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# Determination of Crop Coefficients and Water Requirements of Cucumber (*Cucumis Sativus*) Under Greenhouse Conditions

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**ABSTRACT**

This study investigated the growth-stage-specific crop coefficient (Kc) and consumptive use (CU) of Cucumber plant in the rainforest ecological zone of Ibadan Nigeria. Daily CU and Kc for Cucumber were measured with a well-calibrated weighing lysimeter, from July to September 2021. The CU and Kc were obtained using CROPWAT 8.0. The Kc values for initial, mid and end stages of C. sativus growth were found to be (0.45-0.72); (0.71- 1.38); and (0.38 and 0.71) respectively for the two lysimeters. The seasonal crop water needed for the Cucumber (Cucumis sativus) was 422.32- 446.32 mm and the reference evapotranspiration increased from July to September from 5.31mm/day to 6.65mm/day. The monthly CU of Cucumber was 228.6 mm/day in June, with an increasing reference evapotranspiration from 2.98 mm.day-1 in July to 3.18 mm.day-1 in August. The daily CU moved from 2.16 mm.day-1 in July to a peak of 4.03 mm.day-1 in August in the growing period. The monthly CU increased from 64.80 mm. month-1 in July to 120.90 mm. month-1 in August. All these are based on values obtained within the greenhouse. These findings offer a helpful guide for precisely applying water to places surrounding Ibadan and comparable agroecological characteristics.

**KEYWORDS**

Consumptive use
Crop coefficient
Cucumis sativus
Greenhouse
Lysimeter

## 1. INTRODUCTION

Water is an important resource in rainfed or irrigated open fields or agricultural activities in a controlled environment. More importantly, a good understanding of crop water requirements is essential to effective farming since it has a major impact on overall production. Any savings made through self-water management methods lower the cost of essential inputs like water, which is limited, can help to protect agricultural yields and lead to an increase in income gained indirectly (Singh et al., 2016; Samudro et al., 2023).

Cucumber (*Cucumis sativus*) is a widely cultivated creeping vine plant in the *Cucurbitaceae* gourd family that bears cucumiform fruits, which are used as vegetables. Considered an annual plant, there are three main varieties of cucumber - slicing, pickling, and burpless/seedless - within which several cultivars have been created. The cucumber is a creeping vine that roots in the ground and grows up trellises or other supporting frames, wrapping around supports with thin, spiralling tendrils. The plant may also root in a soilless medium, whereby it will sprawl along the ground in place of a supporting structure. The vine has large leaves that form a canopy over the fruits. (Mariod et al., 2017).

There is continuous competition between agriculture, industry, and domestic water use, with almost 70% of consumption of freshwater worldwide accounted for by agriculture, which is undoubtedly the greatest user of water. (Raphael et al., 2018; Ogbozige and Alfa, 2019). Water demand is increasing on a global scale as a result of increased competition and the need for it by humans, crops, and animals, as the effects of climate change begin to increase. Crops need water to grow, to transport nutrients from the soil, and to maintain cell integrity. As people have become more aware of the growing impact of environmental stress, attempts have been made around the world to adapt agricultural output to severe environmental conditions, concentrating only on reducing quantitative yield loss (Godfray et al., 2010). Knowing how to use water efficiently in a crop production system is therefore critical to water resource management (Oyedokun et al., 2023).

Evapotranspiration (ET) is an important part of the water cycle in the global terrestrial ecosystems (Niu et al., 2024). Estimating evapotranspiration from vegetated surfaces is a fundamental tool for estimating crop consumptive use (CU) and irrigation requirement (IR) in crop production (Pereira, et al., 2015). Over the years, there has been a considerable amount of research in this area, which has produced a good theoretical understanding and several practical applications, which have mostly been validated through acceptable field measurements (Igbadun, and Salim, 2011; Raphael et al., 2018; Oyedokun et al., 2023). Due to the difficulties of getting reliable field measurements, prediction methods for crop water requirements are typically used. However, these approaches are frequently used under open field climatic and agronomic settings that are substantially different from those in controlled environments, with the results demonstrating that for all months, the average daily $ET_0$ under polyhouse conditions was observed to be lesser than the open field conditions $ET_0$ (Sharma and Yadav, 2021; El-Fattah et al., 2023). Among the several $ET_o$ equations established and used, the Penman-Monteith reference evapotranspiration approach is widely accepted as the most reliable $ETo$ estimating method in open-field agriculture. An optimal model for $ET_o$ estimation for greenhouse cultivations is created with the fewest data input but reliable estimation accuracy (Feng et al., 2017). A streamlined empirical model with fewer parameters than other empirical models is the Makkink FAO 24 equation (Alexandris et al., 2008).

The screenhouse have unique microclimates that affect Kc of the crop grown in them (Sharma and Yadav, 2021). It was that in most cases models based on internal climatic conditions were in better agreement with measurements that are based on open field or external conditions (Hadah et al., 2020). The shading from the screenhouse structures or covering materials impacts crop water requirement and crop performance in them (El-Fattah et al., 2023; Oyedokun et al., 2023)

The unconventional practice of cultivating crops inside covered structures made partially or completely of transparent

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material is known as greenhouse farming. Greenhouses are primarily used to protect crops from various pests and to create ideal growth conditions (Omobowale, 2011; Akpenpuun et al., 2022). The area of crop cultivation under screens and in screenhouses is constantly increasing worldwide. Screens are used for insect exclusion, frost protection, shading from supra-optimal solar radiation, protection from wind and water saving (Tanny et al., 2018). The design of the frame size, cover material, durability, and level of management and operational technology are all important aspects of this style of farming. When attempting to protect a crop from the damaging impacts of weather, factors like as sunlight exposure, natural ventilation, farm size, heating requirements, condensation runoff, material efficiency, and cost must all be considered (Inas et al., 2017). It is well-adapted to the cultivation of vegetables, flowers, herbs, and small fruits like strawberries.

Within the Cucurbitaceae family, the popular creeping vine plant known as cucumber (*Cucumis sativus*) yields cucumiform fruits that are used as vegetables. It climbs trellises and other supports by its underground roots, encircling them with slender, twisted tendrils. If there is no supporting structure, the plant may spread out across the ground and take root in a soilless medium. A canopy of large leaves covers the fruits that hang from the vine (Mariod et al., 2017; Pal et al., 2020).

The climate change impact on field crops has encouraged protected cultivation through greenhouse farming; however, elevated temperatures in greenhouses result in a high loss of crop water through evapotranspiration (Akpenpuun & Mijinyawa, 2020). The availability of information on the amount of water needed to raise these crops from planting to maturity is crucial, especially where water must be managed through proper irrigation scheduling. Allen et al. (1998) contain the published list of Kc values for different crops at different growth stages under open field conditions and suggested their usage where locally determined values are not available. It was also suggested that experimental determination of Kc values be done under a specific climatic condition for spatial-temporal crop consumptive use determination. Weighing lysimeters have been used in the determination of crop water use of different crops under different conditions (Hochberg et al., 2023). Research on crop coefficients and irrigation scheduling for vegetables on drip irrigation under particular greenhouse conditions in the study location is scarce. To fulfil the increased demand for vegetables, it is imperative to evaluate the cultivation of various crops under various water-saving irrigation techniques. Thus, this study aimed at investigating the location-specific and the growth stage- specific water use of Cucumber (*C. sativus*) in the rainforest ecological zone to ensure optimum production.

## 2. MATERIALS AND METHODS

### 2.1. Experimental site

The study was conducted at the Department of Agricultural and Environmental Engineering, University of Ibadan. The field lies between latitude 7°23'05.2"N and longitude 3°50'09.2"E, at a height of 658 meters above mean sea level. The study area is in a tropical environment with annual precipitation ranging from 1300 to 1500 mm and an average daily temperature of 37.2°C and 65% relative humidity (FRIN, 2019). The experiment was carried out in a (5.8 x 4.0 m) 23.2 $m^2$ with a 2.5 m height greenhouse, with ventilation at the ridge and both sides of the greenhouse. The type of covering materials used was just a mixture of conventional mosquito net type and UV plastic covering materials. These ventilated openings were covered with an insect-proof net of 60 mesh size to prevent the entry of insects.

### 2.2. Soil sample collection

A representative soil sample at a depth of 0-150 mm from a previously cultivated land was obtained from the study site was examined for its physical and chemical properties such as total phosphorus (TN), total nitrogen (TN), pH, and organic carbon (OC), acidity, calcium, magnesium, potassium, sodium, iron, zinc, cation exchange capacity and soil textural classification parameters, bulk density and soil hydraulic conductivity. The pH was determined using a multi-function meter WA-2015). The Bouyoucos hydrometer method was used to determine the soil particle size distribution. The soil's organic carbon content was measured using the procedure outlined in (Eleanor and Gary, 2010). The colorimetric Palintest Photometer 7100 method was used to test TN and TP. Every analysis was completed in compliance with the Standard Procedures for the Analysis of Water and Wastewater. (American Public Health Association. APHA 2005). An atomic absorption spectrometer was used to examine the following metals: Ca, Mg, Na, Fe, and Zn. (AAS SearchTech AA320N, UK). Three separate samples were obtained for each parameter, and the average values were taken. The soil samples were weighed. Flame photometry was used to assess the levels of exchangeable potassium ($K^+$) extracted with HCl solution. Soil CEC was determined by a modified ammonium acetate compulsory displacement method described in Domingues *et al.* (2020). Cation Exchange Capacity (CEC) with ammonium acetate at pH 7.2. The soil sample weights were calculated. Using the gravimetric approach described by Fasinmirin and Adesigbin (2012), the bulk density was obtained with the relation in equation 1. The Walkey Black wet oxidative method was used to determine the OC.

$$\text{Bulk Density } (\rho b) = \frac{\text{weight of oven−dried soil}}{\text{unit volume of the soil}} \quad (1)$$

### 2.3. Lysimeter construction and weighing mechanism

A cylindrical plastic drum with a diameter of 600 mm and a circular cross-sectional area of 0.28 $m^2$ that was obtained locally was used as a weighing lysimeter. The lysimeter tank is 450 mm deep and 3 mm thick walls. The cucumber plant's roots could grow normally and unhindered at the lysimeter depth. According to Fisher (2012), the lysimeter's walls are made of plastic, which reduces heat transfer through conduction. The lysimeter was filled with soil obtained from a nearby cultivated land. To reduce disturbance, soil was carefully collected and placed into the lysimeter. The topsoil was mixed with manure in a ratio of 1:3 (manure: soil) (w/w). There was a tap and drain at the bottom of the lysimeter tank. If needed, the drain mechanism makes it possible to remove any extra water that may have built up in the tank. There was also a rectangular plank base frame to guide the automobile tyre tube on the interior as it was being loaded and to act as the glass tube's (burette) connection point. The frame was made from pipe to prevent shadows from falling on the plants in the soil tank (Figure 1). Three sets of lysimeters were constructed and installed in the screenhouse for the study. Readings were taken in triplicate for the study.

### 2.4. The Weighing Mechanism

A mercury U-tube manometer was used in the hydraulic weighing lysimeter to connect a graduated burette (with an accuracy of 0.1 mm) to a water-filled tube, or float. The burette was linked to one end of the mercury manometer, and the water-filled tube was connected to the other end using a hose with a 7.5 mm diameter. Changes in the lysimeter system's weight are measured by the hydraulic weighing lysimeter. The water-filled tubing serves as a hydraulic load cell, supporting the soil-filled lysimeter tank. The weight on the tubes creates pressure, which causes the water in the U-tube manometer to rise in the tube. The water levels in the graduated burette rise and drop in response to the pressure (Raphael et al., 2018).

The calibration of the weighing mechanism was done by subjecting it to a series of loading and unloading procedures to establish a model for the weighing mechanism. To determine a calibration factor for the average hydraulic output for the tank, a linear regression analysis was performed. Equation 2 represents the linear regression equation.


*Figure 1: The weighing lysimeter setup inside the greenhouse.*

*A – graduated burette*
*B – connection hose between burette and manometer*
*C – hose connecting the automobile tube with the manometer*
*D – soil tank* *E – manometer* *F –frame wood*

$$W = aH + b \quad (2)$$

where: W is the measured output (kg), H is the volume (ml), the calibration slope is denoted by a, and the intercept by b.

The output readings were noted for every weight increment. Each lysimeter's average change in water level (measured in millilitres) was plotted against the rise in weight. Based on previous studies (Igbadun, 2012; Raphael et al., 2018), the lysimeter was separately calibrated. A cucumber was planted inside the lysimeter to test it after calibration. Using a relationship between the height of water in the manometer glass tube and the known weight packed into the lysimeter tank, the lysimeter tank weight was obtained based on the water level in the burette tube on any given day. Weight variations in kg were converted to equal depths of water in mm by dividing the weight change by the inner tank's surface area ($m^2$) and the water's density ($g/cm^3$). The weight of the lysimeter obtained from the regression equation of calibration and their differences were translated to the depth of water in $mm.day^{-1}$ using a factor of 6.04 similar to that used in Igbadun (2012) by dividing the weight change (kg) by the density of water ($g/cm^3$) and the inner tank surface area.

## 2.5. Reference Evapotranspiration Estimation ($ET_0$)

The weather data were collected from using Campbell Scientific Weather station located at the study site within the University campus. The University is located on latitude 07°24N, longitude 03°54 E, and altitude 658m above mean sea level Dew point temperature, relative humidity, precipitation, solar radiation, wind speed, air temperature, and barometric pressure are among the data gathered. With these parameters, the FAO-Penman-Monteith equation (Allen et al., 1998) represented in Eqn. (3) was utilized to estimate the $ET_0$.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3)$$

where: $ET_o$ stands for reference evapotranspiration (mm $d^{-1}$); $R_n$ for net radiation at the crop surface (MJ $m^{-2}d^{-1}$); G for soil heat flux density (MJ $m^{-2}$ $day^{-1}$) = 0 for daily calculations of ET because G is small; T for mean daily air temperature at 2 m height (°C); $u_2$ for wind speed at 2 m height ($ms^{-1}$); es for saturation vapour pressure (kPa); $e_a$ for actual vapour pressure (kPa); ($e_s$-$e_a$) = saturation vapour pressure deficit (kPa); Δ stands for gradient of the saturated vapour pressure-temperature curve (kPa°$C^{-1}$); and the γ for psychometric constant (kPa°$C^{-1}$). The meteorological station data were fed into the CROPWAT 8 model to estimate $ET_o$.

## 2.6. Estimation of Consumptive Use of Cucumber (*Cucumis sativus*)

From July to September, daily evapotranspiration for the cucumber (*Cucumis sativus*) in the lysimeters was recorded and analysed. The experiment was replicated in duplicates with a control pot to compare the setup under monitoring and the unmonitored plants. Two (2) potted plants per pot were planted in case any of them failed. The readings were taken early in the morning to prevent the effect of evaporation on the daily reading. The amount of water evaporated and transpired was determined by calculating the difference in weight from one time period to the next. The changes in water content from one day to the next were determined by calculating the difference in lysimeter weights between 7:00 am and 8:00 am on consecutive days. The period was chosen before the evapotranspiration for the next day began. The following formula was used to determine the daily crop water consumption: (Igbadun, 2012).

$$CU_i = P_i - R_{fi} - D_i - [(W_{i+1} - W_i) *cf] \quad (3)$$

where $P_i$ = Total Rainfall (mm) for the day I recorded in the rain gauge; R = Runoff (mm) for the day I. $D_i$ represents the day's drainage (mm), Weights $W_i$, W, and $CU_{i+1}$ represent the crop water use on day I, $W_i$ = Weight of the lysimeter soil on day I, W = Weight of the lysimeter soil the next day at a 24-hour interval, and cf = A factor translating weight to equivalent depth of water was taken to be 6.04 as stated in (Igbadun, 2012).

Soil-water depletion was determined by the TDR moisture meter readings and replenished by a factor of 1.1 on the same day, to meet the crop evapotranspiration on the next following day. All insignificant parameters outside the ones in the Equation 3 were overlooked and assumed to be zero. Daily ET measured with the lysimeter in the greenhouse was computed as the difference between mass gains and losses in the lysimeter.

## 2.7. Development of the Kc curve

The daily $ET_c/ET_o$ ratio was used to compute each growing stage's crop efficiency (Kc). Following a plotting of the daily crop coefficient $K_c$ against the day after planting, the reference evapotranspiration, $ET_0$, was estimated using the Crop Water Model (CROPWAT 8) and weather station data (Raphael *et al.,* 2018). This was done through the CROPWAT interface that allows weather data to be inputted to obtain $ET_0$.

# 3. RESULTS AND DISCUSSION

## 3.1. Physical and Chemical properties of soil

The results of the physical and chemical examination of the soil utilized to cultivate the cucumber plant is shown in Table 1. The loamy sand soil that was utilized contained 62.0 g/kg of clay, 144.0 g/kg of silt, and 794.0 g/kg of sand. It was discovered that the nutrient content was low; nevertheless, to raise its level, organic manure was added in the ratio 1 to 3(1kg of manure to 3 kg of soil.

### *3.1.1. Calibration of the lysimeter*

Table 2 shows the outcomes of the lysimeter calibration experiment. It was found that when the burette's water level reading drops, so does the cumulative weight on the lysimeter. The regression equation shows a negative slope because burettes are graduated from zero ml at the top to 50 ml at the bottom. Verification of the high linearity of the data suggests a close link between the observed and measured values estimated in the lysimeters during the loading and unloading procedures.

*Table 1: The physical and chemical properties of the soil in the study site*

| Parameters | Mean ± SE |
|---|---|
| pH (H2O) | 6.80 ± 0.03 |
| Organic Carbon g/kg | 24.49 ± 2.09 |
| Total Nitrogen g/kg | 2.25 ± 0.02 |
| Available Phosphorus mg/kg | 14.40 ± 3.08 |
| Exch Acidity (cmol/kg) | 0.55 ± 0.001 |
| Ca (cmol/kg) | 1.57 ± 0.03 |
| Mg (cmol/kg) | 0.99 ± 0.002 |
| K (cmol/kg) | 0.17 ± 0.003 |
| Na (cmol/kg) | 0.14 ± 0.004 |
| Mn (mg/kg) | 22.65 ± 3.01 |
| Fe (mg/kg) | 9.82 ± 1.03 |
| Ca (mg/kg) | 0.82 ± 0.002 |
| Zn (mg/kg) | 3.02 ± 0.001 |
| Silt (g/kg) | 144.0 |
| Clay (g/kg) | 62.0 |
| Bulk density (g/cm2) | 1.67 |
| Sat Hydraulic Conductivity %Vol | 36.8 |

As a result, the lysimeters can identify the components of the soil, plant, and atmospheric system's water balance with sufficient sensitivity while detecting weight differences.

*Table 2: Results of lysimeter calibrations*

| Weight (kg) | Loading (kg) | Unloading (kg) |
|---|---|---|
| 7.4 | 42.6 | 42.8 |
| 9.8 | 37.8 | 39.9 |
| 12.35 | 31 | 32.7 |
| 14.65 | 27.4 | 28.1 |
| 17.35 | 21.2 | 22.4 |
| 19.8 | 17.4 | 17.1 |

The relationship was obtained as:

$$W = -1.2235H + 75.294 \quad (4)$$

$$R^2 = 0.9824 \quad (5)$$

Where H is the water level (mm) in the burette and W is the lysimeter's weight (kg). In Figure 2, the calibration curve is presented.

*3.1.2. Reference Evapotranspiration (ETo)*

The analysed weather data obtained for the study area fitted into CROPWAT 8.0 gave the daily and monthly $ET_o$ for the growing period between July and September 2021, Singh et al., 2016 and are shown in Table 3 with the fully-grown cucumber plant (Figure 3).

*Table 3: $ET_c$ for the growing season of Cucumis sativus in the study site.*

| Month | July | August | September |
|---|---|---|---|
| ETo (mm/day) | 2.98 | 2.92 | 3.18 |
| Growth Stage | Initial | Dev/Mid | End |
| length of days (113 days) | 21 | 74 | 18 |
| Kc for growth stages (inside the greenhouse) | 0.71 | 1.38 | 0.45 |
| ETcrop (mm/day) | 2.16 | 4.03 | 1.43 |
| ETcrop (mm/month) | 64.80 | 120.90 | 42.90 |

## 3.2. Crop coefficient kc of cucumber

The growth period of the studied cucumber was between July, August and September 2021. The polynomial regression equation was used to read the Kc values for the initial, middle, and late stages of the cucumber's growth from the quadratic crop coefficient curve and the R-squared value in Figure 4, The Kc for the cucumber in the lysimeter and found to be 0.71, 1.38 and 0.45 for initial, mid and late stages respectively. These $K_c$ values were close to what was obtained by Fathalian and Nouri-Emamzadei, (2013), who used a weighing lysimeter and meteorological data recorded within the screen house with ETo computed using the Makkink, Hargreaves-Samani, and Penman-Monteith-FAO techniques (Alexandris et al., 2008). For the early, developing, mid, and late stages, they determined the Kc values to be 0.14, 0.78, 1.37, and 0.86, respectively. For the early, mid, and late stages, respectively, the average value of Kc was found to be 0.16, 1.23, and 0.87 in a screen house ETc determination by Hamaza and Almasraf (2015). According to El-Fattah et al. (2023), Egypt's initial, mid, and late phases of cucumber $K_c$ are, respectively, 0.32, 1.03, and 0.56 when grown in greenhouses.

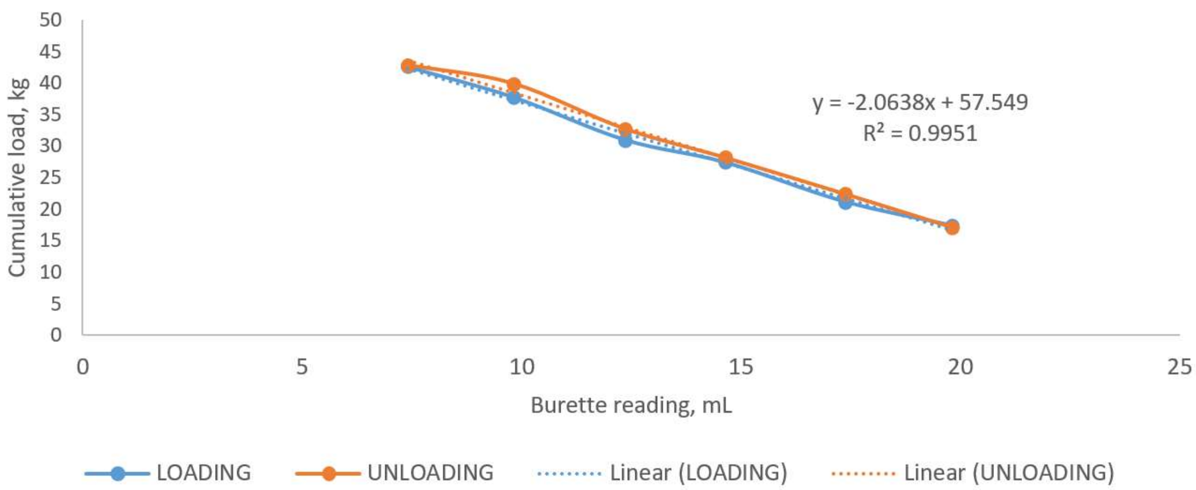


*Figure 2: Lysimeter calibration curve*

Figure 3: Fully-grown cucumber plant in the greenhouse

Throughout the growth season, which runs from July to September, the daily measured CU for *Cucumis sativus* was also noted and computed. Cucumber requires 228.6 mm of water for the entire growing season, but $ET_o$ rose from 2.98 $mmday^{-1}$ to 3.18 $mmday^{-1}$ from July to September. During the growing season, the crop's daily water requirements increased from 2.16 mm/day in July to 4.03 $mm.day^{-1}$ in August, when it peaked, and then decreased to 1.43 mm/day in September. Cucumber's monthly crop water need rose from 64.80 mm/month in July to 120.90 mm/month in August, when it peaked, and then fell to 42.90 mm/month in September.

## 4. CONCLUSION

The results showed $K_c$ to be at its peak during the mid-stage of plant growth when the consumptive use is also at its peak. The air temperature, vapour pressure deficit, and increased amounts of solar radiation during the growth month all significantly enhance the recorded rates of evapotranspiration. The Kc values for initial, mid and end stages of *C. sativus* growth were found to be (0.45-0.72); (0.71- 1.38); and (0.38 and 0.71) respectively for the two lysimeters. The total crop water needed for the whole growing season of Cucumber (*Cucumis sativus*) was 422.32 mm and the reference evapotranspiration increased from July to September from 5.31mm/day to 6.65mm/day. One key observation is the increased water usage during the mid-stage, which coincides with the flowering and maturity stages in the plant growing stages. During this phase, cucumber plants are actively growing, producing flowers, and preparing for fruit production, leading to heightened water demand. In contrast, the initial stage experiences more evaporation than transpiration with a focus on root establishment and initial leaf development, and experiences lower water consumption due to the plant's smaller size and emphasis on the establishment. In the final stage, when cucumber is in the fruiting and harvesting phase, water remains essential, although the demand is not as high as in the mid-stage. It is important to determine Kc from region to region especially when there is time to do so instead of relying on FAO-56 listed values which may not be available for all crops. It also enhances proper irrigation water management under a controlled environment.

## DECLARATION OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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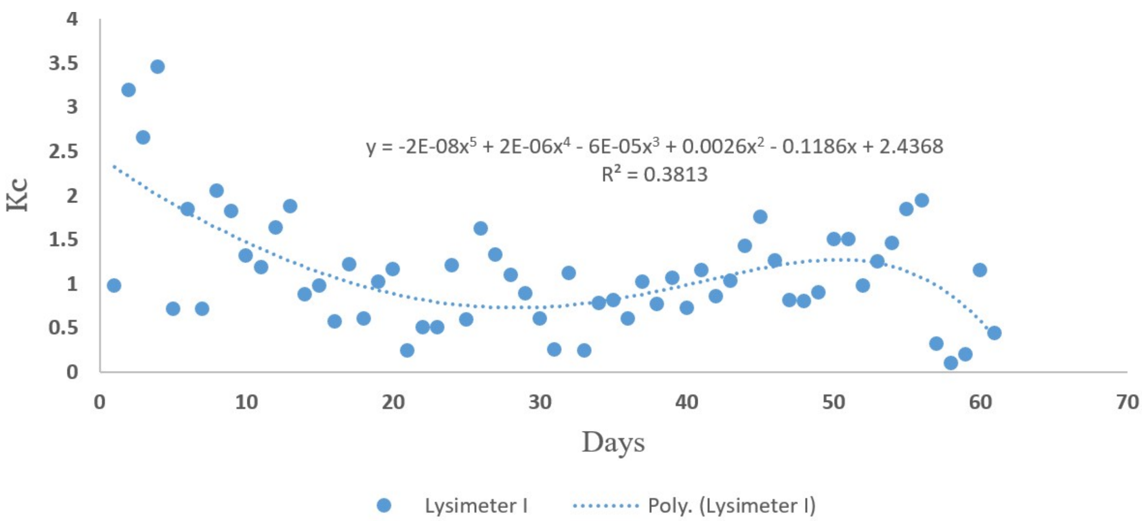


Figure 4: Lysimetric Kc curve of Cucumis sativus for lysimeter one

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