# Predicting Crop Coefficient Values of Cucumber (Cucumis sativus) inside Greenhouse

Ahmed Abied Hamaza
Graduate Student
College of Engineering
University of Baghdad
E-mail:albabele.ahmed@yahoo.com

Asst. Prof. Sabah Anwer Almasraf
Department of Water Resources Engineering
College of Engineering
University of Baghdad
E-mail: Sabah_dawood@yahoo.com

## ABSTRACT

The objective of the study was to predict crop coefficient ($K_c$) values for cucumber inside the greenhouse during the growing season 2014, using watermarks gypsum blocks and atmometer apparatus during the growing stages and to compare the predicted values of the crop coefficient with different methods and approaches. The study was conducted in the greenhouses field within Al-Mahawil Township, 70 km south of Baghdad, Iraq. The watermarks soil water sensors and atmometer apparatus were used to measure crop evapotranspiration and reference evapotranspiration on daily basis, respectively. The comparison and the statistical analysis between the calculated $K_c$ in this study and values obtained from greenhouse gave a good agreement. The root mean square difference (RMSD) and relative error (RE) gave an average value of: 0.065 mm/day and 9%, respectively. While, the comparison between the predicted $K_c$ values and approaches developed by FAO (modified) and Ministry of Water Resources of Iraq gave less agreement. The values of RMSD and RE gave an average value of: 0.188 mm/day, 27%, and 0.17 mm/day and 26.8%, respectively. The method used by FAO and Ministry of Water Resources of Iraq was conducted on basis of using modified empirical equation suggested by FAO-56.

**Key words:** crop coefficient, evapotranspiration, water sensor, atmometer.

## أستنباط معامل الخيار(Cucumissativus) داخل البيوت الخضراء

أحمد عبيد حمزة
طالب ماجستير / قسم هندسة الموارد المائية
كلية الهندسة- جامعة بغداد

أ.م صباح أنور داود المصرف
قسم هندسة الموارد المائية
كلية الهندسة/ جامعة بغداد

## الخلاصة

يهدف هذا البحث الى أستنباط معامل نبات الخيار داخل البيوت الخضراءللموسم الزراعي 2014 بأستخدام متحسسات الجبس وجهاز الاتوميتر خلال مراحل نمو النبات, ومقارنة القيم المستنبطة لمعامل نبات الخيار مع القيم المستنبطة من طرق واساليب مختلفة. تمت الدراسة داخل بيوت خضراء مغطاة في حقل ضمن منطقة المحاويل التي تبعد 70 كم جنوب بغداد- العراق. أستخدمت متحسسات الرطوبة الجبسية وجهاز الاتوميتر لقياس الاستهلاك المائي للنبات والاستهلاك المائي الكامن بشكل يومي على التوالي. أظهرت نتائج المقارنة والتحليل الاحصائي بين قيم معامل النبات المستنبطة في هذه الدراسة مع قيم لطريقة أجريت داخل البيوت الخضراء بتوافق جيد, اذ كان معدل الجذر ألتربيعي للفرق والخطأ النسبي :0.065 ملم/يوم و 9% على التوالي. بينما كانت نتائج المقارنة بين القيم المستنبطة من الدراسة الحالية والقيم المعدلة من منظمة الفاو و وزارة الموارد

المائية في العراق اقل توافقا. كان معدل الجذر التربيعي للفرق والخطأ النسبي :0.188 ملم/يوم و 27% و 0.173 ملم/يوم و 26.8% على التوالي, اذ تم أحتساب قيم معامل النبات اعتمادا على المعادلة الوضعية المقترحة من قبل منظمة الفاو (التقرير 56).

**الكلمات الرئيسية**: معامل النبات, الاستهلاك المائي, متحسسات الرطوبة, الاتموميتر

## 1. INTRODUCTION

The plastic covering utilized on greenhouses significantly changes the radiation balance relative to the external environment, because of the attenuation of the incident solar radiation, resulting in a reduction of the internal radiation balance and, consequently, affecting evapotranspiration ,**Sentelhas, 2001**. The difference between internal and external evapotranspiration varies according to meteorological conditions, usually evapotranspiration inside greenhouses around 60 to 80% of that verified outside , **Montero, et al., 1985 ,Rosenberg, et al., 1985 and Hashem, et al., 2011** studied the effect of polyethylene sheet white, and black net of greenhouse covers, and 80%, 100%, and 120% of potential evapotranspiration (as an irrigation levels), estimated according to class A pan equation on plant growth and crop yield of cucumber. The results showed that white net greenhouse cover optimized growth and yield of cucumber plant. Estimating crop evapotranspiration for specific crops is important for irrigation scheduling and agricultural water management ,**Irmak and Martin, 2005** and **Fernandes, et al., 2003** estimated and compared $ET_o$ by different methods inside and outside a greenhouse. They used A class pan (CAPi), a reduced pan (RPi), and an atmometer (Ai) installed inside a greenhouse, and another class A pan (CAPo) installed outside. $ET_o$ estimates, obtained by CAPi, RPi, and Ai were 56%, 69% and 63% of those estimated by CAPo, respectively. A simple linear regression showed the level of significance coefficients R = 0.94 for the RPi and the CAPi, R = 0.91 for the Ai and the CAPi, R = 0.70 for the CAPi and the CAPo, R = 0.66 for the RPi and the CAPo, and R = 0.62 for the Ai and the CAPo. It is possible to use reduced pans or atmometers to estimate the $ET_o$ inside the greenhouse. **Mujahed, 2007**, in his work measured evapotranspiration and weather parameters for cucumber grown in a greenhouse during the growing season. A model was developed that correlated simple weather data to evapotranspiration for cucumber under greenhouse conditions. **Abedi- Koupai, et al., 2009**, used climate data for calculating evapotranspiration inside greenhouse from indirect methods. They used artificial neural networks (ANNs) to estimate daily grass reference evapotranspiration ($ET_o$) and compared the performance of ANNs with the conventional methods: Penman, Penman-Monteith, Stanghellini and Fynn. Meteorological variables including air temperature, solar radiation, wind speed, and relative humidity were considered daily. The results showed that ANNs, Penman, and P-M models were overestimated ETo, while the Fynn and Stanghellini models underestimated $ET_o$. Crop water requirements, also called crop evapotranspiration, are usually represented as $ET_c$. As $ET_c$ varies with plant development stage and weather conditions, both the amount and timing of irrigation are important. The water balance method of irrigation scheduling is one method of estimating the required amount and timing of irrigation for crops **, British Colombia, 2001** and **Allen, et al., 1998** suggested an empirical equation to adjust the crop coefficient values when air velocity is about 2 m/s and the minimum relative humidity is approximately 45%. Crop coefficient values recommended by FAO for different crops and tress are values under typical irrigation management and soil wetting conditions. Crop evapotranspiration can be observed and measured by monitoring soil moisture content, when no rainfall and irrigation were added to the soil. Soil water status can be measured directly with sensors such as watermark sensors. **Balnco** and **Folegatti, 2003**, predicted crop coefficient values for the cucumber inside a greenhouse during winter-spring season in Brazil. Crop was irrigated with water of three different levels of salinity. The average value of crop coefficient for initial, development, mid-season and late of season was: 0.16, 0.89, 1.4 and 0.6, respectively. **Fathalian** and **Emamzadei, 2013** calculated the evapotranspiration and crop coefficient of greenhouse cucumber by installing two microlysimeters for growing cucumber and grass. Daily evapotranspiration rate of both plants was measured by weighing method. Also, by using meteorological data, recorded inside the greenhouse, $ET_o$ was calculated by using Penman-Monteith equation. They concluded that $K_c$ for cucumber in a greenhouse was 0.14 for initial stage of growth, 0.78 in the development stage, 1.37 in the middle stage, and 0.86 in the last stage. **Fakhri, 2014** predicted crop coefficient values for eggplant and maize in open field based on daily basis using watermark sensors, measuring crop evapotranspiration, and atmometers measuring reference evapotranspiration. The objective of this study was to predict crop coefficient values for the cucumber crop inside the greenhouses through the growing stages. Comparison was conducted between the predicted crop coefficient values with different approaches and models.

## 2. MATERIALS AND METHODS

### 2.1 Location of the Greenhouses Field Study

The research field for this study is located within AL-Mahawil Township, 70 km south of Baghdad. The greenhouse field is located at latitude: 32° 76' N, longitude: 44° 59' E, altitude: 27 m. **Fig. 1** shows a Google map for the greenhouses field site location. The main source of water is from a water pond charged continuously from a local stream from Al- Mahawil River. Three soil samples were taken from two locations in the greenhouse field of cucumber and at layers 0-20 cm, 20- 40 cm and 40- 60 cm. Analyses of soil samples were conducted in the laboratories of the College of Agriculture-University of Babylon. The goal of the analysis was to identify the physical characteristics of the soil in order to determine soil texture and physical properties of the soil which included bulk density, soil texture, field capacity, and permanent wilting point. The soil texture type of the two greenhouse fields is classified as loam soil.

## 2.2 Devices and Equipment

The followings are specifications and description of devices and equipment used in the field work.

### 2.2.1 Atmometer apparatus

An atmometer, the brand name (ETgage), has gained increasing popularity. It is one of the alternative tools that can be used to measure the amount of water evaporated to the atmosphere from a wet, porous ceramic surface. The atmometer consists of a canvas-covered ceramic evaporation plate mounted on a distilled water reservoir. The reservoir capacity is 300 mm as water depth. The fabric covering creates a diffusion barrier (resistance) that controls the evaporation rate and ranging from 112–294 s/m similar to that found in healthy leaves in a well-watered plant community. The green canvas cover that surrounds the ceramic plate mimics the crop albedo so that solar radiation absorption by the ETgage will be similar to the solar radiation received at the crop canopy. In theory, the diffusion barrier of the canvas cover and the stomata resistance of healthy, actively growing, green, and well- watered grass vegetation is assumed to be similar. In the ETgage system, water is provided to the ceramic cup by suction through a glass or plastic supply tube and check valve consisting of a diaphragm mounted in a section of silicon tubing attached at the lower end of the glass supply tube. The ETgage reservoir is ventilated by two holes (1.5 mm diameter) drilled at the upper end of the clear polyvinyl chloride pipe. Distilled water is always used in the ETgage reservoir to prevent accumulation of solutes in and on the plate that can reduce the porosity of the plate and affects the evaporation rate. A sight glass on the water reservoir allows the water level in the reservoir to be read manually. The ETgage is easy to install and requires little maintenance which is typically mounted on a wooden post and to be above the top level of the crop as shown in **Fig. 2**. It should not be installed near tall trees, buildings, or tall crops that may prevent full exposure of the gage to prevailing winds and other environmental factors affecting evapotranspiration.

### 2.2.2 Watermarks soil water sensor

Watermark sensors are widely available and have a number of favorable technical characteristics for on farm use, due to its low cost, ease of installation, and durability. These sensors typically require site calibration of the threshold soil-moisture content to which the soil will be allowed to dry before irrigation will be permitted. The patented watermark sensor is a solid-state electrical resistance sensing device that is used to measure soil water tension. This type of sensor consists of two electrodes embedded in a reference matrix material, which is confined within a corrosion-proof and highly permeable case (unit range from (0-wet- to 200 cb-dry). The matrix material includes gypsum to buffer against the effects of salts and fertilizer, but these sensors do not dissolve like gypsum block sensors. Soil moisture is constantly absorbed or released from the sensor as the surrounding soil moisture conditions change. As the soil moisture changes, the sensor moisture reacts as reflected by the change in electrical resistance between the electrodes. Granular matrix sensors operate on the same electrical resistance principle as gypsum blocks. As the moisture level increases, conductivity increases, and the sensor is calibrated to output the moisture level in terms of soil tension, **McCready, et al., 2009**. Total of three watermark sensors were used in the field area within the root zone of cucumber crop at depths equal 15, 30 and 40 cm.

### 2.3 Description of the Greenhouse

In this study two greenhouses were used each was 56 m long, 9 m wide and 3 m high (or an area of about 500 $m^2$). They were covered by 100 μm transparent polyethylene film treated against ultraviolet radiation. The greenhouse was without heating nor air ventilation. The greenhouse was classified as low technology greenhouse. Trickle irrigation system has been used in the two greenhouses, which was a perfect method for water application and simple in scheduling the irrigation water at low cost. **Fig.3** shows the layout of the greenhouse. The system consists of five double irrigation lines of 55 m long (each). Each line consists of two drip tapes, the distance between two drip tapes 0.3 m (T-Tape). Trickle drip tape contains 500 dripper points along its total length. The dripper points were spaced 0.1 m apart. The discharge of each dripper point was 17 $cm^3$/min. Cucumber crops (*Cucumis sativus*) were planted at a spacing of 0.3-0.4 m and the planted points form rows running parallel to the lines. The irrigation date and duration were scheduled by agricultural advisor responsible for managing the greenhouses. In other words, the greenhouse conditions were uncontrolled in the study. However, in each irrigation process, date, flow rate from the dipper, and time of the irrigation were recorded when possible.

## 3. CALCULATION AND PROCEDURES

Modified or predicted crop coefficient values for the cucumber crop were calculated from water consumption by dividing daily measured crop evapotranspiration ($ET_c$) by reference evapotranspiration ($ET_o$) which is measured from the atmometer as follows **, Allen, et al., 1998.**

$$K_c = \frac{ET_c}{ET_o} \qquad (1)$$

where:

$K_c$ = estimated or predicated crop coefficient,
$ET_c$ = crop evapotranspiration (mm/day), and
$ET_o$ = reference evapotranspiration (mm/day).

The crop evapotranspiration ($ET_c$) was calculated from the following water balance equation:

$$IR - DP - R - ET_c = \Delta\theta \qquad (2)$$

where:
$\Delta\theta$ = change in soil water content in two consecutive days (mm),
IR = irrigation water depth (mm),
DP = deep percolation (mm), and
R = surface runoff (mm).

The water content in the effective root zone was estimated by using watermarks sensors readings throughout the growing season of the cucumber. The water balance equation was applied when there is no irrigation, so Eq. (2) becomes:

$$ET_{c} = \Delta\theta \quad (3)$$

Daily values of reference evapotranspiration ($ET_o$) were calculated on the basis of atmometer readings which equal to the difference between two consecutive readings (mm/day). The crop coefficient value for the cucumber was predicted for each growing stage which are: initial, development, mid of season, and harvest time or end of season, starting from the date of planting till the harvest time. The growing stages (initial, development, mid of season, and late of season) of the cucumber were based on the observation of the crops development in the greenhouses which was similar to the study conducted by Ministry of Water Resources **, Ministry of Water Resources-Iraq, 2014**. The time period of each growing stage was identified depending on an estimation of the percentage of the period length of the cucumber crop stage starting from the planting date till the harvest date, as shown in **Table 1**.

### 3.1 Statistical Analysis Methods

Comparison between predicted $K_c$, local, and international values were conducted on daily basis, monthly, and growing stages. The following parameters were used:

$$RMSD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(yi - xi)^2} \quad (4)$$

$$RE = \frac{RMSD}{xav} * 100 \quad (5)$$

where:

RMSD = root mean square difference (with its optimal value equal to zero),
n = number of observations,
yi = predicted crop coefficient,
xi = local or FAO crop coefficient,
xav = average value of crop coefficient (from local or FAO values), and
RE = relative error (%).

## 4. RESULTS AND DISCUSSIONS

Daily and average values of the predicted crop coefficients ($K_c$) for the cucumber crop throughout the growing stages were plotted as shown in **Fig. 4**. The average value of $K_c$ in the initial stage was about 0.16. The development stage started with an average value of 0.87 and reached a value of 1.23, which was represented the mid-season stage. At the end of the mid-season and beginning of late season, the crop coefficient value decreased to an average value of 0.87 at the end of the late of season. The crop coefficient values suggested by FAO **,Allen, et al., 1998** for cucumber crop were for open field conditions and expected for sub-humid climatic conditions. Additionally, $K_c$ suggested by FAO were for typical irrigation management and soil wetting conditions and where the wind velocity equal to 2 m/s and minimum relative humidity equal to 45%. For $K_c$ values more or less than the assumed values for wind speed and relative humidity. FAO suggested an empirical formula to be used to correct the $K_c$ values for initial, mid, and late of season and as follows:

$$FAO_{modified} = FAO_{value} + \left(0.04(U_2 - 2) - 0.004\ (RH_{min} - 45)\right) * (\frac{H}{3})^{0.3} \qquad (6)$$

where:
$RH_{min}$= min. relative humidity (%),
$U_2$ = wind speed at 2 m height (m/s), and
H = crop's height (m).

Daily wind speed and minimum relative humidity values were measured inside the greenhouse. The predicted crop coefficient values of the cucumber in the case study were compared with different approaches and models inside the greenhouse. **Table 2** shows the $K_c$ values predicted in the case study, **FAO** (modified) using Eq. 6, **Fathalian** and **Emamzadei, 2013**, and Ministry of Water Resources **, Ministry of Water Resources Iraq, 2014**. The summary of the statistical analyses for the comparison between the predicted $K_c$ and different approaches and models for cucumber inside greenhouses are shown in **Tables 3**, **4**, **and 5.** The values of RMSD and RE for the comparison between predicted and different approaches for the $K_c$ values showed that the approach developed by **Fathalian** and **Emamzadei, 2013** gave an agreement as a first approach with the predicted $K_c$ in the case study for all growing stages. While, the $K_c$ values developed by Ministry of Water Resources-Iraq **,Ministry of Water Resources, 2014,** agreed with the predicted $K_c$ except for the initial stage. Statistical analyses for RMSD and RE showed that $K_c$ values recommended by FAO **, Allen, et al, 1998** rank the third. Moreover, the statistical analyses showed that the adjusted values of $K_c$ by FAO and even by the Ministry of Water Resources – Iraq were unsatisfactory for the following reasons:

- Low technology of the greenhouses where there were no ventilation, air exchange, and uncontrolled temperature, effect the adjustment of $K_c$ values.
- Water management and method of applying water.
- Height and density of crop.
- Number and surface area of the crop's leaf.
- Starting time of the growing season.
- Crop's height and if the crop was vertically supported or grows on the ground surface.

**Fig. 5** shows a comparison among the crop coefficient values for the cucumber for different models inside the greenhouses for the growing stages.

## 5. CONCLUSIONS

The calculated $K_c$ values and the values estimated by **Fathalian** and **Emamzadei, 2013** agreed well. The statistical analyses using RMSD and RE gave an average value of: 0.065, 9%, respectively. While, the comparison between the predicted $K_c$ values and approaches developed by FAO (modified) and Ministry of Water Resources of Iraq **,Ministry of Water Resources – Iraq, 2014,** gave an fair agreement. Values of RMSD and RE gave an average value of: 0.188, 27%, and 0.17 and 26.8%, respectively. Where the methods used by FAO and Ministry of Water Resources of Iraq was conducted on basis of using Eq. (6), **Allen, et al., 1998**, and measuring weather parameters inside the greenhouses. Accurate values of the crop coefficient could be obtained from the ratio of crop evapotranspiration and reference evapotranspiration. The trend and variation of the crop coefficient for cucumber inside and outside greenhouses is affected by many factors due to followings: type of technology used inside greenhouse, type of the greenhouse's shaded cover, type of crop (height, density, leaf area), and irrigation management.

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**NOMENCLATURE**

DP = deep percolation (mm).
$ET_c$= crop evapotranspiration, mm/day.
$ET_o$= reference evapotranspiration, mm/day.
H = crop' height (m).
IR = irrigation water depth (mm).
Kc = crop coefficient.
n = number of observations.
R = surface runoff (mm).
RE = relative error (%).
$RH_{min}$= min. relative humidity (%).
RMSD = root mean square difference.
$U_2$ = wind speed at 2 m height (m/s).
xav = average value of crop coefficient.
xi = value of crop coefficient.
yi = predicted crop coefficient.
$\Delta\theta =$ change in soil water content in two consecutive days (mm).

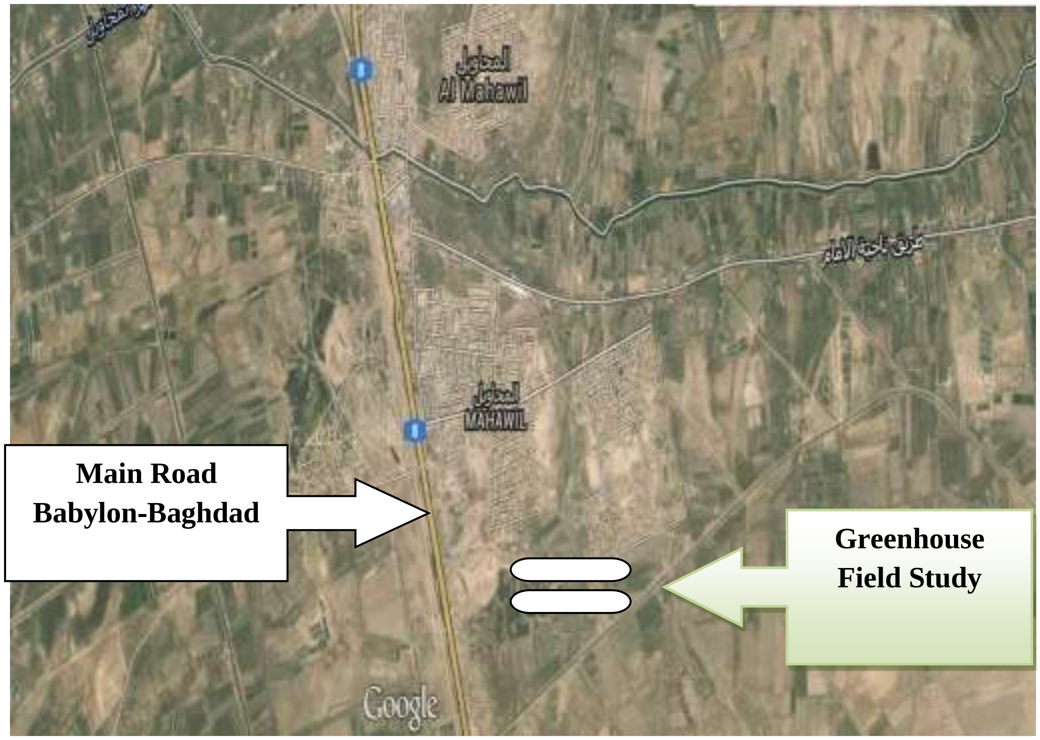


**Figure 1.** Google map for the research site work.

**Figure 2.** Location of the atmometer apparatus in the cucumber's greenhouse.

**Figure 3.** Layout of the greenhouse.

**Table1.** Estimation of the period and percentage of the growing stage of cucumber.

| **Stage and period** | **Initial** | **Development** | **Mid-season** | **Late season** |
|---|---|---|---|---|
| Growing stage (%) | 19 | 27 | 38 | 16 |
| Stage period (day) | 21 | 31 | 43 | 18 |

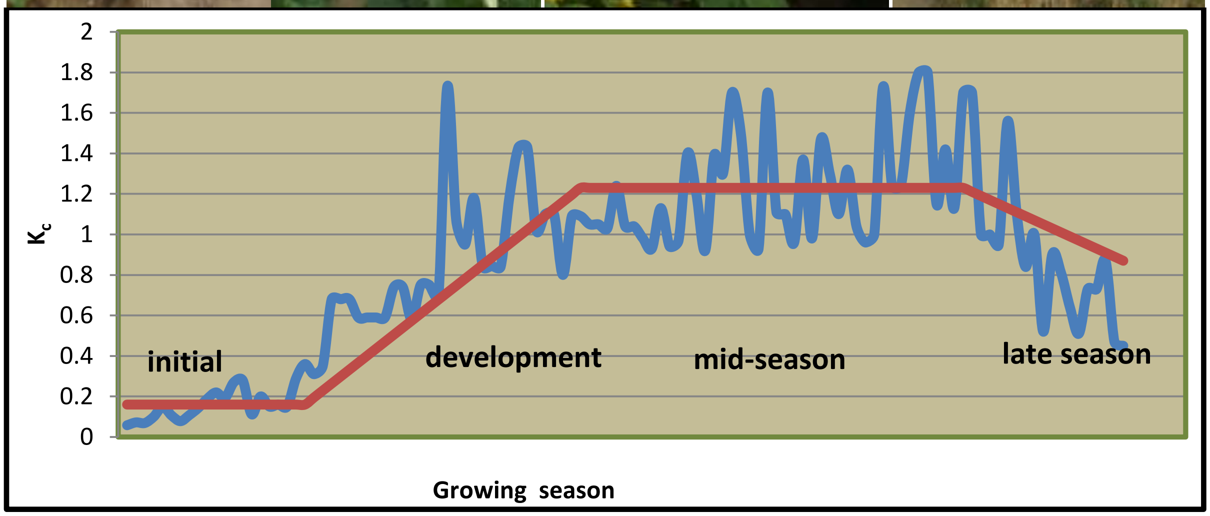


**Figure 4.** Daily and average values of the cucumber's crop coefficient throughout the growing season, 2014.

**Table2.**Crop coefficient values of the cucumber inside the greenhouse as predicted in the case study, Fathalian and Emmazadei, Ministry of water Resources and FAO (modified).

| Approach and model | Growing season -$K_C$ | | | |
|---|---|---|---|---|
| | Initial | Development | Mid-season | Late-season |
| Case study | 0.16 | 0.87 | 1.23 | 0.87 |
| Fathalian,and Emamzadei (2013) | 0.14 | 0.78 | 1.37 | 0.86 |
| Ministry of Water Resources- Iraq ,2014 | 0.45 | 0.75 | 0.98 | 0.85 |
| FAO (modified) | 0.15 | 0.6 | 0.97 | 0.66 |

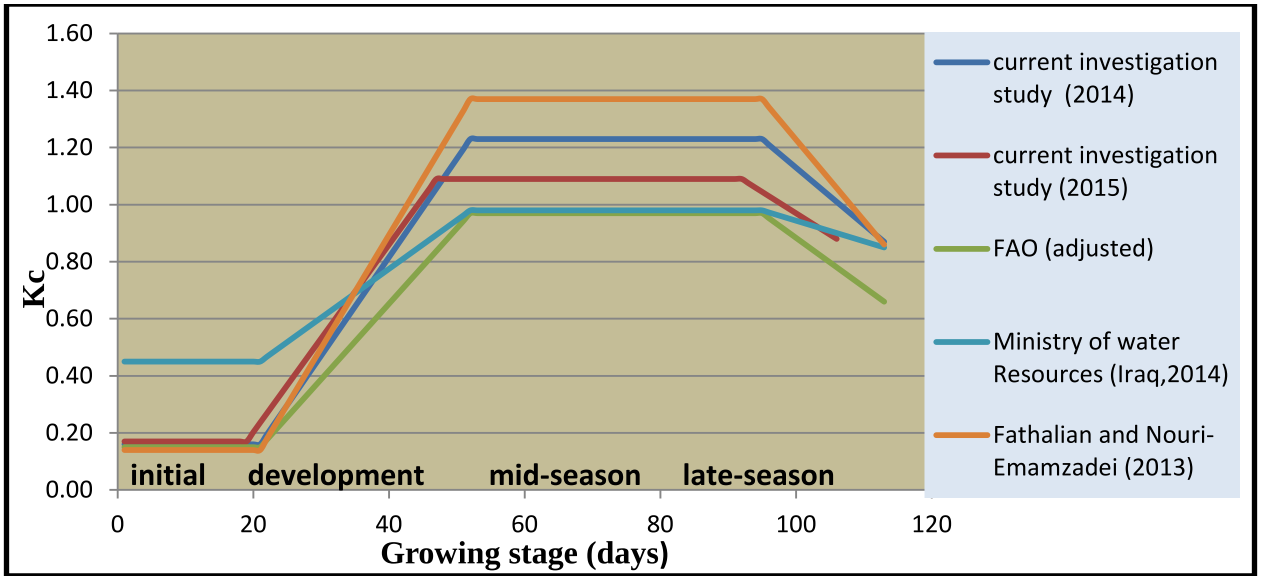


**Figure 5.** Comparison of the crop coefficient values for the cucumber inside greenhouse.

**Table 3.** Root mean square difference and relative error between predicted $K_c$ and the FAO (modified) values.

| Growing stage | RMSD | RE (%) |
|---|---|---|
| Initial | 0.01 | 6 |
| Development | 0.27 | 45 |
| Mid of season | 0.26 | 26 |
| Late of season | 0.21 | 31 |
| Average | 0.188 | 27 |

**Table 4.** Root mean square difference and relative error between predicting $K_c$ and the values from **Ministry of Water Resources- Iraq, 2014**.

| Growing stage | RMSD | RE (%) |
|---|---|---|
| Initial | 0.29 | 64 |
| Development | 0.12 | 16 |
| Mid of season | 0.25 | 25 |
| Late of season | 0.02 | 2 |
| Average | 0.17 | 26.8 |

**Table 5**. Root mean square difference and relative error between predicting $K_c$ and from **Fathalian** and **Emamzadei, 2013**.

| Growing stage | RMSD | RE (%) |
|---|---|---|
| Initial | 0.02 | 14 |
| Development | 0.09 | 11 |
| Mid of season | 0.14 | 10 |
| Late of season | 0.01 | 1 |
| Average | 0.065 | 9 |