Applying Penman-Monteith Equation to Evaluate the Performance of Atmometer Apparatus in Greenhouse for Estimating Reference Evapotranspiration

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ABSTRACT

In this paper an atmometer apparatus were used in the greenhouses for estimating reference evapotranspiration values. Experimental work was conducted in the agriculture research center in the College of Agriculture-University of Baghdad west of the city of Baghdad. One atmometer was used in eggplant greenhouse and in cucumber greenhouse through the winter growing season 2013-2014. FAO Penman-Monteith equation was applied outside the greenhouse and used only 65% from the value of ET_o in the greenhouses for estimating the reference evapotranspiration in the greenhouse. Moreover, Penman-Monteith equation was applied in greenhouses for the evaluating the performance of the atmometer. The results show that the error analyses between FAO Penman-Monteith equation in greenhouse and the atmometer readings, the root mean square difference (RMSD), mean bias error (MBE) and relative error (RE) for eggplant and cucumber greenhouses were: 1.163mm/day, 0.933mm/day, 30.19%, and 0.688mm/day, 0.518mm/day and 22.93%, respectively. A fair agreement was found. While the error analyses between 65% from outdoor ET_o of FAO Penman-Monteith equation and the atmometer readings, the RMSD, MBE and RE for eggplant and cucumber greenhouses were: 0.930mm/day, 0.743mm/day, 24.27%, and 0.374mm/day, 0.289mm/day and 12.47%, respectively. A good agreement was found. The atmometer apparatus could be used successfully by researchers and farmers in estimation daily or weekly reference evapotranspiration in greenhouses as well as in low technology greenhouses.

Keywords: **G**reenhouse, reference evapotranspiration, atmometer, Penman-Monteith.

تطبيق معادلة بنمان-مونتيث لتقييم أداء جهاز الاتموميتر في البيوت الخضراء لتخمين الاستهلاك المائي الكامن

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الخلاصة

في هذا البحث تم أستخدام أجهزة الاتموميتر داخل البيوت الخضراء لتخمين قيم الاستهلاك المائي الكامن, حيث أجريت الدراسة العملية في المركز البحثي الزراعي التابع الى كلية الزراعة – جامعة بغداد غربي مدينة بغداد. أستخدم جهاز الاتموميترداخل البيوت الخضراء المزروعة بمحصولي الباذنجان والخيار وخلال الموسم الزراعي الشتوي 2013-2014. طبقت معادلة بنمان- مونتيث, وأستخدم منها فقط 65% من القيم المحسوبة للاستهلاك المائي الكامن. بالاضافة الى انه قد استخدمت معادلة بنمان – مونتيث داخل البيت الاخضر وبالاعتماد على المتغيرات الجوية المقاسة داخليا وذلك لتقييم أداء جهاز الاتموميتر. أظهرت التحليلات والمقارنات الاحصائية لقيم الاستهلاك المائي الكامن اليومية من جهاز الاتموميتر ومع مثيلاتها من معادلة بنمان – مونتيث المقاسة داخل البيت الاخضر لنبات الباذنجان والخيار بأن الجذر التربيعي لمعدل مربع الفرق, مطلق معدل الفرق والنسب المئوية للفروقات كانت على التوالي: 1.163 ملم\يوم و0.933 ملم\يوم و 30.19% و 0.688 ملم\يوم و 0.518 ملم\يوم و 22.93%. تشير النتائج الى توافق ضعيف. بينما أظهرت التحليلات والمقارنات الاحصائية لقيم الاستهلاك المائي الكامن اليومية من جهاز الاتموميتر مع مثيلاتها من قيم نسبة 65% من معادلة بنمان – مونتيث الخارجية للبيت الاخضر لنباتي الباذنجان والخيار بأن الجذر التربيعي لمعدل مربع الفرق, مطلق معدل الفرق والنسب المئوية للفروقات كانت على التوالي: 0.930 ملم\يوم و 0.734 ملم\يوم و 24.27% و 0.374 ملم\يوم و 0.289 ملم\يوم و 12.47%. حيث تشير النتائج الى توافق جيد. يمكن الاعتماد على القراءات اليومية أو الاسبوعية لجهاز الاتموميتر من قبل الباحثين والمزارعين لتخمين الاستهلاك المائي الكامن في البيوت الخضراء بالاضافة الى البيوت الخضراء واطئة التكنلوجيا.

الكلمات الرئيسية: البيوت الخضراء, الاستهلاك المائي المرجعي, الاتموميتر, بنمان-مونتيث

1. INTRODUCTION

Evapotranspiration (ET) is one of the major components of hydrological cycle. Accurate estimation of this parameter is essential for studies such as water balance, irrigation system design and management and water resources management. Greenhouses type materials and technology used are also effect on prediction of reference evapotranspiration values**. Fazlil, 2009**, used weighting lysimeter and atmometer apparatus in different types of greenhouses models (low, medium and high technology), and was found to be good reference evapotranspiration (ET_o) equipment in greenhouse which can give accurate measurement of crop (actual) evapotranspiration (ET_c). While FAO Penman model was recommended to calculate ET_o in low technology (plastic) and Hargreaves method in greenhouse with screen cover rather than plastic one. Moreover, Stanghellini model was most accurate method in medium and high technology greenhouses. Reference evapotranspiration inside greenhouses was also estimated by using class A pan, a reduced pan and an atmometer, and another class A pan was installed outside the greenhouses. A good agreement relation was found between atmometer, class A pan and reduced pan, but fair agreement relations was found between class A pan, reduced pan and class A pan outside the greenhouses, **Ferrandes, et al., 2003**. Five methods were evaluated to estimate ET_c in greenhouse conditions and compared their performance in relation to the evapotranspiration directly determined from water balance measurement in an irrigated Lettuce crop during nine weeks. Daily values of the ET_o from class A pan, atmometer,and drainage lysimeter were used between 1993 and 2004 to measure ET_o inside a plastic greenhouse with a perennial grass in south-eastern of Spain. Different methodologies to calculate ET_o were checked against the measurements in the greenhouse with and without whitening. The results show that the performed best in terms of accuracy and statistics were: FAO Penman-Monteith with a fixed aerodynamic resistance, and FAO 24 Pan evaporation method with a constant value. Additionally the Hargreaves and the radiation equations were recommended for the calculation of greenhouse ET_o because of their simplicity, **Fernandez, et al., 2010**. Actual evapotranspiration ET_c for a crop can be found from ET_o and crop coefficient (K_c). **Fahkri, 2014**, predicted crop coefficient values for eggplant and maize in open field based on daily basis using watermark sensors measuring ET_c and atmometers measuring ET_o through the growing stages. The results indicted a good agreement in mid and late of seasons between the predicted, FAO and Russian study K_c values.

In this paper FAO Penman-Monteith equation in the greenhouses and 65% from outdoor ET_o of Penman-Monteith equation were applied in the greenhouses to evaluate the performance of the atmometer for estimating reference evapotranspiration (ET_o) in greenhouse. Weather parameters were measured outside and inside the greenhouse.

2. MATERIALS AND METHODS

2.1 Location of the Field Study

The research greenhouses field for this study was located within College of Agriculture – University of Baghdad in Abu-Ghraib Township, 30 km away from west part of city of Baghdad-Iraq. The site was located at (latitude: 33°12' N, longitude: 44°12'E, altitude: 32m). **Fig.1** shows Google map for the field site location. Two numbers of low technology greenhouses (no automatic ventilation system was available) were used; the approximated total area of the greenhouse was 250 m^2 for each. **Fig. 2** shows the interiors structure of the greenhouses. Eggplant and cucumber crops were used in the study for the winter growing season of 2013-2014. Trickle irrigation system was used in the greenhouses. The laboratory analyzes of the soil samples were conducted in the soil laboratories of College of Agriculture. The objective of the analysis was to verify the physical characteristics of the soil in order to determine the texture of the soil and all physical properties. The soil textures for eggplant and cucumber greenhouses were loam and clay loam, respectively as shown in **Table 1**.

2.2 Devices and Equipment

The followings were specifications and description of apparatus and equipment were used in the study field work.

2.2.1 Atmometer or ETgage

An atmometer, the brand name (ETgage), has gained increasing popularity. It is one of the alternative tools that can be used to measures 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 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 shape of the evaporating surface also helped in easier fabric mounting and maintained better contact between the canvas cover and the ceramic plate. **Fig. 3** shows the main parts of the atmometer. 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 levels in the reservoir to be read manually. Accuracy of daily ET data by reading the plastic sight tube is limited. The ETgage is easy to install and requires little maintenance which is typically mounted on a wooden post with the evaporation surface approximately 1 m above the ground surface or according to the height of crop canopy. **Fig.4** shows the location of the atmometer in the greenhouses.

2.2.2 Hand weather station tool

Scientific Mini Environmental Quality Meter, hand movable weather station tool was used for measuring: air temperature, relative humidity and wind speed in the greenhouse. **Fig. 5** shows mini environmental quality meter.

2.3 FAO Penman-Monteith Model

FAO Penman-Monteith **(Allen, et al., 1998)** simulates a reference crop of 0.12 meter in height. This method estimates evaporation from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and under non-limited soil water. The Penman-Monteith equation for the calculation of daily ET_o (mm/day) is as follow:

$$ET_o = \frac{0.408\, \Delta\, (R_n - G) + \gamma \frac{900}{T_{mean}+273} u_2 (es - ea)}{\Delta + \gamma\, (1 + 0.34 u_2)} \quad (1)$$

Where:

ET_o = Reference evapotranspiration, mm/day.
R_n = Net radiation at the crop surface, MJ m^{-2} day^{-1}.
G = Soil heat flux density, MJ. m^{-2}. day^{-1}.
T_{mean} = Mean daily air temperature at 2 meter height, °C.
u_2 = Wind speed at 2 meter height, m. s^{-1}.
es = Mean saturation vapour pressure, kPa.
ea = Mean actual vapour pressure, kPa.
es – ea = Vapour pressure deficit, kPa.
Δ = Slope vapour pressure curve, kPa $°C^{-1}$.
γ = Psychrometric constant, kPa $°C^{-1}$.

For day and ten-day periods, G is assumed to be zero **(Allen, et al., 1998).**

2.4 Statistical Analysis Methods

In this paper, comparison between estimated reference evapotranspiration from the atmometers, FAO Penman-Monteith equation in greenhouse and 65% from ET_o of FAO Penman-Monteith outdoor equation values **(Fernandez et al., 2010** and **Orgaz et al., 2005)** were conducted on the daily basis through the winter growing season of the eggplant and cucumber. For error analyses the following statistics were used:

$$RMSD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - x_i)^2} \quad (2)$$

$$RE = \frac{RMSD}{Xav} \times 100 \quad (3)$$

$$MAE = \frac{\sum_{i=1}^{n}|(y_i - x_i)|}{n} \quad (4)$$

Where:

RMSD = Root mean square difference.

RE = Relative error, %.
MBE = Mean bias error.
n = Number of daily observations.
x_{av} = Average values of estimated ET_o, mm/day
x_i = ET_o calculating value by using equations in the i^{th}.day, mm/day, and
y_i = ET_o measured by the atmometer in the i^{th}.day, mm/day.

3. RESULTS AND DISCUSSIONS

FAO-Penman-Monteith equation in the greenhouse conditions and 65% from outdoor reference evapotranspiration of FAO Penman-Monteith equation were applied; air temperature, relative humidity and wind speed were recorded daily in the greenhouses, while sun shine radiation, air temperature and all other parameters in the Penman-Monteith equation for the outdoor were provided daily through the winter growing season of eggplant and cucumber crops by the Ministry of Agriculture / Directorate of Planning & Pursuance / Project of Agricultural Weather Forecasting. The materials of the cover used for the greenhouse was white plastic hard sheet; the manufacturer company of the plastic sheet recommend that transmit of the sun shine through the sheet is about 89%. Therefore, the sun shines radiation outdoor will be multiply by 0.89 to get the value in greenhouses. Atmometers readings for eggplant and cucumber greenhouses were recorded on daily basis which represented reference evapotranspiration, starting from 17-2-2014 to 29-5-2014 and from17-2-2014 to 10-5-2014, respectively. **Figs. 6** and **7** shows the daily reference evapotranspiration estimated from atmometers recording, Penman-Monteith equation in greenhouses and 65% from outdoor ET_o for eggplant and cucumber greenhouses through the winter growing seasons of 2014, respectively. The statistical error analysis for comparison between atmometer readings and FAO Penman-Monteith equation in greenhouses for reference evapotranspiration in eggplant and cucumber greenhouses, the following parameters were calculated: RMSD, MBE and RE were: 1.163mm/day, 0.933mm/day, 30.19%, and 0.688mm/day, 0.518mm/day and 22.93%, respectively. The results indicated a fair agreement between the two values. On the other hands, the statistical error analyses for comparison between atmometer readings and 65% from FAO Penman-Monteith outdoor equation for reference evapotranspiration in eggplant and cucumber greenhouses, the following parameters were calculated: RMSD, RE and MBE were: 0.930mm/day, 0.743mm/day, 24.27%, and 0.374mm/day, 0.289mm/day and 12.47%, respectively. The results indicted a good agreement between the two values, especially in cucumber greenhouse. **Figs. 8, 9, 10** and **11** show the statistical error analyses to compare the performance of atmometer readings with the Penman-Monteith equation inside the greenhouse and with the 65% of the outdoor ET_o for the two greenhouses. Comparison between the atmometer readings with the 65% from outdoor Penman-monteith equation, indicated that the atmometer apparatus could be used successfully in estimating the ET_o inside the low technology greenhouses, where no ventilation or automation systems technologies were available. The behavior of the atmometer could be affected by the environmental and weather parameters in greenhouse such as humidity, air temperature, sun shine and vapor pressure. Therefore some of the atmometer readings were higher in some days. Also, water management and quantities of application water could be effected on atmometer's performance.

4. CONCLUSIONS

The conclusions for this paper were:

1- Statistical error analysis from the comparison between atmometer readings and Penman-Monteith equation in greenhouse for reference evapotranspiration show a fair agreement. While, the statistical error analysis from the comparison between atmometer readings and 65% of the outdoor Penman-Monteith equation in greenhouse for reference evapotranspiration show a good agreement.

2- Atmometer apparatus could be used successfully in greenhouses for estimating reference evapotranspiration.

3- Atmometer could be used in a low greenhouse technology satisfactorily.

4- Different percentage values (60-80%) from outdoor Penman-Monteith equation were tested. no clear variation was noticed. The value of 65% was more suitable percentage represented the Penman-Monteith equation inside the low technology greenhouses.

5. A percentage of 65% from outdoor of the Penman-Monteith equation can be applied in greenhouse for estimating reference evapotranspiration using external weather parameters.

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NOMENCLATURE

ET_o = Reference evapotranspiration, mm/day.
ET_c = Crop evapotranspiration, mm/day.
K_c = Crop coefficient, dimensionless.
R_n = Net radiation at the crop surface, MJ m^{-2} day^{-1}.
T_{mean} = Mean daily air temperature at 2 meter height, °C.
u_2 = Wind speed at 2 meter height, m/s.
G = Soil heat flux density, MJ m^{-2} day^{-1}.
ea = Mean actual vapour pressure, kPa.
es = Mean saturation vapour pressure. kPa.
es – ea = Saturation vapour pressure deficit, kPa.
Δ = Slope vapour pressure curve, kPa.°C^{-1}.
γ = Psychrometric constant, kPa.°C^{-1}.
RMSD = Root mean square difference.
RE = Relative error, %.
MBE = Mean bias error.
n = Number of daily observations.

x_{av} = Average values of estimated ET_o, mm/day
x_i = ET_o calculating value by using equations in the i^{th}.day, mm/day and
y_i = ET_o measured by the atmometer in the i^{th}.day, mm/day.

Figure1. Google map for the field study area.

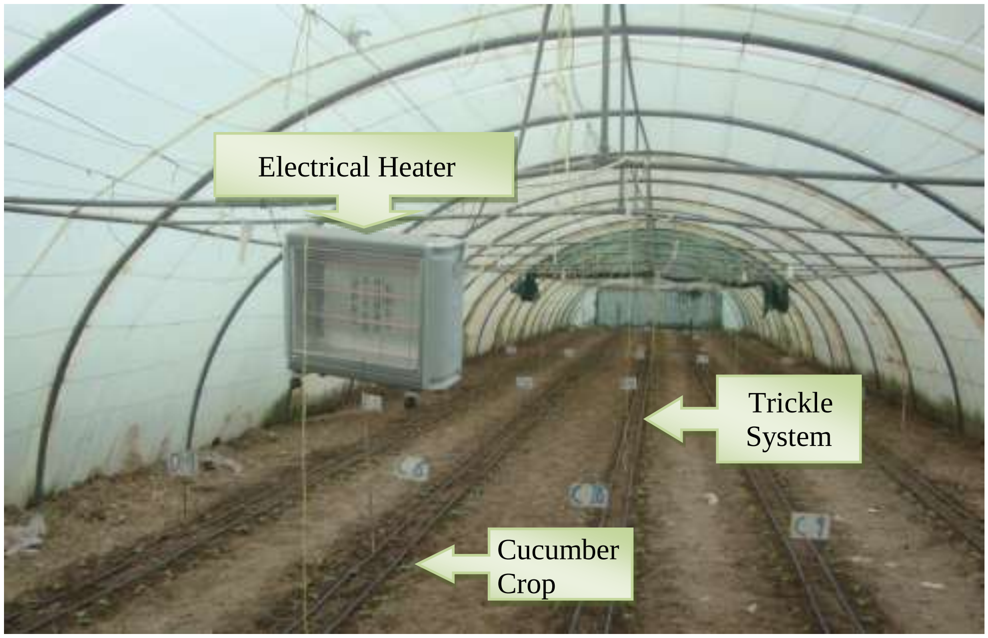

Figure2. Interior structure of the greenhouse.

Table 1. Physical properties for the soil of eggplant and cucumber greenhouses.

Types of test	Specifications of the soil	
	Eggplant greenhouse	Cucumber greenhouse
Bulk (apparent) density (gm/cm^3)	1.245	1.237
Soil texture	Loam	Clay loam
Water content at field capacity (% by volume)	29.30	29.49
Water content at permanent wilting point (% by volume)	15.90	17.01

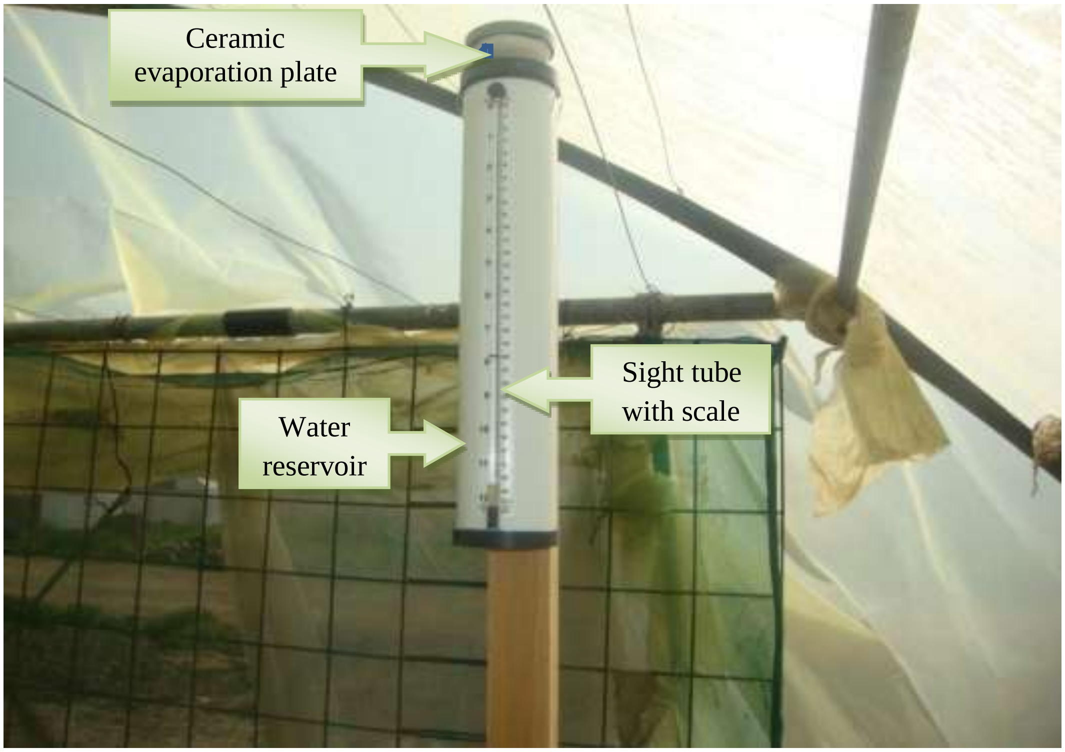

Figure 3. Main parts of the atmometer.

Figure 4. Location of the atmometer in the greenhouses.

Figure 5. Mini environmental quality meter.

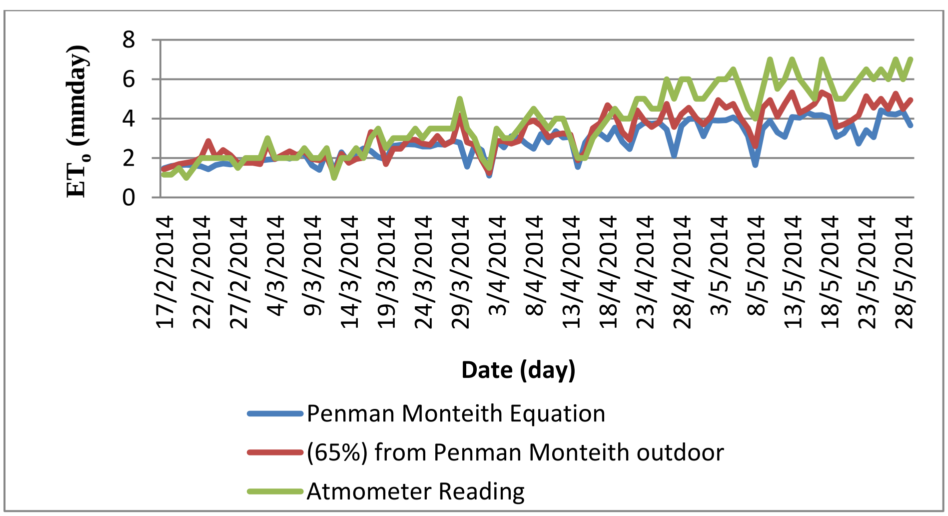

Figure 6. Daily reference evapotranspiration estimated from atmometers readings, Penman-Monteith equation in greenhouses and 65% from outdoor ET_o for eggplant through the winter growing season 2014.

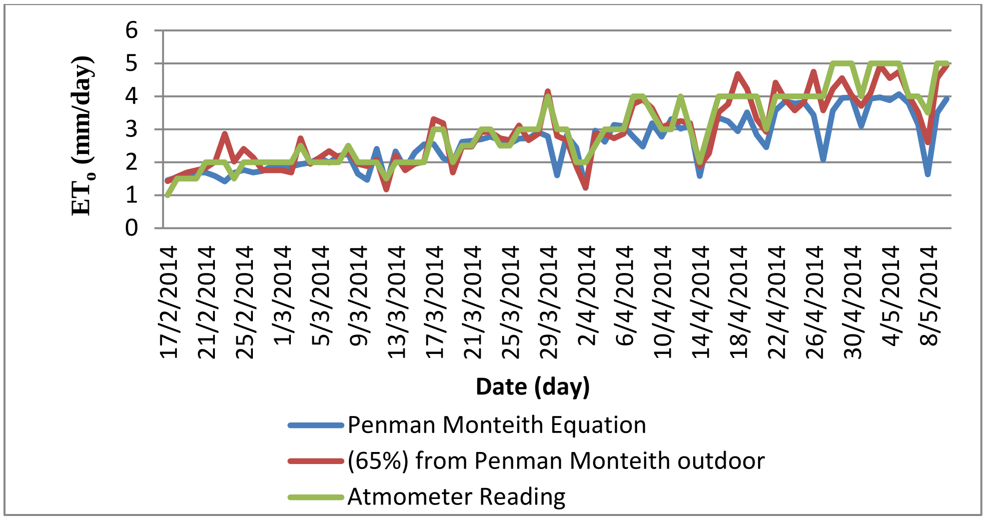

Figure 7. Daily reference evapotranspiration estimated from atmometers readings, Penman-Monteith equation in greenhouses and 65% from outdoor ET_o for cucumber through the winter growing season 2014.

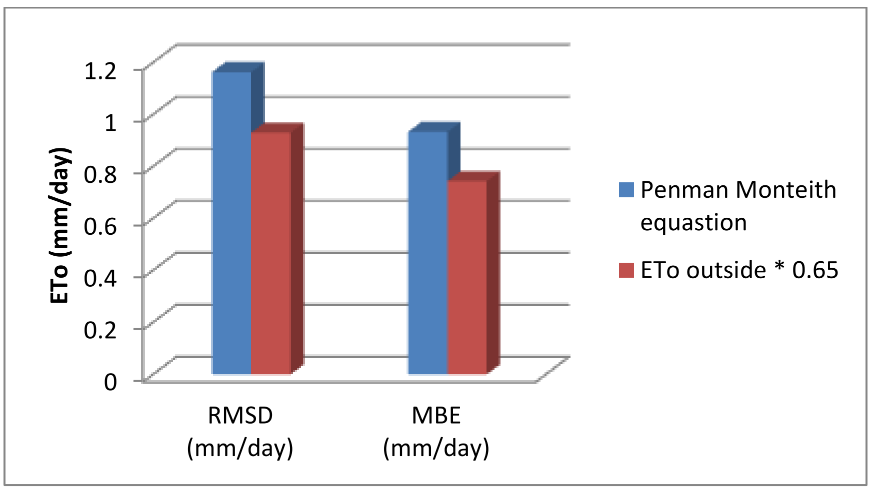

Figure 8. RMSD and MBE error analyses for eggplant greenhouse.

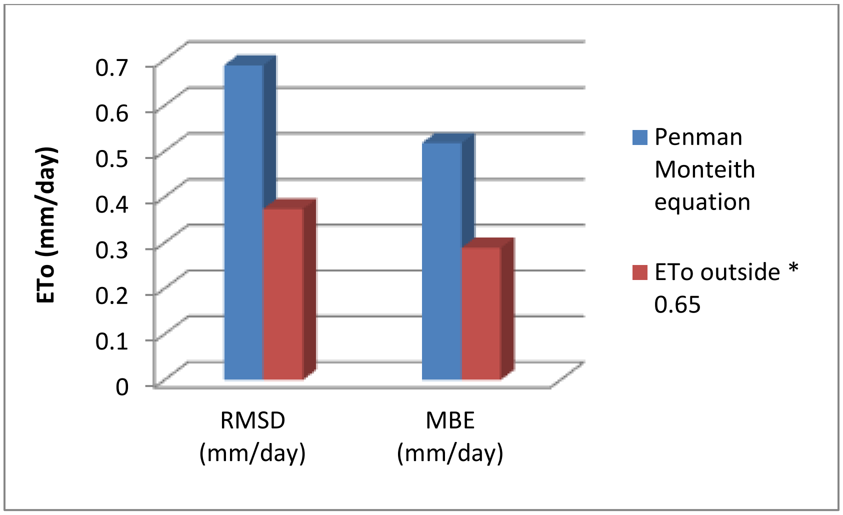

Figure 9. RMSD and MBE error analyses for cucumber greenhouse.

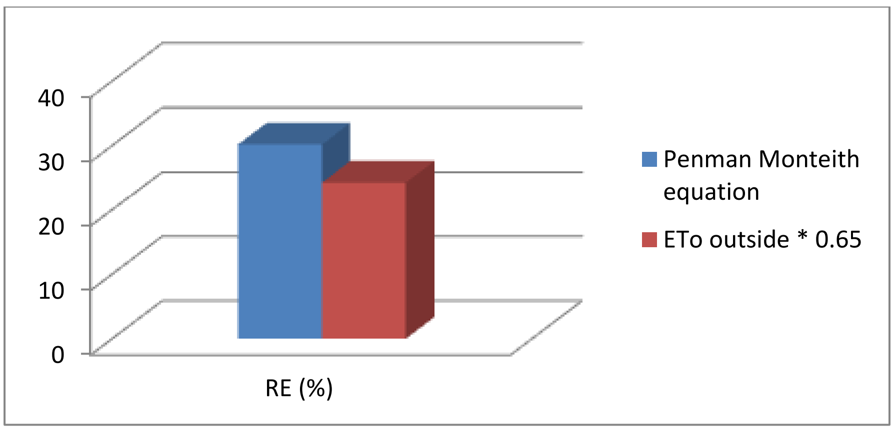

Figure 10. Relative error analyses for eggplant greenhouse.

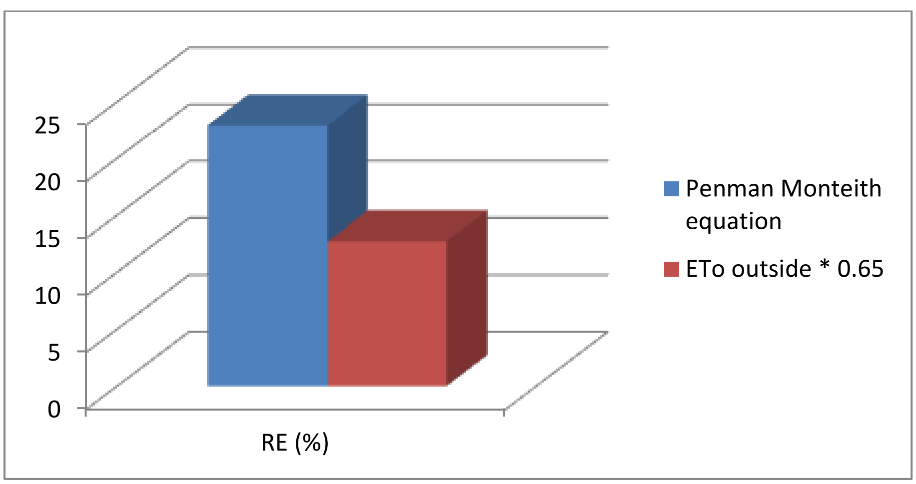

Figure 11. Relative error analyses for cucumber greenhouse.