VALIDATION OF ACCURATE DETERMINATION OF MAIZE WATER REQUIREMENTS IN NILE DELTA

VALIDATION DE LA DÉTERMINATION PRÉCISE DES BESOINS EN EAU DU MAÏS DANS LE DELTA DU NIL

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ABSTRACT

Research on evapotranspiration and crop coefficient provides sound theoretical and practical applications. The region of interest of this study is Zankalon, which is located in the eastern part of the Nile Delta, El-Sharkia, Egypt. The experiment conducted during summer season of 2012. The experiment aimed to determine maize water requirements and compare the water consumptive use and crop coefficient of maize using two methods as follows: i) high precision weighing lysimeter; ii) the eddy covariance. In addition, further analysis of some water relations for maize crop were produced. FAO Penman-Monteith equation provides values more consistent with actual crop water. It is the recommended method for estimating reference evapotranspiration under local climatic data. The results showed that the reference evapotranspiration of maize was about 605.8 mm. Lysimeter data showed that the crop evapotranspiration of maize was 524.5 mm. While, the evapotranspiration derived from the latent heat measured from eddy covariance method was about 347.2 mm. The crop coefficients developed from eddy covariance method were started from 0.50 to 0.58 then 0.62 and at the end 0.60 for initial, development, and flowering and late season of growth stages, respectively. The lysimeter crop coefficient started with 0.55 to 0.86 and 1.11, then 0.85 for the same different maize growth stages. The evapotranspiration derived from latent heat using eddy covariance method and crop coefficient estimated always affected from many agricultural conditions. The crop evapotranspiration and crop coefficient developed from eddy covariance method underestimated by about third of the water consumed and crop coefficient derived from lysimeter method.

RÉSUMÉ

La recherche sur l'évapotranspiration et coefficient de culture fournit des applications théoriques et pratiques. La région d'intérêt de cette étude est Zankalon, qui est située dans la partie orientale du Delta du Nil, El-Sharkia, Egypte. L'expérience a été menée pendant la saison estivale de 2012. L'expérience est destinée à déterminer les besoins en eau du maïs et de comparer la consommation d'eau et le coefficient de culture du maïs en utilisant deux méthodes comme suit: i) lysimètre à pesée de haute précision, ii) eddy covariance. De plus, une analyse plus approfondie de certaines relations de l’eau pour les cultures de maïs a été produite. L’équation FAO Penman-Monteith fournit des valeurs plus conformes avec l'eau réelle des cultures. Elle est la méthode recommandée pour l'estimation de l'évapotranspiration de référence sous les données climatiques locales. Les résultats ont montré que l'évapotranspiration de référence du maïs été d'environ 605,8 mm. Les données lysimétriques ont montré que l'évapotranspiration des cultures du maïs été de 524,5 mm. Alors que, l'évapotranspiration dérivée de la chaleur latente mesurée à partir de la méthode de covariance été d'environ 347,2 mm. Les coefficients de cultures développées à partir de la méthode de covariance ont commencé de 0,50 à 0,58 puis 0,62 et 0,60 à la fin pour les stades de croissance initial, développement et floraison et fin de saison, respectivement. Le coefficient lysimètrique des cultures a commencé avec 0,55 à 0,86 et 1,11, puis 0,85 pour les mêmes

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différents stades de croissance du maïs. L'évapotranspiration dérivée de chaleur latente en utilisant la méthode de covariance et le coefficient de culture estimé sont toujours affectés de nombreuses conditions agricoles. L'évapotranspiration des cultures et le coefficient de cultures développés à partir de la méthode de covariance sous-estiment d'environ un tiers du coefficient de l'eau consommée et du coefficient de culture dérivé de la méthode lysimètrique.

Keywords: weighting lysimeter; eddy covariance; reference and crop evapotranspiration; maize; Egypt

1. Introduction

Maize is the world's third most important crop with the rapid population increase. In Egypt, maize is one of the most important cereal crops. It is a summer feeding crop for human consumption, animal and industrial purpose especially for oil production. However, there is a gap between the local production and consumption of maize. Agriculture sector in Egypt consumes a huge amount of the total available water about 85% (Abu-Zied, M., 1999). About 50% of maize production is grown shortage will be accrue and critical constrains will face the most common method used world-wide to determine evapotranspiration remains the one suggested by Doorenbos and Pruit (1977), in the irrigation and drainage paper FAO-24. FAO-56 have served as widely used source for crop coefficients and application procedures for a large number of crops. The approach is to derive the actual evapotranspiration ETc by the product of a crop dependent coefficient (crop coefficient) Kc and a climate dependent reference evapotranspiration (ETo). Recently, the eddy covariance technique is particularly adapted as studying ecosystem physiology. Meyers and Hollinger (2004) point out that the combination of soil and canopy heat storage and the energy used in photosynthesis in maize and soybean need to be considered for an accurate estimation of the energy balance. However, using advanced technologies for precision irrigation and estimation of evapotranspiration is scanty and not well documented. Therefore, the objective of this research is to summarize the results of the maize evapotranspiration and crop coefficients derived from weighing lysimeter and eddy covariance methods. The comparison will include evapotranspiration which is derived from Modified Penman-Monteith equation with locally available meteorological data.

2. Material and methods

This study was conducted in Zankalon Water Requirements Experimental Station, Water Management Research Institute, National Water Research Center, Egypt. The site is located at 30^o 35' N and 31^o 30' E with an elevation of about 7 meters above sea level. All agricultural operations were the same for all treatments. The experiment was performed to compare the crop evapotranspiration and crop coefficient for the two methods, weighing lysimeter and eddy covariance methods for maize crop. The American Society of Civil Engineering standardized Modified Penman Monteith method for reference ETr be applied. The eddy covariance method determines the surface fluxes as the sum of turbulent eddy-fluxes, measured above the surface, and the flux divergence between the surface and the eddy covariance measurement level. Eddy covariance system was provided to WMRI through cooperation project with Japan funded by JST-JICA. The lysimeter used in this experiment is classified as a high-precision weighing lysimeter and has been constructed and installed by precision lysimeter Inc. (Red Bluff, CA, USA). The tank containing the soil under measurement is of 8 m^2 (2 m × 4 m) surface area and 2 m depth. Lysimeter in its simplest form involves the volumetric measurement of all incoming and outgoing water of a container which encloses an isolated soil mass with vegetated surface (Aboukhaled, 1982). (Allen et al., 1998) reported that estimating ET accurately at different ecosystem has an important significant to study the ecosystem productivity and water balance, as well as to guide the agricultural drainage, irrigation and improve agricultural water use. Of all the methods, eddy covariance (EC) can measure the exchange of water vapor, energy and carbon dioxide between the earth's surface and atmosphere directly, and has been used widely in the world. The eddy covariance technique is a key atmospheric measurement technique to measure and calculate vertical turbulent fluxes within atmospheric boundary layers. The technique is mathematically complex, and requires significant care in setting up and processing data. Estimates of evapotranspiration (ET) were computed using the eddy covariance technique and compared to the water balance equation from lysimeter.

3. Result and discussion

3.1 Evapotranspiration estimation and validation

Evapotranspiration is one of the most difficult parameters to measure on the ground. Many researches goes to estimate using indirect method such as pan evaporation or catchment water balance equation. While, the most general and widely used equation for calculating ET is Modified Penman-Monteith equation which is recommended by Food and Agricultural Organization (FAO). Due to shortage of water resources in arid land countries such as Egypt, accurate estimation of ET is getting more essential for precision irrigation. Figure 1 shows the obtained data of three of the main methods to estimate evapotranspiration. Those methods are; i) hydro-meteorological equation using Modified Penman-Monteith equation as a reference value; ii) weighting lysimeter which depend on the change in storage water in a soil column; and iii) eddy covariance technique in which fast fluctuations of vertical wind speed are correlated with fast fluctuations in atmospheric water vapor density. The daily reference evapotranspiration was calculated using Penman-Monteith equation using the local climatic data of the study area. Amount of applied water (mm) each irrigation event also presented in the same figure. The presented data shows that ET for eddy covariance recorded the lowest trend compared with ETo or ET of lysimeter. ET from Modified Penman-Monteith take the same trend of eddy covariance data. The lysimeter data is sharply fluctuated from time to time. This mainly affected by each irrigation event. Polynomial equations used to explain the obtained results from each method as follow:

1) To identify ET using eddy covariance method:
ET_{eddy}= $-1E\text{-}05x^3 + 0.0016x^2 - 0.0378x + 3.5902$, ($R^2$= 0.4322)………. (1)
2) To identify ET using lysimeter method:
ET_{lys} = $-3E\text{-}05x^3 + 0.0035x^2 - 0.0562x + 4.3448$, ($R^2$= 0.1791)………. (2)
3) To identify Modified Penman-Monteith method:
ET_{PM} = $-1E\text{-}05x^3 + 0.0017x^2 - 0.0617x + 7.1451$, ($R^2$= 0.6919)………. (3)

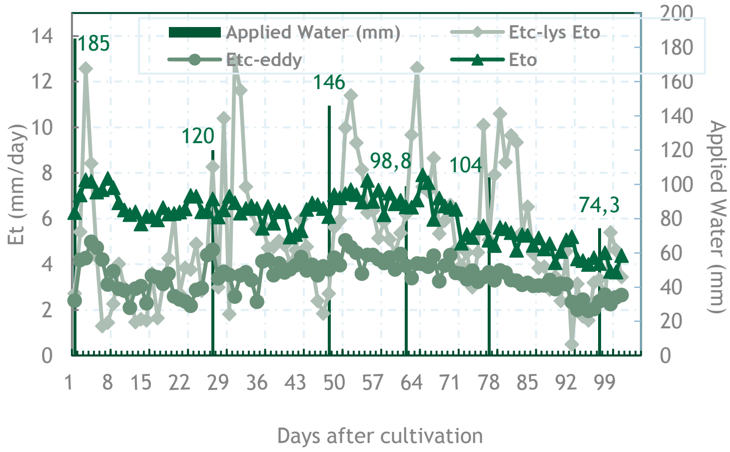

Figure (1): Crop evapotranspiration for study different methods compared with reference evapotranspiration and applied water

The correlation values of each methodology shows that the Modified Penman-Monteith still the most reliable methodology to depend on followed by eddy covariance method for maize crop in the study area. Lysimeter shows a very low correlation. This mainly due to the applied water fluctuated according to growth stages as well as soil moisture content. For example, the highest amount of applied water was 185 mm (first irrigation). It is mainly due to pre-drying period after harvesting of pervious crop. Water applied trend is mainly depending on the growth stages of maize crop. Even though, further studies and modifications should use to confirm the obtained trend. For an example, automation of used lysimeter is recommended as well as validation for other main crops of the study area
are recommended.

3.2 Growth stages and evapotranspiration

As shown in Figure 2, the reference evapotranspiration gradually decreases during the crop growth, it depends on the climatic conditions not the crop itself. The crop evapotranspiration for both methods (eddy covariance and lysimeter) are gradually increase with the growth stages until reach the maximum at flowering stage and decrease during the late stage (harvesting time). Polynomial equations used to explain the effect of growth stages of maize on evapotranspiration trend for each studied method as follow:

1) To identify ET using eddy covariance method:
ET_{eddy}= $-0.365x^2 + 1.671x + 1.96$,
(R^2 = 0.888)……… (4)
2) To identify ET using lysimeter method:
ET_{lys} = $-1.23x^2 + 6.332x - 1.605$,
(R^2 = 0.862)……… (5)
3) To identify Modified Penman-Monteith method:
ET_{PM} = $-0.3875x^2 + 1.3005x + 5.6375$,
(R^2 = 0.930)……... (6)

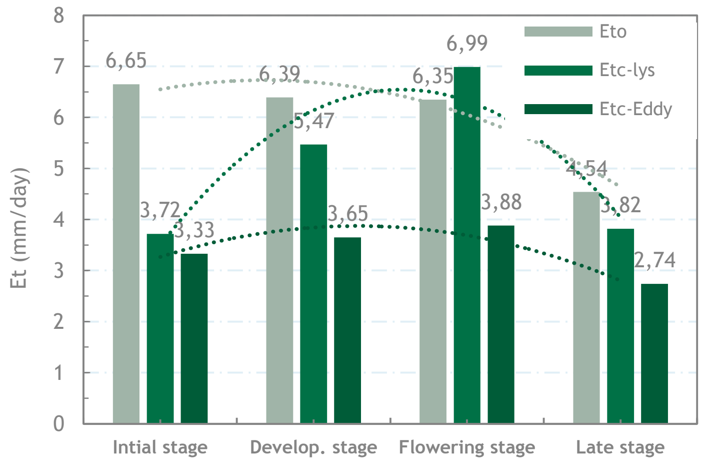

Figure (2): crop and reference evapotranspiration for maize crop growth stages

Theoretically, the Modified Penman-Monteith still the higher correlation value 0.93. Practically, depending on growth stages, both of eddy covariance and lysimeter methodologies have almost the same correlation value.

3.3 Crop coefficient

The crop coefficient (Kc) takes into account the crop development stages as well as crop type in order to adjust the ETo for that specific crop. There may be several crop coefficients used for a single crop throughout an irrigation season depending on the crop's stage of development. Figure 3 and Table 1 shows crop coefficient in different stages of maize growth using different methodologies (eddy covariance, lysimeter and climatic data obtained from weather station).

It is clear that crop coefficient of lysimeter was higher that crop coefficient from eddy covariance in all growth stages. While crop coefficient which depend on weather data is the highest. Flowering stage recorded the highest values of crop coefficient compared with other growth stages in different methods.

Aqua crop model used to calculate average water requirements for maize in the study area as presented in table 1. Through the model, development and flowering stages called Mid-season. Both stages recorded 1.2 as a crop coefficient. Then, monthly crop water requirements could be calculated using for Aqua crop model. Comparing different methodologies, shows the importance of further studies to approve the suitable model for calculation of evapotranspiration. Also, it is clear that Crop coefficients may also vary depending on how the evapotranspiration data has been calculated or obtained.

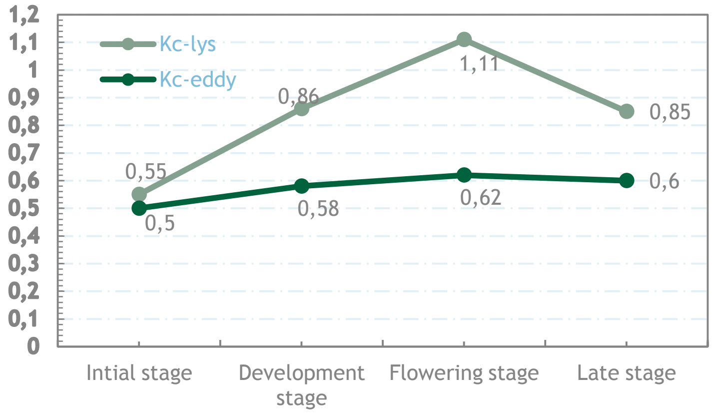

Figure (3): Average monthly latent heat for two different cultivation methods

Table (1): Maize crop water requirements according to FAO-Kc in the study area

Months	June	July	Aug.	Sept.	Ave. water requirements (mm/day)
ET0 (ET0 (mm/day)	7.13	6.28	6.65	4.77	
Growth stages	Initial	Mid-season		Late season	
Kc per gr. St.	0.6	1.2	1.2	0.6	
Kc per month	0.6	1.2	1.2	0.6	
ET crop (mm/day)	4.3	3.8	8.0	2.9	4.7
ET crop (mm/month)	128.3	113.0	239.5	85.8	141.7

4. Conclusions

Among different methodologies to estimate reference evapotranspiration, Modified Penman-Monteith equation as a reference value, weighting lysimeter and eddy covariance technique methods used as a precision techniques. The obtained results showed that the Modified Penman-Monteith is the most reliable methodology followed by eddy covariance method to measure reference evapotranspiration. As influenced by growth stages, eddy covariance and lysimeter methodologies could be used to find out reference evapotranspiration. Also, crop coefficients is depending on how the evapotranspiration data has been calculated or obtained. Lysimeter shows a very low correlation and sharply fluctuated data. Therefore, a recommendation for further validation and studies among the studied methodologies for the main crops of different agro-climatological regions of the country due to shortage of water resources.

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