Initial, Development, Mid and late stage) was 0.30, 0.60, 1.01 and 0.81 while it was 0.32, 0.79, 1.03 and 0.56 under greenhouse, where the Mid stage recorded the highest value in both cultivation systems. The estimated results of total AIW indicated that significant irrigation water saving occurs through the cultivation of cucumber under the greenhouse as compared to open field cultivation by nearly 33.5 % as the value of AIW inside the greenhouse was 903.9 m^3/fed, while the value outside was 1359.7 m^3/fed. Regarding the *WP* result, values were 33.46 and 15.97 kg/m^3 under the greenhouse and open field conditions respectively.

Keywords: Cucumber; Greenhouse; Crop coefficient; Heat units; Irrigation water requirements; Water productivity

INTRODUCTION

According to Liu *et al.,* (2017), water is the most significant element in the planet and makes up more than 80% of the growing tissue. The amount of water applied during irrigation, the timing and technique of water delivery, as well as the irrigation water's quality, are all crucial factors in plant growth and yield production because they are necessary for most plant functions. There is a need to research irrigation water-saving and management strategies and to use them in a scientific way because water resources are finite globally and are becoming increasingly scarce for irrigation. Because of the limited supply of water in Egypt, farmers must utilize a variety of water-saving irrigation techniques, such as growing crops in greenhouses. Compared to open field agriculture, greenhouse cultivation is a type of farming technology that maintains a controlled or semi-controlled environment suited for optimal crop output. This entails developing an atmosphere conducive to increased productivity at work and improved agricultural growth. In contrast to open fields, greenhouses have different climatic conditions due to the existence of a cover (Hemming *et al*., 2008). Because it is challenging to produce food of high quality year-round in open circumstances, crops should be grown in greenhouses.

The main source of food and nourishment is vegetables. One of the most significant fresh vegetables consumed worldwide, cucumber (Cucumis sativus L.) is grown in open fields and greenhouses. After China, Russia, Iran, and Turkey, Egypt is the fifth-largest producer of cucumbers in the world, with a production volume of roughly 736.54 thousand tons in 2020 (FAOSTAT, 2020). Cucumbers are high in vitamins A and C despite having 95% water content. Fruit juice is frequently utilized in cosmetic products since it has an alkaline pH (Kaygisiz, 2000). Numerous scientific studies on cucumbers have been established because of these traits.

Drip irrigation has been shown to be a successful method for conserving water, and it is a crucial part of greenhouse and open-field cultivation systems that improves water uniformity and increases water use efficiency in a variety of crops, particularly in areas with limited water resources (Megersa and Abdulahi 2015). Studies using drip irrigation on various fruit and vegetable crops revealed increases in production, water savings, higher water use efficiency, and net increases in profit (Tewari *et al.* 2014).

Crop evapotranspiration (ET_c), is a crucial factor in hydrological, environmental, and agricultural studies because it affects how much water a crop needs, when to irrigate it, and how productively it uses water. While crop (ET_c) is calculated indirectly using crop coefficients (Kc) and reference crop evapotranspiration (ETo). Jensen (1968) was the first to use the conversion factor known as crop coefficient (Kc) to compare real crop evapotranspiration to reference evapotranspiration. According to Djaman *et al.*, (2017), the Kc is crop- and growth-stage-specific and is the result of the interaction between crop characteristics, soil moisture status and soil type, crop management practices, canopy and aerodynamic resistance, and climatic conditions such as the amount of energy that is available, the amount of vapor in the surrounding air, the amount of air vapor deficit, etc. The physiological state of plant organs must be considered when developing Kc curves as a function of heat

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unit. Cucumber cultivated under various open field and greenhouse environments has been the subject of substantial research on the HUs and GDD concepts. It is often used to calculate Kc for each growth season.

Reference evapotranspiration (ETo) expresses how weather conditions affect crops' need for water (Wang *et al.*, 2008). The precise measurement of ETo is crucial for the study of environmental effects and global climate change as well as for enhancing irrigation guidance and freshwater utilization (Fan *et al.*, 2016). Among the several ETo equations established and used, the Penman-Monteith reference evapotranspiration approach is widely regarded as the most reliable method for estimating ETo in open field agriculture. An optimal model for ETo estimation for greenhouse cultivations is created with the fewest possible data without compromising the estimation's accuracy (Feng *et al*., 2017). A streamlined empirical model with fewer parameters than other empirical models is the Makkink FAO 24 equation (Makkink, 1957).

To ensure water for agricultural production and boost crop yield, water productivity (*WP*) must be improved (Jacobsen *et al.*, 2012). *WP* is crucial to contemporary agriculture, which tries to maximize yield per unit of water used, primarily during irrigation. When comparing the amount or value of the product to the volume of water supplied to the crop, *WP* with dimensions of kg/m3 is only used. The product's worth may be stated in a variety of ways, including as biomass, grain, or cash (Istaitih and Rahil 2018). Due to the massive amounts of water that the irrigation systems applied during the season, the *WP* decreased (Biradar and Patil 2018).

The objectives of this study were to: (1) estimate the monthly reference evapotranspiration (ETo) in an open field using "FAO-56 Penman-Monteith method" and inside the greenhouse using the Makkink FAO-24 equation. (2) estimate the crop coefficient for each growth stage based on the values of heat units. (3) estimate cucumber water requirements and water productivity under greenhouse and open field conditions.

MATERIALS AND METHODS

1. Study area and data collection

The experimental study was conducted in Talkha city, Dakahlia Governorate, Egypt which is located on flat land at Latitude 31.04 N, longitude 31.38 E and altitude of 17 m above sea level, to compare reference evapotranspiration (ETo), crop coefficient (Kc), applied irrigation water (AIW) and water productivity (WP) for Cucumber crop grown under greenhouse and open field conditions. The study was carried out during the period from the end of February to June, 2023.

The soil type of the field was assessed as sandy clay texture by the Physical and mechanical analysis of homogeneous soil of the experiment at 40 cm depth which is suitable for cucumber growing roots as shown in Table 1. The irrigation water is chemically analyzed as illustrated in Table 2 for the calculation of leaching requirements (LR) of the cucumber crop at the experimental site.

The climatic data for the open field were obtained from NASA POWER (https://power.larc.nasa.gov/data-access-viewer/), whereas, the data inside the greenhouse obtained by using prediction models based on the outside weather data (Wang-Jun and Yu-Haiye 2015) as presented in Table 3. The greenhouse used in this experiment was classified as low technology greenhouse as shown in Figure 1, which has no heating and air ventilation and is manufactured from steel frames covered with transparent plastic roof polyethylene (PE) 130µm thickness, with 2.6 m high, 35 m long and 6.5 m wide 228 m^2 area.

Table 1. Some physical and chemical properties of the homogeneous soil of the experiment were analyzed before cultivation.

Depth	Soil particle size distribution %			Texture	F.C %	P.W.P %	ECe (dS/m)	pH
	Sand	Clay	Silt					
(0-20) cm	56.04	32.17	11.79	Sandy Clay Loam	28.11	14	0.88	8.28
(20-40) cm	46.77	9.78	43.46	Sandy Clay	31.07	15	0.61	8.34

Where, F.C: Field Capacity%, P.W.P: Permanent Wilting Point were determined as percentages in weight%, ECe: Electrical conductivity of the soil saturation extract for a given crop.

Table 2. Some irrigation water's chemical analysis.

pH	ECw (dS/m)	Available nutrients (mg/l)			Soluble cations(mg/l)
		Nitrogen (N)	Phosphorus (P)	Potassium (K)	Na^+
7.21	0.83	363.64	0	3.01	28.11

Where, ECe: Electrical conductivity of the irrigation water.

Table 3. Monthly average climatic parameters for the experimental site of cucumber crop outside and inside greenhouse cultivation.

Months	Average climatic data during the season, 2023								
	Open field					Greenhouse			
	T_{max} (°c)	T_{min} (°c)	RH_{mean}(%)	Wind(m/s)	Rain(mm)	T_{max} (°c)	T_{min} (°c)	Wind(m/s)	Rain(mm)
February	24	9.4	73	4	0	33.3	14.2	0	0
March	24	12.7	64	7.3	0.2	33.2	17.1	0	0
April	23.9	16.3	68	7.6	0.18	33.1	20.2	0	0
May	25.1	19.9	70	6.1	0.25	34.5	23.4	0	0
June	26.6	21.7	71.2	5.8	0	36	24.9	0	0

(a)

(b)

Figure 1. A photograph of the experiment: 336 plants of "cucumber" were grown under the (a) open field and (b) inside the greenhouse.

2. Crop Details

Cucumber plants (*Cucumis sativus L.*) were transplanted in the open field and greenhouse under a drip irrigation system on 23 February, 2023 at a spacing of 1.2 m between rows and 0.4 m between plants in a row, maximum root depth was 30 cm after 105 days from planting date. Cucumber was harvested on 22 June, 2023 with total growing season 120 day. The grown plants were drip-irrigated using one lateral per bed, and one emitter of 4 l/h at 1 bar operating pressure which met the water requirements of the plant and recommended dose of soluble fertilizers with irrigation water. The drip irrigation system application efficiency was determined as 90%.

3. Crop Water-Use Parameters

Solar Radiation (R_s) inside and outside the greenhouse

The daily solar radiation during the experimental period was calculated by the estimation equations (1 and 2) of the cloudiness method outside and inside the greenhouse respectively according to (Allen *et al.*, 1998).

$$R_{s\,(outside)}=(0.75+2*10^{-5}*z)\,R_a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

$$R_{s\,(inside)}=(0.75+2*10^{-5}*z)\,R_a*\tau \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where;

R_s= Daily solar radiation, (MJ/m^2/day)

z= Altitude above sea level, (m)

R_a= Is the estimated external solar radiation, (MJ/m^2/day), which estimated from the solar declination, solar constant and number of the day in the year using the equations that found in FAO56 guideline.

τ=Transmittance of plastic film (polyethylene, PE) for the greenhouse (82%)

Reference Evapotranspiration (ETo)

In the Open Field

The potential evapotranspiration *(ETo)* for the cucumber plants in the open field was estimated by equation (3) based on the "FAO Penman-Monteith method" according to (Allen *et al.*, 1998).

$$ETo_{(P-M)}=\frac{0.408\,\Delta(R_n-G)+\gamma\left(\frac{900}{T+273}\right)u_2(e_s-e_a)}{\Delta+\gamma(1+0.34u_2)}\ldots\ldots\ (3)$$

Where;

ETo is the reference evapotranspiration (mm.day^{-1}), Rn is the net radiation (MJ.m^{-2}.day^{-1}), G is the soil heat flux density (MJ.m^{-2}.day^{-1}), T is the mean daily air temperature at 2m height (°C), U_2 is the wind speed at 2m height, es is the saturation vapor pressure (kPa), ea is the actual vapor pressure (kPa), (es - ea) is the vapor pressure deficit of the air (kPa), Δ is the slope vapor pressure curve (kPa. °C^{-1}) and γ is the psychometric constant (kPa. °C^{-1}).

Inside Greenhouse

The ETo of the grown plant in the greenhouse was calculated by Makkink equation 4 (Makkink, 1957) which was introduced as a simplified version for providing a credible estimate of ETo using only daily R_s and τ observations according to De Bruin (1987).

$$ETo_{Makkink}=0.61\left[\left(\frac{\Delta}{\Delta+\gamma}\right)\left(\frac{R_s}{2.45}\right)\right]-0.12\ldots\ldots\ (4)$$

Where;

ETo = Potential evapotranspiration, (mm/day)

Δ= Saturation slope vapor pressure curve (kPa.°C^{-1})

γ= Psychrometric constant (kPa.°C^{-1})

Heat Units (HU_s)

Heat unit is the accumulation of the growing degree days (GDD), which is a cumulative temperature that contributes to plant growth during the growing season. Cucumber heat units were calculated on a daily basis using the following equation:

$$HUs=\sum_{i=1}^{n}(T_{max}-T_{base}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

Where;

HUs = Heat Units (°C)

n= Number of days

T_{max} = Maximum threshold temperature for cucumber (32 °C).

T_{base} = Base temperature threshold for cucumber (15.5 °C),

The base temperature for calculating growing degree days is the minimum threshold temperature at which plant growth starts. According to FAO (2007) all temperature values exceeding the threshold were reduced to 32 °C, and values below 15.5 °C were taken as 15.5 °C because no growth occurs above or below the threshold (base) temperature values

Crop coefficient (K_c)

Climate, soil moisture levels and plant growth phases all have an impact on cucumber crop coefficient. As the crop matures the ground covering, crop height and leaf area all change. The K_c values fluctuate over the growing season because of variations in evapotranspiration during various growth stages. The K_c values were estimated on daily basis according to Sammis *et al.*, (1985):

$$k_c=0.12+0.00168*HU-2.45*10^{-7}*HU^2-4.37*10^{-10}*HU^3\ldots\ldots\ (6)$$

Where;

k_c = A daily crop coefficient

HU = Heat unit (°C)

Crop Evapotranspiration (ET_c)

Crop evapotranspiration refers to the amount of water that is lost through evapotranspiration, it was computed by multiplying the crop coefficient (k_c) with ETo at different growth stages inside and outside the greenhouse by the following equation according to (Allen *et al.*, 1998).

$$ET_{c}=ETo*K_c\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7)$$

Where;

K_c= Crop coefficient, dimensionless.

ETo = Potential evapotranspiration in the open field and greenhouse conditions, (mm/day).

Crop Water Requirements (CWR)

The daily crop water requirements for cucumber crop in the open field and greenhouse were estimated according to (Cuenca, 1989) using the following equation:

$$CWR=ETo*K_c*k_r\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (8)$$

Where;

CWR = The crop water requirement under a drip irrigation system (mm/day)

ETo = Potential evapotranspiration in the open field and greenhouse conditions, (mm/day).

K_c= Crop co-efficient, dimensionless.

k_r = The reduction factor that reflects the percent of soil covered by crop canopy (taken as 0.7 for cucumber) according to (Masria *et al.*, 2021)

Applied Irrigation Water (AIW)

The leaching requirement (LR) is the water used for salt leaching in the root zone depth. In a drip irrigation system LR is calculated according to (Doorenbos and Pruitt, 1977) by equation 9, and according to the physical and chemical properties of water and soil samples at the experimental site as in Tables (1 and 2) its value was estimated 0.041 which is lower than 0.1, so it wasn't included in the AIW calculation.

$$LR=\frac{ECW}{2Max\,EC_e}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (9)$$

The daily irrigation water for any crop mainly depends on the water transpired by the plant and amount of water evaporating from the soil surface. The amount of applied irrigation water for cucumber crop under the green house and open field conditions was calculated by the following relationship (Howell 2003)

$$AIW = \frac{CWR * A}{1000 * E_a} \ldots\ldots\ldots\ldots\ldots (10)$$

Where;

AIW = The amount of applied irrigation water (m^3/ day)
CWR = The crop water requirement under a drip irrigation system (mm/day)
A = Plant area, m^2 (i.e., spacing between rows, m x spacing between plants, m)
E_a = Water application efficiency of the drip irrigation system (assumed as 0.9) (Clark *et al.*, 2007)

Water Productivity (*WP*)

The water productivity as the ratio of crop yield (kg) to volume of water applied (m^3) to produce the yield (Sharma *et al.*, 2015):

$$WP\ (Kg/m^3) = \frac{\text{Yield (kg/fed)}}{\text{Applied irrigation water (m3/fed)}} \ldots\ldots (11)$$

RESULTS AND DISCUSSION

Estimation of ETo, ET_c and K_c Values in the Open Field and Under Greenhouse Cultivation.

According to the climatic data during the study period, mean air temperature and radiation in the open field and greenhouse from February 23, 2023 to June 22, 2023 showed that the solar radiation component is the main factor influencing the total evapotranspiration as illustrated in Table 4 and Figure 2. It increases from 21.5 to 27.8 and 18.3 to 23.7 MJ/m^2/month outside and inside the greenhouse respectively. The Rs reached the highest values during the months of May and June in both farming systems.

Table 4. Monthly averages of air temperatures and solar radiation inside and outside greenhouse during the experimental period.

Months	Average climatic data during the season, 2023			
	Open field		Greenhouse	
	T_{mean} (°c)	Rs (MJ/m^2/month)	T_{mean} (°c)	Rs (MJ/m^2/month)
February	16.7	21.5	23.8	18.3
March	18.4	23.7	25.2	20.1
April	20.1	26.5	53.3	22.5
May	22.5	27.8	57.9	23.5
June	24.2	27.8	30.5	23.7

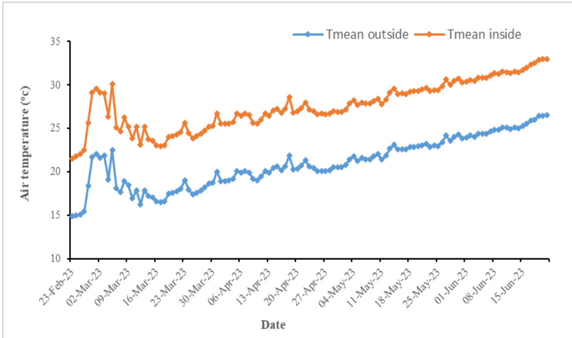

Figure 2. Daily Average air temperature between inside and outside greenhouse (^{0}C).

The monthly reference evapotranspiration (ETo) values under the open field and greenhouse cultivations are shown in Table 5. The average ETo values is low at the begging of growing season and with the increase of sunshine hours and the intensity of radiation along the growing season, the ETo values gradually increased till the peak value of ETo (134.24 and 179.2 mm) in May under greenhouse and open field respectively. Generally, a comparison of total full plant season ETo values of both cultivation systems showed that ETo of greenhouse is always lower than outside due to the reduced evaporative demand inside the greenhouse. And that is probably because of the decrease in solar radiation about (15 % on average) and wind speed is nearly zero inside greenhouse than outside. These findings match with those reported by Möller and Assouline (2007) and Fernández *et al.*, (2010).

The estimated ETo values by (mm/month) were lower for greenhouse cultivation compared to open field cultivation as recorded in Feb 18.3 & 23.6, in Mar 107.8 & 165.4, in Apr 120.3 & 165.8, in May 134.2 & 179.2 and in Jun 94.9 & 138.1 for both systems respectively. These results are in agreement with (Fernandez *et al.*, 2010) who observed that the ETo inside the greenhouses are always lower than outside, also the results in a high match with those reported by (Abdrabbo, 2001) who reported that open field recorded the maximum evapotranspiration along the whole season.

Table 5. Monthly ETo, ET_c and K_c Values of cucumber crop inside and outside greenhouse cultivation

Growing stage	Months	ETo (mm/month)		ETc (mm/month)		HU		K_c	
		Open field	Greenhouse	Open field	Greenhouse	Open field	Green house	Open field	Green house
Initial (20 day)	February	23.67	18.34	3.79	3.66	207.8	239.4	0.30	0.32
Development (30 day)	March	165.45	107.86	74.45	58.24	415.9	693.2	0.60	0.79
	April	165.84	120.38	131.0	122.78				
Mid (50 day)	May	179.23	134.24	195.36	135.58	1197.4	1408.0	1.01	1.03
Late (20 day)	June	138.18	94.95	116.1	55.1	1527.4	1618.5	0.81	0.56
Total		672.37	475.77	520.7	375.37				

Crop coefficient value for cucumber on a daily basis during the Four growth stage (Initial, Development, Mid and late stage) was estimated under greenhouse and open field conditions as presented in Figure 3 and Table 5. The crop coefficient curve showed that a low K_c values in the first phase then increase gradually in the next two phases K_c Dev and (K_c Mid), and again decrease in the late phase as the values of K_c in open field was 0.30, 0.60, 1.01 and 0.81 while it was 0.32, 0.79, 1.03 and 0.56 under greenhouse, respectively. These findings align with those of Blanco and Folegatti (2003) and FAO, Allen *et al.*, (1998) in crop coefficient estimates.

Difference in the crop coefficient values inside greenhouse and open field during the four growth stages is due to the variations in heat units' values needed by the plant along the growing season in both cultivation systems, whereas the total heat units needed by cucumber inside greenhouse was 1618.5oc while in the open field 1527.4oc.

For the whole crop season, the cucumber crop evapotranspiration (ET_c) was calculated on a daily basis both inside and outside the greenhouse, the results are shown in Table 5 and Figure 4. Under greenhouse circumstances, monthly cucumber ET_c values ranged from 3.6 mm in February to 135.5 mm in May, and in the same range from 3.7 mm to 195.3 mm when grown outdoors. The maximum ET_c values were recorded during the Mid stage in the open field than greenhouse. This result is accepted by the results of Möller and Assouline (2007) who found that the cultivated plant inside the greenhouse has a lower monthly ET_c than planted outside.

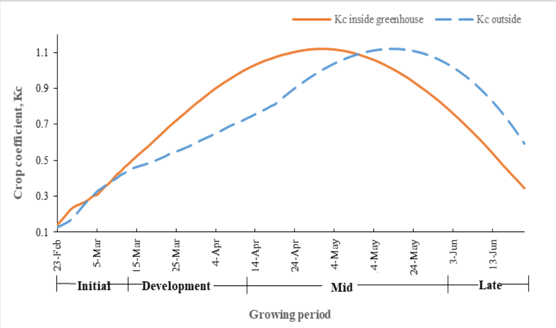

Figure 3. Crop coefficient for cucumber crop inside greenhouse and outside cultivation.

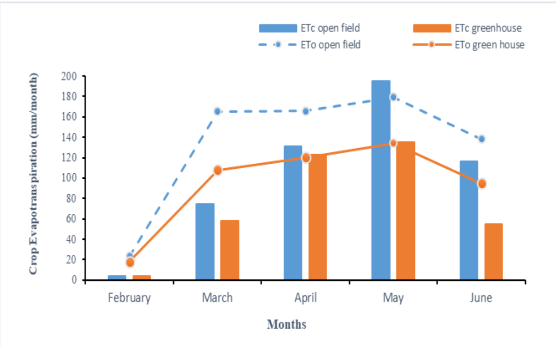

Figure 4. Relationship between ETo and ETc inside greenhouse and outside cultivation.

2. Crop water requirement (CWR) and Applied Irrigation water (AIW) outside and inside greenhouse cultivation.

Cucumber requires a high-water potential for optimal vegetative and reproductive development during the months of April and May in both cultivation systems as shown in Table 6. The total crop water requirement during the whole growing period was 242 mm inside the greenhouse less than CWR 295 mm on the outside. The difference in total CWR values is due to the variation in total ET_o and ET_c between inside and outside the green house. According to the overall findings about the total water requirement, growing cucumbers in a greenhouse instead of an open field result in a significant irrigation water savings as that reported by Santosh *et al.*, (2017).

For cucumber real time irrigation scheduling under open field and greenhouse cultivation, the daily accumulated deficit for the whole season is plotted together with the MAD and rain as illustrated in Figure (5&6).

The grown plants in the open field needed 27 irrigations totaling 319.3 mm/season, whereas, the greenhouse needed 24 irrigations totaling 270.5 mm/season, as the irrigation time was determined when accumulated deficit value is equal to or exceed the management allowable depletion. In both systems of cultivation, as presented in Table 6 and Figure 7 the lowest amount of AIW was applied during the initial stage of plant growth, meanwhile the highest amount of AIW during the Mid stage. The applied irrigation water (AIW) of cucumber plant was 903.9 m^3 /fed during the growing season under the greenhouse cultivation, whereas its amount in the open field cultivation was 1359.7 m^3 /fed. These results explain that the water saving rate might reach 33.5 % according to the difference between the AIW amounts along the growing season under greenhouse cultivation when compared to outside cultivation and the farmers can utilize this water saving rate for irrigating additional areas of crop to enhance their income.

Table 6. Crop water requirement and Applied Irrigation water of cucumber crop outside and inside greenhouse cultivation.

Growing stage	Months	CWR(mm/growing stage)		AIW(m^3/fed)		Water saving rate (%)
		Open field	Greenhouse	Open field	Greenhouse	
Initial (20 day)	February	19.54	12.40	90.46	47.1	47.9
Development (30 day)	March	54.49	59.21	254.8	224.55	11.8
Mid (50 day)	April May	202.67	153.59	945.2	582.45	38.3
Late (20 day)	June	18.28	16.97	69.3	49.8	28.1
Total		295	242.17	1359.76	903.9	33.5

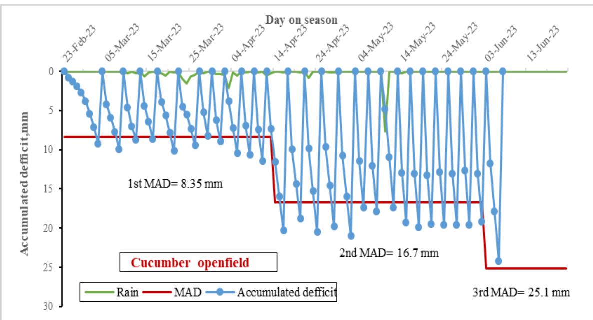

Figure 5. Irrigation scheduling for a cucumber grown outside greenhouse on a sandy clay loam soil during the season 2023.

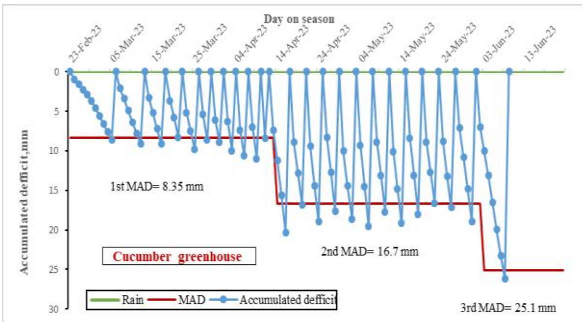

Figure 6. Irrigation scheduling for a cucumber grown inside greenhouse on a sandy clay loam soil during the season 2023.

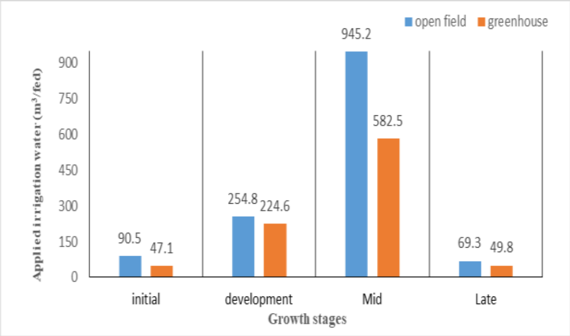

Figure 7. Comparison between applied irrigation for each growing stage inside greenhouse and outside cultivation.

3.Water productivity (*WP*)

The water productivity values were 33.4 kg/m^3 for the greenhouse, however it was 15.97 kg/m^3 for open field conditions. The differences in *WP* values between greenhouse and open fields result from the quantity of yield and total applied irrigation water. *WP* values were increased as the amount of irrigation water supply decreased. These results agree with Pereira *et al.,* (2012) and Masria *et al.,* (2021).

CONCLUSION

The daily reference average evapotranspiration (ETo) under greenhouse circumstances was discovered to be lower than ETo under open field conditions for all months. It is probably because of the greenhouse effect and the low radiation under the greenhouse. In both cultivation systems the crop coefficient (K_c) values during the Mid growth stage recorded the highest value among the different growth stages. The above data of this study concluded that, cucumber production in open field conditions requires a higher crop water requirement of 295 mm as compared to greenhouse cultivation of 242.1 mm, also the greenhouse cultivation technique enhances water saving of the applied irrigation water (AIW) over open field cultivation. The water productivity value inside the greenhouse was higher than in the open field, where, the WP value was 33.46 and 15.97 kg/m^3 under the greenhouse and open field conditions respectively. The water saving rate might reach 33.5 % along the growing season under greenhouse cultivation when compared to outside cultivation and the farmers can utilize this water saving rate for irrigating additional areas of crop to enhance their income. In general, the high productivity of cucumber crop and the considerable saving in irrigation water could be taken as a justification to construct greenhouses.

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تقدير معامل المحصول واحتياجات مياه الري للخيار باستخدام الوحدات الحرارية التراكمية تحت ظروف الحقل المفتوح والبيت المحمي

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الملخص

أجريت هذه الدراسة لمقارنة البخرنتح المرجعي(ETo) ، معامل المحصول(k_c) ، كميات مياه الري الفعلية(AIW) ، وإنتاجية مياه الرى للمحصول (WP) تحت ظروف الحقل المفتوح والبيت المحمي لمحصول الخيار. يعد التقدير الدقيق لـ ETo, k_c, ET_c على أساس يومي أمرًا مهمًا لإضافة كميات مياه الري المناسبة من خلال نظام التنقيط في الحقول المفتوحة والبيوت المحمية. تم تقديرالـ ETo في الحقول المفتوحة باستخدام طريقة "FAO-56 Penman-Monteith" بينما تم تقديرالـ ETo داخل البيوت المحمية باستخدام "MakkinkFAO-24". تمثل قيمة k_c عامل محدد لإضافة المياه للمحاصيل حيث تستخدم فى التقدير الدقيق للإحتياجات المائية للمحصول. تم استخدام الوحدات الحرارة التراكمية (HUs) لتحديد قيمة k_c على أساس يومي لكل مرحلة من مراحل النمو. أظهرت نتائج الدراسة أن قيم ETo الشهرية لمحصول الخيار تحت ظروف البيت المحمي أقل من تلك القيم للنبات المنزرع تحت ظروف الحقل المفتوح على طول موسم الزراعة، كما أوضحت النتائج أن أعلى قيمة لمعامل المحصول كانت خلال مرحلة تكوين الثمار حيث كانت قيم k_c فى الحقل المفتوح خلال مراحل النمو الأربعة ٠,٣٠، ٠,٦٠، ١,٠١ و ٠,٨١ بينما كانت قيمها ٠,٣٢، ٠,٧٩، ١,٠٣ و ٠,٥٦ تحت البيت المحمى. أما بالنسبة للنتائج الخاصة بإجمالي كميات مياه الري الفعلية التى تم إضافتها للمحصول أشارت إلى أن زراعة محصول الخيار تحت ظروف البيوت المحمية أدت إلي توفير كبير في مياه الري مقارنة بزراعته في الحقول المفتوحه بمقدار ٣٣,٥%، حيث بلغت قيمة الـ AIW داخل البيت المحمي ٩٠٣,٩ م٣/فدان، بينما بلغت قيمتها فى الحقل المفتوح ١٣٥٩,٧ م٣/فدان. فيما يتعلق بنتيجة WPكانت ٣٣,٤٦ و١٥,٩٧ كجم/م٣ تحت ظروف البيت المحمي والحقل المفتوح علي التوالي.

الكلمات الدالة: محصول الخيار؛ البيت المحمى؛ معامل المحصول؛ الوحدات الحرارية التراكمية؛ احتياجات مياه الري؛ إنتاجية مياه الرى.