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Reference evapotranspiration estimation by the Irrigameter in Southern Tocantins State, Brazil

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A B S T R A C T

The choice for the most appropriate method to estimate evapotranspiration depends on the availability of meteorological data, required level of precision and cost of equipment acquisition. For this estimate, the Irrigameter is simple to operate, precise and economically viable to farmers. In addition, it collaborates in the application of the necessary water depth to crops, thus avoiding unnecessary energy consumption, environmental degradation, and increasing crop yield and improving crop quality. In this context, the objective of this research was to estimate the reference evapotranspiration using the Irrigameter, for the climatic conditions of the Southern Tocantins state, Brazil. The experimental design was completely randomized with Irrigameters operating with seven water heights in the evaporator, as treatments, with three replicates. The reference evapotranspiration was obtained by FAO-56 Penman-Monteith method. For the analyzed climatic conditions, the water height in the evaporator recommended to estimate the reference evaporation in the spring is 3.4 cm; summer, 4.0 cm; fall, 3.8 cm; and winter, 2.3 cm.

Palavras-chave:
manejo da irrigação
agricultura irrigada
evaporatório

Estimativa da evapotranspiração de referência pelo Irrigâmetro no Sul do Estado do Tocantins

R E S U M O

A escolha do método mais apropriado para estimar a evapotranspiração depende da disponibilidade de dados meteorológicos, do nível de precisão exigido e do custo de aquisição dos equipamentos. Para tal estimativa, o Irrigâmetro é de simples operação, preciso e economicamente viável aos produtores rurais, haja vista que colabora para a aplicação da lâmina de água necessária às culturas, evitando o consumo desnecessário de energia e a degradação do meio ambiente, além de aumentar a produtividade e melhorar a qualidade das culturas. Neste contexto, objetivou-se, por esta pesquisa, estimar a evapotranspiração de referência utilizando o Irrigâmetro, para as condições climáticas do Sul do Estado do Tocantins. O delineamento experimental foi inteiramente casualizado com Irrigâmetros operando com sete alturas da água no evaporatório do aparelho, representando os tratamentos, e três repetições. A evapotranspiração de referência foi obtida pelo método de Penman-Monteith – FAO 56. Para as condições climáticas analisadas, a altura da água recomendada no evaporatório do aparelho para estimar a evapotranspiração de referência na primavera é 3,4 cm; no verão, 4,0 cm; no outono, 3,8 cm e no inverno, 2,3 cm.

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Introduction

In all the world, 18% of the agricultural area, which corresponds to 275 million ha, is irrigated (Nobre et al., 2010). These cultivated areas, where irrigated agriculture techniques are practiced, achieve a physical yield higher than two fifths of the total agricultural production (Christofidis, 2013). The practice of irrigation is considered as an alternative of guarantee in the agricultural production (Fernández-Cirelli et al., 2009; Fernandes et al., 2010); however, in most of the irrigated area in Brazil, it is common to observe the absence of rational water management.

In this context, information on reference evapotranspiration that leads to the estimate of the evapotranspiration of the crops becomes important tool in irrigation management (Araújo et al., 2007; Souza et al., 2009).

According to Tagliaferre et al. (2014; 2015), the Irrigameter invented (its patent is filed in the National Institute of Industrial Property - INPI - under the number PI0502488-9) and developed at the Federal University of Viçosa (UFV) is an evapo-pluviometric device to be used in irrigation management, to optimize water use in irrigated agriculture, which can be used to estimate the reference evapotranspiration (Tagliaferre et al., 2012b; Oliveira et al., 2008; 2011a;b).

In this context, this study aimed to establish, for each season of the year, the water height in the evaporator of the Irrigameter, for the device to estimate the reference evapotranspiration (ET_0) under the climatic conditions of the Southern Tocantins state.

Material and Methods

The study was carried out in the experimental area of the Federal University of Tocantins (UFT), on the University Campus of Gurupi, TO, Brazil. The geographic coordinates of the municipality are 11° 45' S and 49° 03' W, at an altitude of 287 m. In this area, 21 Irrigameters were installed at spacing of 3.0 x 3.0 m.

The meteorological station installed in the experimental area is a DAVIS, model Vantage Pro II. The values of reference evapotranspiration (ET_0) were obtained by the FAO-56 Penman-Montheith method, through the computer program REF-ET (Allen, 2000), using data of solar radiation, relative humidity, wind speed and air temperature.

The period of data collection started in September 2008 and ended in September 2011, thus resulting in three years of observation. The data collection for the treatment in which the water height in the evaporator was 1 cm started in September 2010 and ended along with the others, encompassing one year of data. Rainy days were removed from the study, since the rainfall alters the water height in the evaporator of the device and the return to the original height did not always occur immediately after rainfall.

The evapotranspired depth estimated by the Irrigameter was read in the feeding tube of the device, which is graduated in millimeters. Such reading was daily performed at 9 a.m. and the daily evapotranspiration estimated by the Irrigameter was obtained by the difference of level inside the feeding tube of the device, in the interval of 24 h.

The experiment was set in a completely randomized design, guaranteed by a drawn, with seven water heights in the evaporator of the device representing the treatments, with three replicates, totaling 21 Irrigameters. The following water heights were used as treatments: H1 = 1 cm; H2 = 2 cm; H3 = 3 cm; H4 = 4 cm; H5 = 5 cm; H6 = 6 cm and H7 = 7 cm, taken from a reference level in an ascending scale, existing inside the evaporator of the device.

The conical shape of the evaporator allows the surface exposed to the atmosphere to increase as the water height increases (Figure 1).

The Irrigameter coefficient (K_I) represents the ratio between the estimate of evapotranspiration obtained in the Irrigameter (ET_I) and the reference evapotranspiration (ET_0). Thus, the value of the angular coefficient (β_1) was attributed to the K_I, not considering the constant β_0 in the model.

For each treatment, one K_I coefficient was determined per season of the year, using Eq. 1, which establishes the relationship between the evapotranspiration estimated by the Irrigameter (ET_I) and the reference evapotranspiration (ET_0):

$$K_I = \frac{\sum ET_0 ET_I}{\sum ET_0^{\ 2}} \tag{1}$$

where:

K_I - irrigameter coefficient, dimensionless;

ET_I - evapotranspiration estimated by the Irrigameter, mm d^{-1}; and,

ET_0 - reference evapotranspiration, mm d^{-1}.

The water height in the evaporator, which corresponds to $K_I = 1$, i.e., the height adjusted for the direct estimate of reference evapotranspiration (ET_0), was determined by the fit of the equations that relate the water heights in the evaporator and the respective coefficients of the Irrigameter, obtained for the different seasons of the year.

The data were subjected to analyses of variance and regression, using the statistical software SAEG (Ribeiro Junior, 2001). The regression models were selected based on the significance of the regression coefficients by t-test, at 0.05 probability level.

Figure 1. Water exposed to the atmosphere inside the evaporator

Table 1 shows the means of the main meteorological elements observed along the experiment.

Table 1. Mean values of maximum and minimum temperature, relative air humidity, wind speed and solar radiation during the different seasons of the year, for the Southern region of the Tocantins state

Meteorological element	Season of the year			
	Spring	Summer	Autumn	Winter
Maximum temperature (°C)	32.94	31.35	32.07	34.58
Minimum temperature (°C)	22.37	22.29	20.57	16.92
Relative air humidity (%)	73.46	82.33	77.44	57.79
Mean wind speed (m s^{-1})	0.83	0.53	0.41	0.76
Solar radiation (MJ m^{-2} d^{-1})	17.39	17.47	16.26	18.46

Results and Discussion

Table 2 shows the summary of the analysis of variance of the ET_I data for the different water heights in the evaporator. It is possible to observe that the evapotranspiration estimated by the Irrigameter was significantly affected by the increase of water height in the evaporator.

Table 3 shows the K_I values and the mean values of the evapotranspiration estimated by the Irrigameter (ET_I) for each treatment, as well as the mean reference evapotranspiration (ET_0) for the analyzed season.

In Table 3, it is possible to observe that, in the spring, the best condition in which the Irrigameter must be to estimate the reference evapotranspiration is that in which the water height in the evaporator is between 3 and 4 cm. The mean value of ET_0 determined by the standard method was equal to 4.31 mm d^{-1}, which is comprehended between the mean ET_I obtained when the water height inside the evaporator was equal to 3 cm (3.94 mm d^{-1}) and 4 cm (4.64 mm d^{-1}).

In the summer, the best condition for the Irrigameter to estimate the reference evapotranspiration is when the water height in the evaporator is close to 4 cm. The mean value of ET_0, determined by the standard method, was equal to 3.97 mm d^{-1}, which is very close to the mean ET_I of the treatment H4 (4.05 mm d^{-1}).

It was also observed that the water height that best estimates the ET_0 values in the autumn season is comprehended between 3 and 4 cm, as occurred in the spring. The Irrigameter, as in the spring, underestimated the value of ET_0 for the heights 1, 2 and 3 cm and overestimated it for the others.

During the winter, it can be observed that the water height in the evaporator that best represents the situation to estimate the reference evapotranspiration is comprehended between 2 and 3 cm. The mean value of ET_0 (4.14 mm d^{-1}) is between the mean values of ET_I estimated for the heights of 2 and 3 cm. Only the treatments H1 and H2 underestimated ET_0, while the others overestimated it.

Table 2. Summary of the analysis of variance of the ET_I data for the water heights in the evaporator

Source of variation	DF	MS
Water heights	6	11.62**
Residual	14	0.06
Coefficient of variation (%)		5.92

** Significant at 0.01 probability by F test; DF - Degrees of freedom; MS - Mean square

Table 3. Water height in the evaporator, K_I and mean value of ET_I for each water height and mean value of ET_0 for each season of the year

Season	Treatment	Water height (cm)	K_I	ET_I	ET_0
				(mm d^{-1})	
Spring	H1	1	0.45	1.56	4.31
	H2	2	0.70	2.99	
	H3	3	0.92	3.94	
	H4	4	1.09	4.64	
	H5	5	1.29	5.64	
	H6	6	1.62	6.95	
	H7	7	1.79	7.72	
Summer	H1	1	0.39	1.56	3.97
	H2	2	0.60	2.48	
	H3	3	0.80	3.29	
	H4	4	0.99	4.05	
	H5	5	1.20	4.91	
	H6	6	1.45	5.95	
	H7	7	1.63	6.72	
Autumn	H1	1	0.53	1.80	3.4
	H2	2	0.67	2.30	
	H3	3	0.85	2.91	
	H4	4	1.07	3.67	
	H5	5	1.34	4.57	
	H6	6	1.69	5.77	
	H7	7	1.89	6.46	
Winter	H1	1	0.80	3.19	4.14
	H2	2	0.90	3.73	
	H3	3	1.10	4.58	
	H4	4	1.42	5.88	
	H5	5	1.72	7.16	
	H6	6	2.09	8.68	
	H7	7	2.28	9.53	

Figure 2 shows the values of K_I as a function of the water heights in the evaporator of the device, for the four analyzed seasons.

In Figure 2, it is possible to observe that the Irrigameter coefficient increases exponentially with the increment of water height in the evaporator in the winter and autumn seasons, while in the spring and summer seasons the Irrigameter coefficient increased linearly with the increment of water height in the evaporator.

Tagliaferre et al. (2012a) observed that this increase was exponential for all seasons of the year, in a study conducted in the region of Vitória da Conquista, BA. Caixeta (2009), on the other hand, found quadratic variation of the Irrigameter coefficient for the climatic conditions of the 'Zona da Mata' in Minas Gerais in the period from March to October 2008.

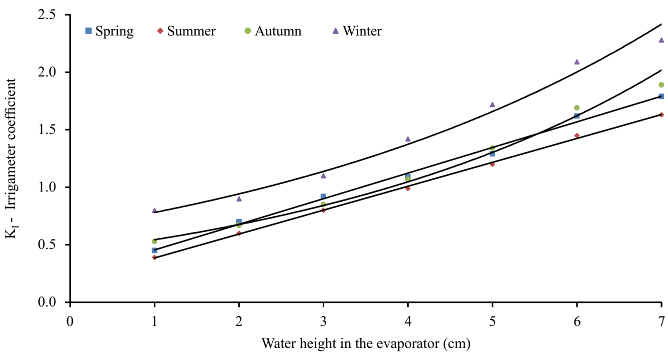

Figure 2. Irrigameter coefficient as a function of the water heights in the evaporator, for the four seasons of the year

In addition, Figure 2 also shows that the winter season led to the highest values of the Irrigameter coefficient. This fact is due to the higher values of maximum temperature and solar radiation and low relative air humidity during this season (Table 1), causing high values of ET_I in the period for all heights evaluated (Table 3). The lowest values of the coefficient occurred in the summer, which can be explained by the lower mean value of maximum temperature and higher mean relative humidity of the years.

For the water height of 1 cm in the evaporator, the Irrigameter coefficients showed the lowest values of the entire experimental period and small variation between the analyzed seasons. Always when the water height decreased, remaining farther from the edge of the evaporator, there was a decrease in the liquid surface exposed to the atmosphere and, consequently, lower value of the estimate of evapotranspiration by the Irrigameter.

Table 4 shows the regression equations that must be used to determine the water heights in the evaporator of the Irrigameter and their determination coefficients, for each season of the year.

Due to the good fit of the equations, evidenced by the significances of the regression coefficients and high determination coefficients, the equations obtained for each season can be used to determine the water heights in the evaporator of the Irrigameter, so that it directly estimates the value of reference evapotranspiration ($K_I = 1$) or crop evapotranspiration for any development stage, making in this case K_I equal to Kc. The water heights in the evaporator of the Irrigameter recommended to estimate the reference evapotranspiration of the Southern region of Tocantins for the spring, summer, autumn and winter are 3.4, 4.0, 3.8 and 2.3 cm, respectively.

According to the studies conducted by Oliveira et al. (2011b), during the months from August 2008 and May 2009, for the region of Alto Paranaíba-MG, the analysis of the data for the entire experimental period showed that, to estimate reference evapotranspiration using the Irrigameter, the device must be operated with water height of 4.1 cm in the evaporator.

According to Tagliaferre et al. (2012b), when operated with water level of 3 cm, the Irrigameter showed satisfactory performance in the estimate of reference evapotranspiration in Guanambi-BA, between April 2009 and January 2010. Oliveira et al. (2011a) elucidated that, to obtain the estimate of reference evapotranspiration under the climatic conditions of Jaíba-MG, it is recommended to use the device equipped with evaporator operating with water height of 3.7 cm.

Table 4. Fitted regression equations for the determination of water heights in the evaporator of the Irrigameter for each season of the year

Season of the year	Equation	Determination coefficient (R^2)
Spring	$\hat{y}$ = 0.2222***X + 0.2348	0.99
Summer	$\hat{y}$ = 0.2070***X + 0.1803	0.99
Autumn	$\hat{y}$ = 0.4382e0.2182X	0.99
Winter	$\hat{y}$ = 0.6455e0.1889X	0.99

***Significant at 0.01 probability level by t-test

Conclusions

The water heights recommended in the evaporator of the Irrigameter, so that it estimates the reference evapotranspiration in the Southern region of the Tocantins state, for spring, summer, autumn and winter are 3.4, 4.0, 3.8 and 2.3 cm, respectively.

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