Comparison of different methods with lysimeter measurements in estimation of rice evapotranspiration in Sari Region

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Abstract.- One of the important parts of the hydrological cycle is water requirement of plants. Evapotranspiration of plant is an important parameter in irrigation planning. Estimation of evapotranspiration for each vegetation is very necessary action. All of the empirical equations are not suitable for estimating potential evapotranspiration in a region, so the choice of the best method for estimating potential evapotranspiration in each region is necessary. Lysimetric measurements were conducted in 2015 year (during the rice cultivation season (May-September)) in the Khazar Abad area of Sari county. Using lysimetric data, evapotranspiration of rice plant (early maturity variety of *Tarom Hashemi*) was estimated in Sari county. The Ref-ET software was used to estimate potential evapotranspiration by Penman-Monteith, Penman, Hargreaves-Samani, Blaney–Criddle, Makkink and Turc methods. The actual evapotranspiration (rice evapotranspiration) represents potential evapotranspiration multiplied by crop coefficients (Kc) at different stages of growth. The efficiency of all methods was evaluated using Root Mean Square Error ($RMSE$), Mean Absolute Error (MAE) and Coefficient of Determination (R^2) statistic parameters. The results showed that the Blaney–Criddle method with $RMSE = 0{,}54$ *mm*, $MAE = 0{,}42$ and $R^2 = 0{,}728$ has the most consistent with lysimetric data. so the Blaney–Criddle method is the most suitable method for estimating the evapotranspiration of the rice plant in Sari region.

Keywords: rice evapotranspiration; lysimeter measurements; estimation methods.

Comparación de diferentes métodos con mediciones lisimétricas en la estimación de la evapotranspiración del arroz en la región Sari

Resumen.- Una de las partes importantes del ciclo hidrológico es el requerimiento de agua de las plantas. En tal sentido, la evapotranspiración es un parámetro importante en la planificación del riego, cuya estimación para cada vegetación es una acción muy necesaria. Existen diversos modelos empíricos para estimar la evapotranspiración potencial, sin embargo no todos se adecuan a diferentes regiones, de allí la importancia de seleccionar el más idóneo. En el presente estudio, se estimó la evapotranspiración de la planta de arroz (variedad de maduración temprana de *Tarom Hashemi*) en el condado de Sari, específicamente en el área de Khazar Abad, a través de mediciones lisimétricas durante la temporada de cultivo (mayo-septiembre 2015). Se usó el software Ref-ET, para estimar la evapotranspiración potencial por medio de los métodos Penman-Monteith, Penman, Hargreaves-Samani, Blaney – Criddle, Makkink y Turc. A partir de cuyos valores se obtuvo la evapotranspiración real del arroz, multiplicando por los coeficientes de cultivo (Kc) en las diferentes etapas de crecimiento. La eficiencia de todos los métodos se evaluó utilizando los parámetros estadísticos de error cuadrático medio ($RMSE$), error absoluto medio (MAE) y coeficiente de determinación (R^2). Los resultados mostraron que el método Blaney – Criddle con $RMSE = 0,54$ mm, $MAE = 0,42$ y $R^2 = 0.728$ es el más consistente con los datos lisimétricos por lo tanto, y por ende es más adecuado para estimar la evapotranspiración de la planta de arroz en la región de Sari.

Palabras clave: evapotranspiración de arroz; mediciones lisimétricas; métodos de estimación.

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1. Introduction

Demand for food due to high population growth and the share of agricultural sector in food production and water consumption, has increased the necessity of pay attention to management and increasing water productivity [1]. Rice in a large part of the Asian continent supplies more than 80 percent of the consumer calories for people [2]. Determining the amount of requirement water for evapotranspiration is one of the main factors in irrigation planning, and the exact estimation of this parameter is very difficult due to the environmental factors affecting it (such as air temperature, wind speed and solar radiation). Methods of evapotranspiration measurement are divided into three groups: direct methods, indirect methods (computational) and modern methods. In the past five decades, most studies by researchers have focused on developing methods for estimating evapotranspiration and improving the performance of existing methods. However, lysimeter is still the most accurate method for estimating the evapotranspiration of the reference plant [3], so that the accuracy of other methods is measured with it. A lysimeter is a measuring device which can be used to measure the actual evapotranspiration which is released by plants. By recording the amount of precipitation that an area receives and the amount lost through the soil, the amount of water lost to evapotranspiration can be calculated. Lysimeters are of two types: weighing and non-weighing [4]. There are different methods for estimating potential evapotranspiration (indirect methods),but the choice of the best methods for each region requires evaluating the performance of these methods using the lysimeter method [5].

Onnabi Milani and Neyshabouri [6] compared some empirical estimating methods of reference evapotranspiration in Tabriz plain using lysimeter and proposed a model for its determination from climatic data. Comparison between the measured and estimated ETo by various methods showed that the pan evaporation (class A) and Hargreaves methods had the highest and lowest correlation with lysimeteric data, respectively. Based on the statistical analysis, Penman-Monteith method had the closest estimates to lysimeteric measurement. In general, Penman-Monteith was introduced as a suitable method for estimating reference evapotranspiration in Tabriz plain. Zareabayneh *et al.* [7] compared Penman-Monteith FAO method and a class pan evaporation with lysimeter measurements for estimation of rice evapotranspiration in Amol region. Obtained results by lysimeter showed, rice evapotranspiration in the first and second year of 578,5 (Tarom variety) and 481,6 mm (Khazar variety), respectively. This is due to a higher being during growth of Tarom variety in the first year than Khazar variety in the second year. However, a Tarom variety is long-term with tall plants. Increased during growth, and tall plant height, is effective in the amount of water. The maximum amount of Kc in the third stage of rice plant growth, for both years was 1,2. The minimum in the fourth stage, for both first and second years was 0,9. In the present study for both farming year, the value of Kc in the initial stage of growth, was 1,09 and 1,13 respectively. Two-year results showed that FAO method overestimate calculated crop evapotranspiration values by 4-5% in comparison of lysimeter measurements. Results showed that Eshnaider method is suitable for ETo estimation of pan coefficient and evaporation pan estimated ETo well in the study region. Estimation of ETc on the basis of pan evaporation data, Eshnaider pan coefficient and FAO modified crop coefficient showed only on the average 1,5% underestimation in comparison with actual ET (ETc). Therefore, this method is suitable and practical in the study region. Overall, the results showed that using appropriate methods for estimating reference crop evapotranspiration and the crop coefficient, evapotranspiration of rice can be calculated with good accuracy.

Applications and is suitable for different regions. Pouryazdankhah *et al.* [8] determined crop coefficient of Binam and Khazar cultivars of rice by lysimeter and controlled basins in Rasht region. In this study, evapotranspiration data for grass and rice i.e. Binam and Khazar cultivars were collected in Rice Research Institute of Rash, by using drainable lysimeter at ten-day periods during three consecutive crop seasons. The reference evapotranspiration was calculated and compared with 16 empirical equations results included in Ref-ET software. Significant differences of them have been evaluated using SPSS software. Also, the crop coefficient values were calculated for each variety of rice. In all three equations i.e. Hargreaves, Priestley-Taylor and Penman (FAO 24) have not shown any significant differences. Among three methods, Hargreaves equation is recommended for Rasht region because, this equation as compared with others is a temperature-based method and would consider global warming phenomenon. Also, the average of crop coefficient (Kc) for Khazar and Binam in three consecutive crop seasons were 1,10 and 1,09 respectively.

Pirmoradian *et al.* [9] extracted the crop coefficients of three rice varieties based on ETo estimation method in Rasht region. This study was conducted to derivate Kc for three rice varieties, Hashemi as a local cultivar, Khazar as an improved cultivar and Bahar as a Hybrid cultivar, in paddy fields of Rice Research Institute of Iran in 2009 and 2010. The values of crop evapotranspiration (ETc) were measured with installing three cylindrical mini-lysimeter for each cultivar. Derivation of Kc were done based on five ETo estimation methods including FAO Penman-Monteith, Radiation, Blaney-Criddle, Pan Evaporation and Hargreaves. As a result, water requirements for Khazar (526 mm) and Bahar (490 mm) varieties were 14,6 and 6,8 percent higher than Hashemi (459 mm) cultivar, respectively. The crop coefficients were varied between 0,76 to 1,09 for initial stage; 1,15 to 1,48 for mid-season and 0,91 to 1,21 for late-season based on ETo estimation method and rice cultivar. Difference between the gained Kc in this study with the recommended values by FAO shows that derivation of crop coefficient based on local conditions is necessary. The obtained Kc based on different ETo methods can increase estimation accuracy of water requirement in availability limitation to meteorological data. Jensen et al. [10] estimated the evapotranspiration and irrigation water requirements by 20 methods in different regions and compared them with the results of lysimeter. The results showed that Penman-Monteith method has the best estimate. Due to lack of rainfall and inappropriate temporal and spatial distribution of rainfall, Iran is in the category of dry and semi-arid countries of the world [11]. Iran is a very large country with different climates. Therefore, it is necessary to select the best indirect method for estimating evapotranspiration in each region according to meteorological data and to be used to formulate irrigation programs and apply them properly. Of course, proper studies have been conducted in some parts of Iran and specific methods have been proposed for those areas. But the number of studies have been conducted for estimate evapotranspiration in the paddy fields of Mazandaran province is very low. The purpose of this study was to investigate the best method for estimating rice evapotranspiration in situation the lack of lysimetric data in Khazar Abad area of Sari county.

2. Materials and methods

This research was conducted during a crop year in Mazandaran province, Sari county, in Hamid Abad village paddy fields. The research area is located in the northern part of Sari county (Khazar Abad region) with a longitude and latitude of 53° 6’ and 36° 46’, respectively. This area has a semi-mediterranean climate. Figure 1 shows the location of the paddy field. Table 1 presents the geographical and climatic characteristics of the study area. Physical and chemical characteristics of this field is presented in Tables 2 and 3.

Table 1: Geographical and climatic characteristics of the study area.

Characteristic	Unit	Value
Temperature	(°C)	17,9
Relative humidity	(%)	78
Pressure	(kPa)	101,4
Wind speed at 10 m height	$(m \cdot s^{-1})$	1,92
Altitude from the sea level	(m)	23

Rice was cultivated in a farm of one hectare (1ha) in 2015 year (May-September). Rice cultivar in this research was Tarom Hashemi which is the dominant cultivation of the region. The amount of evapotranspiration of rice plant was measured using lysimeter during this period. In this research, used from three lysimeter with dimensions of 50× 50×50cm. The depth of placement of the lysimeters

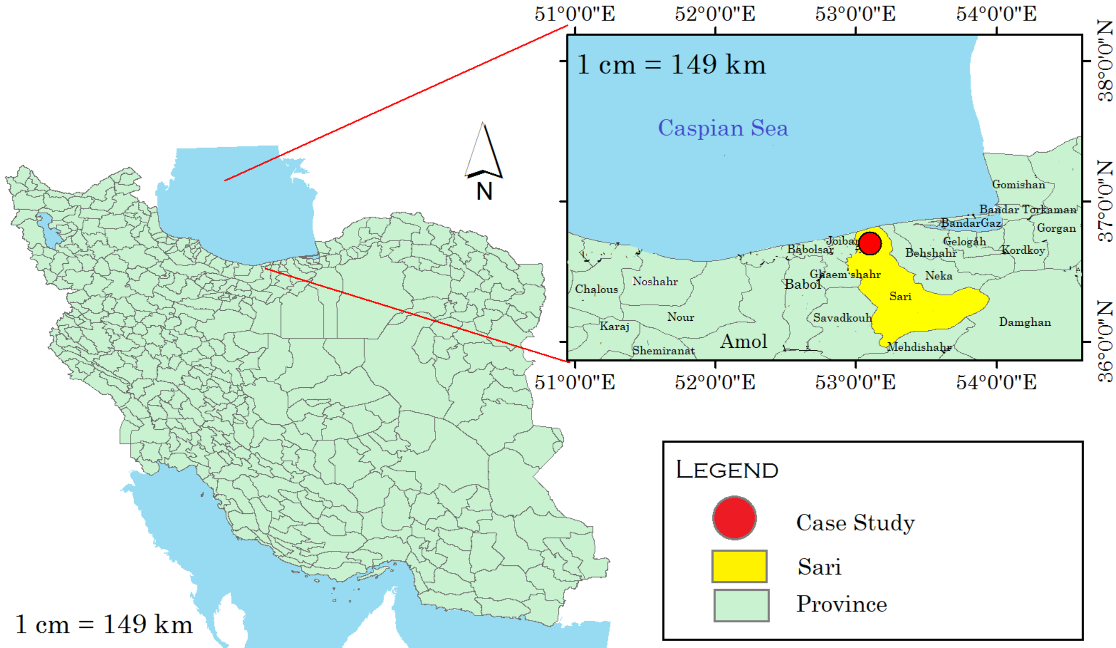

Figure 1: Location of the study area in Iran

Table 2: Physical characteristics of the studied farm soil

Characteristic	Value
Soil texture	Silt
Clay(%)	44
Silt(%)	39
Sand(%)	17
Bulk density($g \cdot cm^{-3}$)	1,32
Sampling depth	0-30

Table 3: Characteristics of studied farm soil fertility

Characteristic	Value
EC($ds \cdot m^{-1}$)	355
PH saturated soil paste($mg.l^{-1}$)	11,4
OC($mg.l^{-1}$)	0,17
Total N	2,07
P ($mg.l^{-1}$)	7,59
K($mg.l^{-1}$)	2,85

in the ground is 24 cm and height of the upper part of the lysimeters was 26 cm on the surface of the earth (according to the standard Japanese lysimeters). The first lysimeter used (Lysimeter A) was without the floor plate and has plant bushes inside it. This lysimeter estimates the amount of evapotranspiration and deep percolation. The second lysimeter used (Lysimeter B) was without the floor plate, and was in contact from the up with air and water and from the down with soil. There is no plant in this lysimeter. The deep percolation and evaporation from free water surface are measured by this lysimeter. The third lysimeter used (Lysimeter C) has a metal floor, and its connection with the soil under the metal floor is interrupted and there is no plant inside it. This lysimeter estimates the amount of evaporation from free water surface. Figure 2 shows the apparent characteristics of the A, B, and C lysimeters.

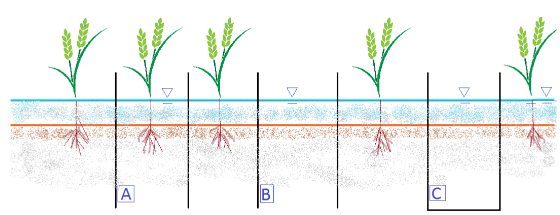

Figure 2: Apparent characteristics of the A, B, and C lysimeters.

Lysimetric data was measured at 7 o'clock in the morning every day. Meteorological data (daily) was received from the nearest weather station (Dashte Naz) in the studied area in 2015 year (May-September) to estimate evapotranspiration of reference plant (ET0). The Ref-ET software was used to estimate potential evapotranspiration by Penman-Monteith, Penman, Hargreaves-Samani, Blaney–Criddle, Makkink and Turc methods. The crop coefficients (Kc) is a factor for considering the characteristics of the plant under study, such as leaf area, plant height, green cover percentage and plant canopy resistance. Table 4 shows the amount of crop coefficient at early stage, middle stage and final stage.

Table 4: Amount of crop coefficient at early stage, middle stage and final stage.

early stage	middle stage	final stage
1,05	1,20	1,05

The actual evapotranspiration (rice evapotranspiration) represents potential evapotranspiration multiplied by crop coefficients (Kc) at different stages of growth according to equation (1).

$$ETc = ET \cdot Kc \tag{1}$$

The efficiency of all methods was evaluated using Root Mean Square Error ($RMSE$), Mean Absolute Error (MAE) and Coefficient of Determination (R^2) statistic parameters. The statistical indices $RMSE$, MAE and R^2 are defined as equations (2), (3) and (4). The $RMSE$ value indicates how much the predictions have estimated the measurements more or less and the MAE value represents the accuracy of the method and the mean value of the error. Whatever the value of the indicators is closer to zero, the better (the difference between the predicted and measured values is lower) [12]. The well-known R^2 statistic, or the (multiple) coefficient of determination, pertains to the proportion of variance in the response variable explained by a fitted model relative to simply taking the mean of the response. In other words, it describes how well the model fits the data. An R^2 close to 1 implies an almost perfect relationship between the model and the data, whereas an R^2 close to 0 implies that just fitting the mean is equivalent to the model fitted [13].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(s_i - o_i)^2}{n}} \tag{2}$$

$$MAE = \frac{\sum_{i=1}^{n}|s_i - o_i|}{n} \tag{3}$$

$$R^2 = \left(\frac{\sum_{i=1}^{n}(o_i - \bar{o})(s_i - \bar{s})}{\sqrt{\sum_{i=1}^{n}(o_i - \bar{o})^2 \sum_{i=1}^{n}(s_i - \bar{s})^2}}\right)^2 \tag{4}$$

In the above relations, s is the predicted value, o the observed value and n is the number of data.

3. Results and discussion

Excessive consumption of water in various sectors, especially agriculture, has caused water scarcity to be a serious crisis that threatens human life worldwide. To solve this problem is necessary to manage water resources. One of the most important factors in water resources management is the accurate estimation of water balance to be based on there could be proper planning for water resources and various uses. One of the important parameters in water balance is evapotranspiration. The accurate estimation of evapotranspiration in a region and on an annual scale is very difficult and requires a lot of time and cost [14]. Therefore, in this study, we have tried to use the lysimetric method for estimation of rice evapotranspiration in the Khazar Abad region and then, using its results, we can select the best method for the Khazar Abad region. The Ref-ET software was used to estimate potential evapotranspiration by Penman-Monteith, Penman, Hargreaves-Samani, Blaney–Criddle, Makkink and Turc methods. The actual evapotranspiration (rice evapotranspiration) represents potential evapotranspiration multiplied by crop coefficients (Kc) at different stages of growth. Figure 3 shows the amount of rice evapotranspiration by different methods. The evapotranspiration estimates by all methods

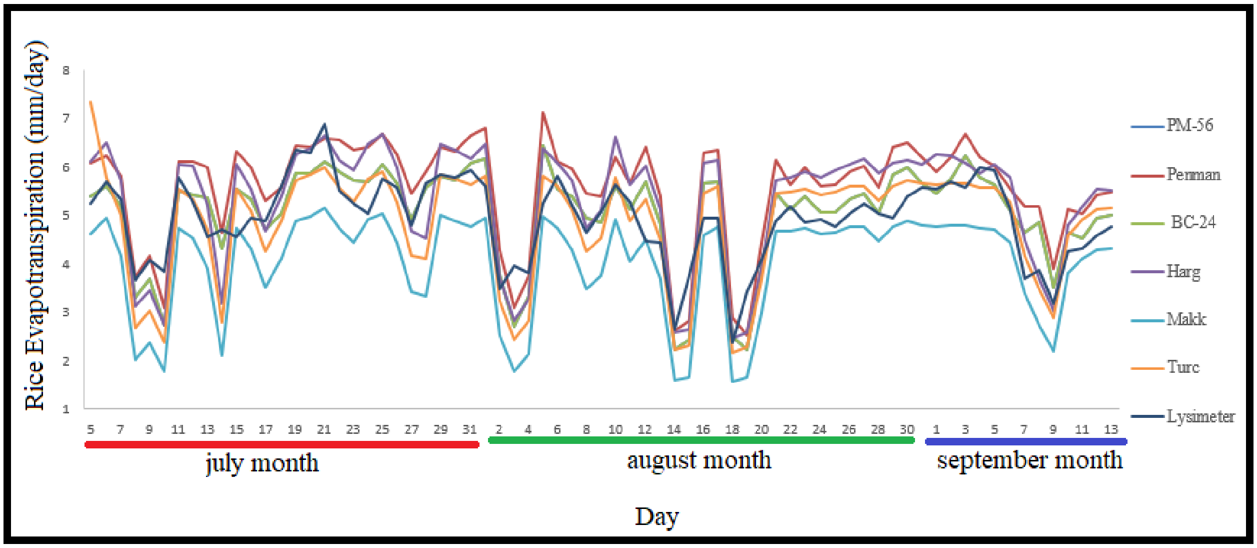

Figure 3: Comparison of rice evapotranspiration by different methods

shows the same trend throughout the crop year. Penman and Hargreaves-Samani methods give the highest estimation of evapotranspiration. The Makkink method give lowest estimation of evapotranspiration. The Makkink method estimate lower values of evapotranspiration with significant difference among different method. Makkink method is significantly different from lysimetric method. According to Figure 3, Blaney–Criddle method has the most conformity with the lysimetric method.

Figure 4 shows the amount of potential evapotranspiration by different methods. All methods were compared with lysimetric method.

According to Figure 4, the Penman-Monteith, Penman, Hargreaves-Samani, Blaney–Criddle, Makkink and Turc gave R^2 0,761; 0,701; 0,717; 0,728; 0,698 and 0,671 respectively. Comparisons of the selected methods against the lysimetric method showed that 4 methods have fairly good R^2. Methods Turc and Penman-Monteith have the lowest and highest R^2, respectively. Table 5 shows the values of statistical indices for different methods compared with lysimetric method. According to Table 5, the Blaney–Criddle method with $RMSE = 0,54$ mm, $MAE = 0,42$ and $R^2 = 0,728$ has the most consistent with lysimetric data. So the Blaney–Criddle method is the most suitable method for estimating the evapotranspiration of the rice plant in Sari region. This conclusion is contradictory with the results of many research studies.

Many studies have confirmed the Penman-Monteith method as the most appropriate method in comparison with the lysimetric method. Namdarian *et al.* [15] compared of the FAO Penman-Monteith method and class A evaporation pan with lysimeter data in estimating evapotranspiration *(Cicer arietinum L.)* in Khorramabad. The aim of this research was to determine the crop coefficients of chickpea in a research field in Lorestan agriculture faculty in 2013 to find *(Cicer arietinum L.)* water requirement and different crop coefficients. For that, 4 drainable lysimeter was selected in which diameter and height were 0,45 and 0,8 m, respectively. The crop density was 50 plant per m^2. The water requirement of chickpea was estimated equal to $438mm$. The potential evapotranspiration also was estimated equal to $554,2mm$. More ever, the best pan coefficient also was determined by comparing with lysimetric results. Different parameters such as $RESE$, MBE, MAE and R^2 were used to determine chickpea evapotranspiration. Finally, the results showed that the FAO model with error $RMSE$ 0,174 is an optimum model for this region and Snyder method was modified in the second accurately. The FAO Penman Monteith method

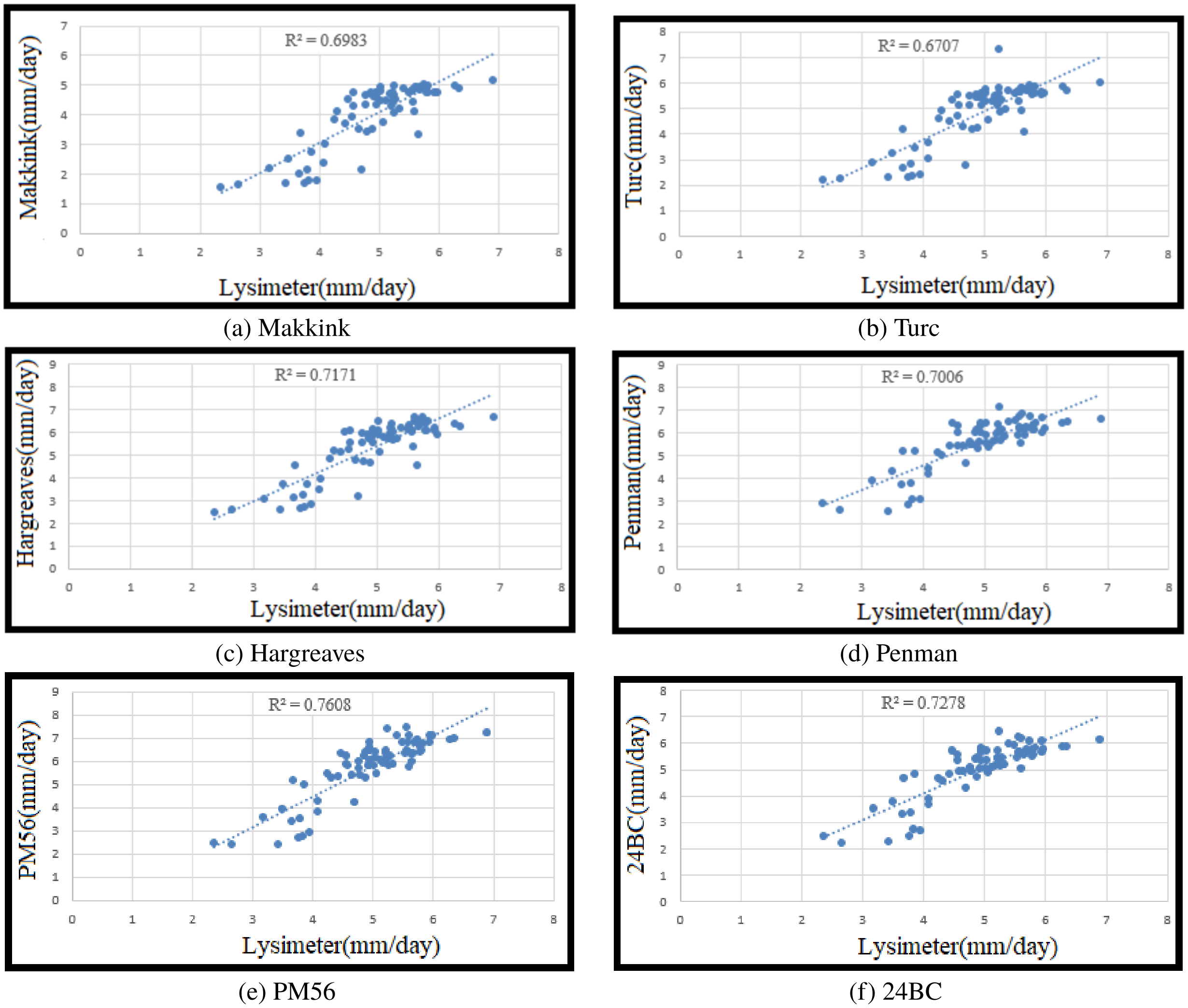

Figure 4: Estimation of potential evapotranspiration by different methods and comparison with lysimetric method

for calculating reference evapotranspiration in the region of 4,8 % less than the amount of the lysimeters. Raoof and Azizi Mobaser [16] evaluated of eighteen reference evapotranspiration models under the Ardabil climate condition. This study was conducted in Hangar research station of the University of Mohagheghe Ardabili, Ardabil. For this purpose, grass was planted in 3 lysimeters and around the lysimeters. Grass evapotranspiration measured by volumetric lysimeters based on water balance equation components (input and output water volume, save moisture and evapotranspiration), was estimated. To estimate reference evapotranspiration 18 models, including models such as temperature, radiation, and the combination was chosen. The meteorological synoptic station of Ardabil was used to prepare the information needed to model. Besides the results of lysimeters, evapotranspiration obtained by the FAO Penman-Monteith model also was used as a reference for comparing the performance model. Evapotranspiration estimation models using statistical indices, root mean square error ($RMSE$), mean absolute error (MAE), the estimated margin of error (PE), the ratio (MR) and spearman's rho coefficient is calculated as follows to cross they were evaluated. The results showed that for all models, high dispersion of points around the line one to one, or answer them consistent with the results of lysimeters answer is not good. Moreover, some of these models overestimated and underestimated some of them to calculate evapotranspiration. Using statistical indicators may be compared with the results of lysimeters, at the most proper research models, respectively Blaney–Criddle, Ravazzani and the Rn and the weakest models respectively Irmak and Valiantzas. Overall fit the model results against the results of the FAO Penman-Monteith model compared to its results compared to the results of lysimeters, was more suitable. Also according to the statistical criteria in this study, the FAO Penman-Monteith model, the most appropriate models were Turk, Berti and the Trajkovic, and the weakest models, modified Hargreaves-Samani, Irmak and Scandal were determined. Conclusion of this research conformity with the results of many research studies. Many studies have confirmed the Blaney–Criddle method as the most appropriate method in comparison with the lysimetric method. Piri [17] evaluated of different methods potential evapotranspiration in Sistan plain. In this study compares the evapotranspiration calculated by the Blaney–Criddle, Jensen Hayes, reform Jensen Hayes and Hargreaves-Samani to FAO Penman-Monteith method and lysimeter in Sistan plain than the way has been identified to be most correlated with the FAO Penman-Monteith. The results shown that Blaney–Criddle has maximum correlation coefficient ($0,973$ and $0,971$) and Hargreaves-Samani method has minimum correlation coefficient ($0,75$ and $0,69$) than other methods of calculating evapotranspiration. Ebrahimipak and Ghalebi [18] determined of evapotranspiration and crop coefficient (kc) of sugar beet using lysimeter and compared it with experimental methods in Shahrekord. This study aimed at determining the evapotranspiration and crop coefficient (Kc) of sugar beet during the plant growth using drainage lysimeter by using water balance and experimental methods for three years in Shahrekord. After sugar beet planting and out of lysimeter, evapotranspiration was measured weekly and monthly by measuring the factors of the water- balance equation. Results showed that the total evapotranspiration of sugar beet was 1016,6 mm during the growing season and the rate of water drainage and the soil moisture content were 73,9 and 66,1 mm, respectively. The amount of evaporation from class A pan was 1364,5 mm. Evapotranspiration of the reference plant was measured by using drainage lysimeter and estimated by using the experimental methods. Results showed that the evapotranspiration rate of the reference plant was 1123,03 mm and among the experimental methods, the Blaney- Criddle FAO24 and Penman-Monteith FAO 56 method had more accuracy. Crop coefficient at early stage, development stage, middle stage, and final stage was 0,72; 0,81; 1,04; and 0,7 with an average of 0,89 for the whole growing period of sugar beet. The average pan evaporation coefficient (Kp) was 0,83; and the average water requirement coefficient ($Kc.p$) was 0,73 for the growing season of sugar beet. so the Blaney–Criddle method is the most suitable method for estimating the evapotranspiration of the rice plant in Sari region.

Table 5: The values of statistical indices for different methods compared with lysimetric method

Evapotranspiration equations	$RMSE$	MAE	R^2
Penman-Monteith	1,042	0,93	0,761
Penman	0,86	0,73	0,701
Blaney–Criddle	0,54	0,42	0,728
Hargreaves-Samani	0,76	0,60	0,717
Makkink	1,079	0,91	0,698
Turc	0,68	0,51	0,671

4. Conclusion

The Comprehensive Assessment of Water Management in Agriculture (Mazandaran province) seeks answers to the question of how freshwater resources can be developed and managed to feed the world's population and reduce poverty, while at the same time promoting environmental security. The Mazandaran province pays particular attention to rice as this crop is the most common staple food of the largest number of people on Earth (about 3 billion people). Climate change will affect rice water requirement through changes in rice physiology and phenology, soil water balance, evapotranspiration, and green water. Adapting with this major environmental challenge is necessary to maintain or improve the current level of rice production in the future. The correct estimation of ET in the water balance equation allows for improved water management in rice cultivation. Evapotranspiration is a major factor affecting dry matter production, and hence, the agricultural production potential of a given region. Realistic evapotranspiration estimates are important to irrigation engineers, agronomists, and others involved in agricultural planning. Six evapotranspiration estimation methods (Penman-Monteith, Penman, Hargreaves-Samani, Blaney–Criddle, Makkink and Turc) were compared with lysimetric method, in the Khazar Abad region. The evapotranspiration estimates by all methods shows the same trend throughout the crop year. Penman and Hargreaves-Samani methods give the highest estimation of evapotranspiration. The Makkink method give lowest estimation of evapotranspiration. The Makkink method estimate lower values of evapotranspiration with significant difference among different method. Makkink method is significantly different from lysimetric method. The Penman-Monteith, Penman, Hargreaves-Samani, Blaney–Criddle, Makkink and Turc gave R^2 0,761; 0,701; 0,717; 0,728; 0,698 and 0,671 respectively. Comparisons of the selected methods against the lysimetric method showed that 4 methods have fairly good R^2. All other methods, which tend to overestimate evapotranspiration were not suitable. The Blaney–Criddle method with $RMSE = 0,54$ mm, $MAE = 0,42$ and $R^2 = 0,73$ has the most consistent with lysimetric data. The Blaney-Criddle is the best method to estimate evapotranspiration in the study area. The Blaney-Criddle method can be used to get somewhat reasonable estimates.

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