Evapotranspiration, crop coefficient and water consumption of pulse-irrigated bell peppers at different growing seasons

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Abstract

Pulse irrigation is among the techniques used to improve the efficiency of water management, consisting of the fractional application of the actual irrigation needed. Seeking to maximize the use of water in agricultural production, the objective was to determine the water consumption of bell peppers through the crop coefficient, crop evapotranspiration and pulse-irrigated reference evapotranspiration, at different growing seasons. The experiments were carried out from January to March, May to July and August to October, with the installation of 25 drainage lysimeters, distributed along five planting rows. The crop coefficient obtained for each irrigation pulse was determined through the ratio between the crop evapotranspiration and the reference evapotranspiration. Crop evapotranspiration was obtained daily for each irrigation pulse, determined by the difference between an applied and a drained depth. The reference evapotranspiration was estimated using the Penman-Monteith, Hargreaves-Samani, Solar Radiation, Blaney-Criddle and Priestley-Taylor methods. The Penman-Monteith method showed higher reference evapotranspiration when compared to the other estimation methods. Crop evapotranspiration was lower in the continuous pulse, due to the availability of water for the plant to be applied in the total irrigation time. Thus, the lowest water consumption obtained in pulse 1 and the higher obtained in pulse 5, in all seasons. Evidencing that the addition of irrigation pulses provided the best use of water by the crop. This study demonstrates the importance of optimizind the use of water in irrigated agriculture, helping technicians and producers in decision making.

Introduction

One of the irrigation techniques that has been implemented is pulse irrigation or intermittent irrigation. This irrigation technique performs the application of water divided into several events, applied to plants throughout the day and according to their water needs, resulting in better use of water (Zamora et al. 2021). The use of techniques and tools that promote the rationalization of inputs and increases in agricultural production necessary for the development of intensive and sustainable agriculture.

To ensure efficient irrigation management, it is essential to determine the water consumption of crops during the growing cycle. Since the water depths are based on the evapotranspiration of the crop consistent with its real water needs demanded.

Proper irrigation management requires knowledge of the crop's water consumption, which is determined by the crop coefficient (Kc), calculated through the ratio between crop evapotranspiration (ETc) and reference evapotranspiration (ETo) (Allen et al. 1998). The determination of ETc can be through direct and indirect methods. Among the direct methods, the procedure used to obtain it is the use of lysimeters, being these drainage, weighing or water table, which can be used in several researches (Wallman and Delin 2022; Mira-García et al. 2021). To estimate the ETo, it is necessary to apply methods or equations, which are calculated through climatic factors (Jiao and Hu 2022).

Kc can vary depending on factors such as plant type and density, sowing time, cultivation site, weather conditions, vegetative growth, plant development stage, soil preparation and cultivation conditions (direct seeding in straw or not, with or without weed control), well as, can integrate the effect of all of them. These factors can influence the achievement of coefficients for different crops. However, there are Kc values tabulated according to Bulletin 33 (FAO), but which need to be adjusted to local conditions.

The bell pepper crop (*Capsicum annuum* L.) is among the ten most economically important vegetables for agribusiness worldwide and this market stimulates family farming, increasing the generation of jobs and income (Camara 2020). According to Carvalho et al. (2011) to obtain high yields in the pepper crop, irrigation is one of the techniques that must be adopted in its management, as this crop requires a regular supply of water throughout the cycle. However, the accumulation of water in the soil must be avoided.

In this way, the climatic differences from one region to another generates alternating consumption of water by the plants, which can be estimated incorrectly, requiring its determination for the region of interest. To analyze the hypothesis, the work seeks to answer the questions: (1) How to determine the water consumption of the pepper crop? (2) Do different growing seasons change the water consumption of the crop? (3) Does the fractionation of irrigation influence water consumption? To answer these questions, the objective of this study was to determine the water consumption of bell peppers, irrigated by pulse, through the crop coefficient, crop evapotranspiration and reference evapotranspiration in different growing seasons.

Material And Methods

The experiments were carried out in the experimental area of Grupo Irriga (Research, Extension and Technological Innovation Group in Water Management for Irrigation), located on the premises of the Federal University of Alagoas - UFAL, Campus de Arapiraca, located in the Agreste region of Alagoas, in Brazilian Northeast. The Agreste region, located in the transition zone between the Zona da Mata and the Sertão of Alagoas, has an ‘As’ tropical climate with a dry summer season, according to the classification criterion of Alvares et al. (2014). The rainy season begins in May and lasts until mid-August, with an average rainfall of 854 mm $year^{-1}$, May to July are the wettest months and September to December are the driest.

The soil is classified as Oxisol medium texture, not saline according to the classification of Soil Survey Staff (2014). The physical-chemical analyzes of the soil in the experimental area, carried out before the implementation of the experiment, at a depth of 0.0–0.20 m, are available in Table 1. Fertilization was performed based on soil analysis and following the recommendations for the use of correctives and fertilizers in Minas Gerais – 5th Approximation (Ribeiro et al. 1999), presented in Table 2.

Table 1
Physicochemical characteristics of the soil in the experimental area, at a depth of 0.0–0.20 m

Physical characteristics											
Coarse sand		Thin sand		Total sand		Silt		Clay			Medium texture
($g\ kg^{-1}$)											
296		303		599		217		184			
Chemical characteristics											
pH	M.O.	PST	V	P	Na	K	Ca	Mg	Al	H + Al	CTC
(H_2O)	$g\ kg^{-1}$	(%)		($mg\ dm^{-3}$)	($cmol_c\ dm^{-3}$)						(pH 7)
6,2	23	1,48	59,70	17	0,07	0,25	1,50	1,00	0,00	1,90	4,72

pH: hydrogen potential; MO: organic matter; PST: exchangeable sodium percentage; V: base saturation; P: phosphor; Na: sodium; K: potassium; Ca: calcium; Mg: magnesium; Al: aluminum; H + Al: total acidity; CTC: cation exchange capacity

Table 2
Nutrient application recommendation for the pepper crop

Fertilization season	Nitrogen source	Phosphorus source	Potassium source
	(Urea)	(Triple Superphosphate)	(Potassium chloride)
	$g\ plant^{-1}$		
Planting	2,67	4,88	1,10
1° fertilizing	1,33	–	0,55
2° fertilizing	1,33	–	0,55
3° fertilizing	1,99	–	0,55
4° fertilizing	1,99	–	0,83
5° fertilizing	2,67	–	1,10
6° fertilizing	1,33	–	0,83

Water requirements, pulse irrigation management, for the hybrid Kolima pepper crop, were evaluated at three different times: January to March, May to July and August to October 2019.

A battery of twenty-five drainage lysimeters was installed, distributed along five planting rows. The lysimeters were spaced at 1.00 m between planting rows and 0.40 m between lysimeters. Each set of five drainage lysimeters corresponded to an irrigation pulse, totaling 25 lysimeters, thus obtaining five irrigation pulses. The irrigation pulses consisted of the fractionation of the applied water layer through the automation of the irrigation system.

The automation of the irrigation system was carried out through the use of five digital timers, which controlled the irrigation time, and five solenoid valves, which had the function of turning irrigation on and off according to the programming performed in the digital timers. Each digital timer controlled a solenoid valve. The interval determined between the beginning of one pulse and the other was 1 hour, thus applying the irrigation depth found daily for the crop.

To determine the irrigation depth of the pepper (ETc) and calculation of the irrigation time (programming for each pulse), the SLIMCAP system was used as a basis for calculation (Santos et al. 2020). The irrigation pulses were divided into five, being them: Pulse 1 (continuous), single application, full depth; Pulse 2, fractionation of the irrigation depth in two applications; Pulse 3, fractionation of irrigation depth in three applications; Pulse 4, irrigation depth fractionation in four applications and Pulse 5, irrigation depth fractionation in five daily applications.

The irrigation system used was drip. Weekly, before the beginning of each irrigation, a uniformity test was carried out in the drippers, the average flow remained at 0.5 L h^{-1} throughout the research.

Before implanting the crop in the lysimeters, the saturation of the soil was carried out by closing the end of each pipe. After 24 hours, the drains were opened to eliminate excess water, allowing the soil to reach field capacity.

Comparison Between Eto Methods

The meteorological data were used in the comparative analysis of the mathematical models for estimating ETo through the methods: Penman-Monteith, Hargreaves-Samani, Blaney-Criddle, Radiação Solar and Priestley-Taylor, whose data were obtained from the meteorological station of the Federal University of Alagoas, Campus de Arapiraca, located approximately 50 m from the experimental area.

The ETo values determined by the Penman-Monteith method were compared with the values obtained by the other methods, using correlation analysis and linear regression to obtain the coefficients of the equation (y = A + Bx) and the coefficient of determination (R^2). To determine whether an ETo estimation method is underestimating or overestimating the Penman-Monteith method, the value of A determined by the equation is observed. If A is less than 1, it underestimates, if it is greater than 1, it overestimates.

For a better correlation of the methods, the analysis was performed to determine the concordance index (d) according to Willmott et al. (1985) and performance index (c) proposed by Camargo and Sentelhas (1997), Equations 1 and 2, respectively:

$$d = 1 - \left[\frac{\Sigma (Pi - Oi)^2}{\sum \left(|Pi - O| + |Oi - O| \right)^2} \right]$$

1

$$c = d * r$$

2

On what: P_i = Estimated evapotranspiration by the method tested (mm); O_i = Evapotranspiration estimated by the standard method (mm) and O = Average of the values observed by the standard method (mm).

The criteria adopted for the interpretation of the ETo estimation methods, using the performance index (c), can be found in Table 3.

Table 3
Values of “c” for criteria for interpreting the performance of the ETo estimate

c values	Performance
> 0.85	Excellent
0.76–0.85	Very good
0.66–0.75	Good
0.61–0.65	Average
0.51–0.60	Sufferable
0.41–0.50	Bad
< 0.40	Terrible

Source: Camargo and Sentelhas (1997).

Table 4 contains the criteria adopted for interpreting the ETo estimation methods using the correlation index.

Table 4
Values of “r” for ranking the correlation index

r values	Classification
0.0–0.1	Very low
0.1–0.3	Low
0.3–0.5	Moderate
0.5–0.7	High
0.7–0.9	Very tall
0.9–1.0	Almost perfect
Source: Hopkins (2000).	

Determination Of Etc For Each Irrigation Pulse (Dup: Abstract ?)

The determination of ETc was performed daily for each irrigation pulse, through the collections performed in the drainage lysimeters with the measurement performed at an interval of 24 hours. ETc was obtained according to Aboukhaled et al. (1982), Eq. 3:

$$ETc = \frac{(L_A - L_D + P)}{A}$$

3

On what: L_A = Water depth applied by irrigation (mm); L_D = Depth drained from lysimeters (mm); P = Rainfall (mm) and A = Lysimeter area (m^2).

To calculate the applied depth (Eq. 4) and the drained depth (Eq. 5) from Eq. 3, exclude the highest and lowest recorded values, arithmetically average the remaining values and divide by the lysimeter area (Santos et al. 2020):

$$L_A = \frac{\sum_{i=1}^{n} V_A - larger\left(V_A\right) - smaller\left(V_A\right)}{A(n-2)}$$

4

$$L_D = \frac{\sum_{i=1}^{n} V_D - larger\left(V_D\right) - smaller\left(V_D\right)}{A(n-2)}$$

5

On what: V_A = Volume applied to the lysimeter; V_D = Volume drained from the lysimeter and n = Number of installed lysimeters (unit).

Determination Of Kc For Each Irrigation Pulse (Dup: Abstract ?)

The crop coefficient (Kc) was calculated as the ratio between the crop evapotranspiration of each irrigation pulse (ETc) and the reference evapotranspiration (ETo), according to Eq. 6:

$$Kc = \frac{ETc}{ETo}$$

6

On what: Kc = Crop coefficient (dimensionless); ETc = Crop evapotranspiration (mm) and ETo = Reference evapotranspiration (mm).

Through the ETc data, from the drainage lysimeters with their respective irrigation pulses and ETo, obtained by the Penman-Monteith equation, the cultivation coefficient was determined for each pulse and for each phenological phase of the pepper crop.

According to Doorenbos e Pruitt (1977) Kc presents distinct phases as it varies according to the phenological phase of the crop, such phases are characterized by:

- Phase I – Represents the initial establishment of the crop in the field, which goes from the transplanting date to 15 days after transplanting;
- Phase II – Characterizes the vegetative development of the pepper crop (16 to 30 days after transplanting);
- Phase III – Flowering and fruiting stage of the pepper crop (31 to 46 days after transplanting);
- Phase IV – Final stage of fructification from the first fruits until harvest (47 to 60 days after transplanting).

Meteorological Variables For Estimating Eto

The meteorological variables used were: temperature, relative air humidity, solar radiation and precipitation. Scoriza and Pinã-Rodrigues (2014) report that the phenological phases of a plant undergo variations according to climatic conditions, with precipitation and air temperature being the factors that cause more effects.

The maximum temperature obtained during the 1st growing season was 37.21°C, minimum temperature of 21.08°C and average temperature of 29.14°C (Fig. 1A). For the 2nd growing season, the maximum temperature obtained was 31.86°C, minimum temperature of 17.44°C and average temperature of 24.65°C (Fig. 1B). During the 3rd growing season, the maximum temperature recorded was 43.59°C, minimum temperature of 17.78°C and average temperature of 30.68°C (Fig. 1C).

The highest relative humidity obtained during the 1st growing season was 92.50% (Fig. 1A). Value close to that found during the 2nd growing season, which was 93.20% (Fig. 1B). In the 3rd growing season it was not different, the maximum relative humidity was 93.10% (Fig. 1C).

The solar radiation presented a daily average of 21,67 MJ m^{-2} day^{-1}, for the 1st growing season (Fig. 1D). The average value obtained for the 2nd growing season was 15,74 MJ m^{-2} day^{-1}, value well below compared to the previous crop (Fig. 1E). In the 3rd growing season, an average of daily solar radiation of 20,85 MJ m^{-2} day^{-1} (Fig. 1F), being between the values presented for the 1st and 2nd growing season.

For precipitation, a volume of 265.86 mm was recorded for the period referring to the 1st growing season of the experiment, with the highest daily volume recorded being 85.33 mm (Fig. 1G). During the 2nd growing season, the total volume obtained was 212.19 mm, with a maximum daily rainfall of 37.85 mm (Fig. 1H). And the total volume of precipitation of 64.01 mm was obtained in the 3rd growing season, with the lowest total volume recorded between the growing seasons, obtaining a maximum daily rainfall of 22.86 mm (Fig. 1I).

Results

Estimation of ETo and methods comparison

The ETo estimation methods showed similar behavior to each other (Fig. 2A). With the highest average ETo obtained by the FAO 56 standard method, Penman-Monteith, and by the Solar Radiation method, the lowest average ETo was obtained by the Hargreaves-Samani method (Table 5). The Hargreaves-Samani method was fitted for semi-arid condition, thus, its performance presents a reduction in the precision of the evapotranspiration estimate in rainy months (Alencar et al. 2011).

Table 5
Minimum (min), average (ave), maximum (max) and total ETo for the 1st, 2nd and 3rd growing season

1st growing season				
Methods	ETo			
	min	ave	max	Total
	(mm day^{-1})			(mm)
Penman-Monteith	2.10	5.53	7.28	337.42
Hargreaves-Samani	3.23	4.99	6.02	304.25
Solar radiation	1.24	5.52	7.68	336.79
Blaney-Criddle	1.47	5.10	7.10	311.05
Priestley-Taylor	2.07	5.28	6.47	322.33
2nd growing season				
Methods	ETo			
	min	ave	max	Total
	(mm day^{-1})			(mm)
Penman-Monteith	1.60	3.56	4.86	210.95
Hargreaves-Samani	1.63	3.19	4.14	194.88
Solar radiation	1.04	3.47	5.36	211.76
Blaney-Criddle	1.02	3.11	4.96	189.70
Priestley-Taylor	1.75	3.46	4.60	211.19
3rd growing season				
Methods	ETo			
	min	ave	max	Total
	(mm day^{-1})			(mm)
Penman-Monteith	3.38	5.88	7.50	358.46
Hargreaves-Samani	3.51	5.33	7.52	325.09
Solar radiation	2.51	5.27	6.98	321.69
Blaney-Criddle	2.22	3.77	5.03	229.88
Priestley-Taylor	3.01	5.16	6.63	315.02

The results observed for ETo, in view of the estimation methods used, were lower than those obtained in the previous cultivation season (Fig. 2B). With the highest mean value of ETo for the Penman-Monteith method and the lowest mean value for the Blaney-Criddle method (Table 5). The Solar Radiation and Priestley-Taylor methods showed approximate ETo results throughout the growing season. These results show that empirical methods require local adjustments in their models, which increases their tendency to be closer to the reference method, FAO 56 standard method, to result in better accuracy in determining the reference evapotranspiration in each analyzed growing season.

In the last growing season there was greater variation between the ETo values estimated by the different evapotranspiration methods (Fig. 2C). With the highest average ETo obtained by the Penman-Monteith method and the lowest average ETo by the Blaney-Criddle method (Table 5), the other methods showed an average ETo above 5 mm day^{-1}. The Priestley-Taylor method is a reference evapotranspiration estimation method sensitive to moisture variations, making it likely to present different results from those obtained in previous growing seasons.

The high mean values of ETo by the Penman-Monteith methods (5.53 mm day^{-1}) and Solar Radiation (5.52 mm day^{-1}) in the 1st growing season, and by the Penman-Monteith method (5.88 mm day^{-1}) for the 3rd growing season, occurred due to this region, at these times, receiving higher incidences of radiation, high temperature and low air humidity.

Silva et al. (2017) determining the Kc of the pepper crop in the Agreste region of the state of Alagoas, obtained ETo values of 4.25 mm day^{-1}, maximum of 6.12 mm day^{-1} and minimum of 1.38 mm day^{-1} for the Penman-Monteith method, and average of 2.78 mm day^{-1}, maximum of 4.18 mm day^{-1} and minimum of 0.77 mm day^{-1} for the Hargreaves-Samani method. Obtaining average, maximum and minimum values lower than those observed in the present research for the FAO standard method and for the Hargreaves-Samani method, referring to the 1st and 3rd growing season. It was also observed that the average and maximum ETo obtained by the Penman-Monteith method was higher than the values obtained in this research in relation to the 2nd growing season and approximate values of maximum ETo for the Hargreaves-Samani method.

When correlating the FAO standard method with the other study methods individually, it was observed that the highest correlation obtained was between the Blaney-Criddle method and the standard method, presenting an R^2 = 0,95 (Fig. 3). The Solar Radiation method was the one that most overestimated the FAO standard method, surpassing the Blaney-Criddle method for the 1st harvest, and the Hargreaves-Samani and Priestley-Taylor methods underestimated the ETo values in relation to the Penman-Monteith method, these behaviors are observed from the coefficient of the equation.

The same behavior was observed for the 2nd growing season when correlating the FAO standard method with the other methods under study individually, there was a greater correlation with the Blaney-Criddle method according to the R^2 obtained, with a value of 0.96 (Fig. 4). For the Solar Radiation method, there was an overestimation in relation to the FAO standard method and the Hargreaves-Samani and Priestley-Taylor methods underestimated when correlated with the Penman-Monteith method.

The correlation between the Penman-Monteith method and the other reference evapotranspiration estimation methods, carried out for the 3rd harvest, resulted in a greater correlation obtained between the Blaney-Criddle method and the FAO standard method, a factor that visualized from R^2, being equal to 0.75 (Fig. 5). Such behavior was observed in all the analyzed crops.

With the coefficient of the equation, it is possible to determine whether the method under study overestimates or underestimates the Penman-Monteith method. In view of this, it can be observed that no method overestimated the standard FAO method. To overestimate the standard method one must have a equation coefficient greater than 1.

Comparing the Hargreaves-Samani method with the other ETo estimation methods, it is observed that there was a similar behavior in all growing seasons, as it underestimated the ETo values. The values of determination coefficient (r^2 = 0.77) and correlation coefficient (r = 0.88) for the Hargreaves-Samani method indicate that this method has a presents average performance to perform the ETo estimate (Table 6), in the 1st growing season, classification present in the Table 3.

High values of determination coefficient (r^2 = 0.94; 0.96 and 0.90) and high correlation coefficients (r = 0.97; 0.98 and 0.95) for the Solar Radiation methods are observed, Blaney-Criddle and Priestley-Taylor, evidencing the accuracy of the ETo estimates by these methods. In addition to these methods having presented excellent performance, only the Hargreaves-Samani method had an average performance.

Table 6

Estimation of coefficient of determination (r^2), correlation coefficient (r) and performance index (c), for the methods of Hargreaves-Samani (H-S), Solar Radiation (R-S), Blaney-Criddle (B-C) and Priestley-Taylor (P-T) referring to the 1st, 2nd and 3rd growing season

Statistical parameters				
1st growing season				
Methods	r^2	r	c	Performance
H-S	0.77	0.88	0.67	Average
R-S	0.94	0.97	0.94	Excellent
B-C	0.96	0.98	0.93	Excellent
P-T	0.90	0.95	0.91	Excellent
2nd growing season				
Methods	r^2	r	c	Performance
H-S	0.77	0.87	0.78	Very good
R-S	0.95	0.98	0.96	Excellent
B-C	0.96	0.98	0.92	Excellent
P-T	0.88	0.93	0.91	Excellent
3rd growing season				
Methods	r^2	r	c	Performance
H-S	0.37	0.61	0.43	Bad
R-S	0.58	0.76	0.59	Poor
B-C	0.75	0.87	0.29	Terrible
P-T	0.57	0.76	0.72	Good

High values of coefficient of determination (r^2 = 0.95; 0.96 and 0.88) were observed for the Solar Radiation, Blaney-Criddle and Priestley-Taylor methods, and high correlation coefficients (r = 0.98; 0.98 and 0.93) for the same methods, respectively, indicating the accuracy of ETo estimates by these methods in the 2nd growing season. Among the methods studied, only Hargreaves-Samani obtained a performance index classified as very good, the other methods obtained excellent performance. For Silva et al. (2018) the Solar Radiation method obtained high values of determination coefficient (r^2 = 0.84) and correlation (r = 0.98), being a method classified as having good performance, which corroborates with this research.

The determination coefficient (r^2 = 0.37) and the correlation coefficient (r = 0.61), for the Hargreaves-Samani method, indicate that this method has a low performance for estimating the ETo, in the 3rd growing season (Table 6). The only method that showed a higher value of coefficient of determination (r^2 = 0.75) was the Blaney-Criddle method and the high values of correlation coefficient (r = 0.76, 0.87 and 0.76) were obtained by the Solar Radiation, Blaney-Criddle and Priestley-Taylor methods, respectively, which demonstrates the accuracy of the ETo estimates by these methods. Regarding the performance index, the only method that presented a good performance was the Priestley-Taylor method, the other methods presented lower performances.

Silva et al. (2018), evaluating the evapotranspiration and the crop coefficient of irrigated carrots in the Alagoas agreste, found that the ETo estimated by the Hargreaves-Samani method showed low values of coefficients of determination (r^2 = 0.24) and correlation (r = 0.49), corroborating the present research. Similarly, Lucena et al. (2016) comparing different reference evapotranspiration estimation methods in the rainy and dry seasons, they also found poor performance of the Hargreaves-Samani method.

Determination Of Etc For Each Irrigation Pulse

The increase in the number of irrigation pulses provided increments in ETc, with the highest maximum value of ETc (8.40 mm) obtained with pulse 5 and the lowest mean value (8.36 mm) with pulse 1. It can be observed that due to the high rainfall that occurred on March 16 (Fig. 1G) there was a lower ETc for all irrigation pulses studied (Fig. 6A).

For the 2nd growing season, an increase in ETc was also observed at the expense of an increase in irrigation pulses. It can be seen from Fig. 6B, that pulse 1 (continuous) provided the lowest average ETc of peppers with 4.41 mm and pulse 5 provided the highest average ETc of peppers with 4.51 mm, with a small difference between the lowest and highest ETc, precisely due to the volume of water precipitated during the growing season.

The highest volumes of pepper ETc were observed in the 3rd growing season. The data presented a behavior similar to those obtained in the first two growing seasons, where with the increase in irrigation pulses there was an increase in the ETc of sweet pepper.

Thus, with a lower ETc, pulse 1, with 8.92 mm. A lower ETc calculated in this growing season surpassed a higher ETc observed in the 2nd growing season. And pulse 5, as mentioned earlier, showed the highest ETc with 9.50 mm (Fig. 6C).

Silva et al. (2017), working with the same crop, reported that the highest occurrences of evapotranspiration were observed in the flowering and fruiting phase of the crop, reaching a maximum of 10.78 mm day^{-1}, with an ETc value higher than that observed in all crops analyzed in this research.

Determination Of Kc For Each Irrigation Pulse

Figure 7A shows the crop coefficient (Kc), obtained using the Penman-Monteith method throughout the entire phenological cycle of the crop, using different irrigation pulses during the 1st growing season. Note that pulse 1 provided the lowest Kc values (0.61; 0.61; 0.81; 1.09 and 1.24) and pulse 5 provided the highest Kc values (0.77; 0.77; 0.89; 1.15 and 1.27) when compared to the other pulses analyzed.

The crop coefficients, referring to the 2nd growing season, obtained throughout the phenological cycle of the crop through the use of different irrigation pulses are shown in Fig. 7B. Pulse 1 provided the lowest Kc values (0.55; 0.55; 0.74; 0.94 and 1.16) and pulse 5 was responsible for providing the obtaining the highest Kc values (0.65; 0.65; 0.83; 0.99 and 1.19) when compared to the others.

And, finally, Kc values throughout the phenological cycle of the crop, obtained using different irrigation pulses during the 3rd growing season (Fig. 7C). The data obtained for the 3rd growing season followed the same behavior observed for the 1st and 2nd growing seasons. It can be seen that the Kc values were the lowest for pulse 1 (0.59; 0.59; 0.84; 1.04 and 1.22) and highest for pulse 5 (0.70; 0.70; 1.00; 1.26 and 1.30) when compared to the others.

Albuquerque et al. (2012) obtained Kc values of 0.27 and 0.33 for phase I, 0.50 and 0.46 for phase II and 0.63 and 0.65 for phase III, two Kc values for the phenological phase due to the treatments used in the research. It can be observed that the cited values aren’t close to the Kc values obtained in the present research, even with pulse 1 that obtained the lowest Kc values. This fact may have occurred due to the different meteorological conditions of the growing seasons.

For Dalmago et al. (2003) Kc presented daily minimum values of 0.02 in the first days after transplanting and some maximum values close to 1.5 in the final period of the experiment, surpassing the maximum value obtained in this season. In a new study carried out Silva et al. (2017) found values of 0.81 for the 2nd phase and 1.05 for the 3rd phase.

The Kc values for the pepper crop recommended by FAO Bulletin 33 for the 1st phase range from 0.30 to 0.40; 2nd stage varies from 0.60 to 0.75; 3rd stage is between 0.95 to 1.1 and for 4th stage it is 0.81.

Discussion

The lowest values of ETo were in charge of the methods of Hargreaves-Samani, Blaney-Criddle and Priestley-Taylor. It is worth remembering that such methods were estimated for specific environmental conditions and, therefore, will have different results when applied to humid, semi-humid, arid and semi-arid regions. Hence the need and importance of analyzing different methods in a given region, in order to determine the best applicability in that environment.

Among the different regions studied in several studies, the Hargreaves-Samani method was the best temperature-based method for grass covered areas in a Mediterranean forest in Greece (Bourletsikas et al. 2018), Blaney-Criddle method performed better than other temperature-based methods in wetlands in

Iran (Tabari et al. 2013) and the Priestley-Taylor method was one of the best to calculate ETo in the Brazilian Savanna (Valle Júnior et al. 2020).

The first and last growing seasons showed relatively higher ETo than the second growing seasons and, according to some studies, air temperature is the main factor that affects reference evapotranspiration (Jiao and Hu 2022; Ferreira et al. 2019), and temperature was one of the meteorological factors that most affected such growing seasons in this study.

The evapotranspiration of the crop showed a similar behavior in all growing seasons, since the continuous pulse resulted in lower ETc and the fractional pulse in five applications showed higher ETc. Thus, irrigation pulses of short duration, application of a water sheet divided into several events during the day, are associated with lower water loss (Eid et al. 2013). The development of a proper handling of check pulses is essential to obtain high production and qualitative tests (Lozano et al. 2020).

Crop coefficients for early and development stages are subject to wide variation in values due to irrigation frequency, so it needs to be improved whenever its use is needed (Matsunaga et al. 2022). Crop coefficients were calculated based on data obtained using the Penman-Monteith method. During the initial phase of growth, Kc values ranged from 0.55–0.61 and 0.65–0.77 for pulse 1 and pulse 5, respectively. In the crop development, the values of Kc increased as the cover of the vegetal canopy increased.

The differences in the final values of Kc mainly depended on the different growing seasons of the crop (Nyawade et al. 2021). As crop coefficients change between seasons, the local specific value of these coefficients is required for the local conditions under which the crop is being grown (Cao et al. 2021).

Marsal et al. (2013) suggested that determining specific local values in relation to plant characteristics and management can be a bit tricky, as many factors can influence crop coefficients in different ways throughout a season. Therefore, the importance of determining Kc values for different growing seasons in the same region. A study showed that the variation in Kc values between seasons can be attributed to several reasons, such as the trend of canopy development, amounts of rainfall in different seasons, and differences in energy absorption characteristics (Sikka et al. 2009).

Therefore, it is concluded that the Penman-Monteith method presented evapotranspiration reference methods, compared to other reference estimation methods. The Solar Radiation method overestimated the FAO standard method in all growing seasons.

The evapotranspiration of the bell pepper crop was lower in the continuous pulse, due to the availability of water for the plant to be applied in total irrigation time. Water consumption by the pepper crop was lower at pulse 1 and higher at pulse 5, in all growing seasons. Evidencing that the addition of irrigation pulses provided the best use of water by the pepper crop.

This study can provide theoretical guidance and technical support for the determination of reference evapotranspiration, crop evapotranspiration and crop coefficient in managing techniques in irrigated agriculture. In addition to contributing to the study of different growing seasons in arid and semi-arid agricultural regions. The results of this study also provide important information for the selection of empirical methods for estimating ETo based on local climatic conditions in regions outside the study area. Research related to irrigation pulses is still scarce, even in an area that covers Sustainable Development Goal 6, however, it is a field for future research.

Declarations

Conflict of interest The authors declare that they have no financial interests.

Authors' contribution All authors contributed to the conception and design of the study. The preparation, collection and analysis of data were performed by Thaís Rayane Gomes da Silva, Samuel Barbosa Tavares dos Santos and Márcio Aurélio Lins dos Santos. The manuscript was corrected and revised by Cícero Gomes dos Santos, Gerônimo Ferreira da Silva, Marcos Alex dos Santos and Valéria Escaio Bubans. All authors read and approved the final manuscript.

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Figures

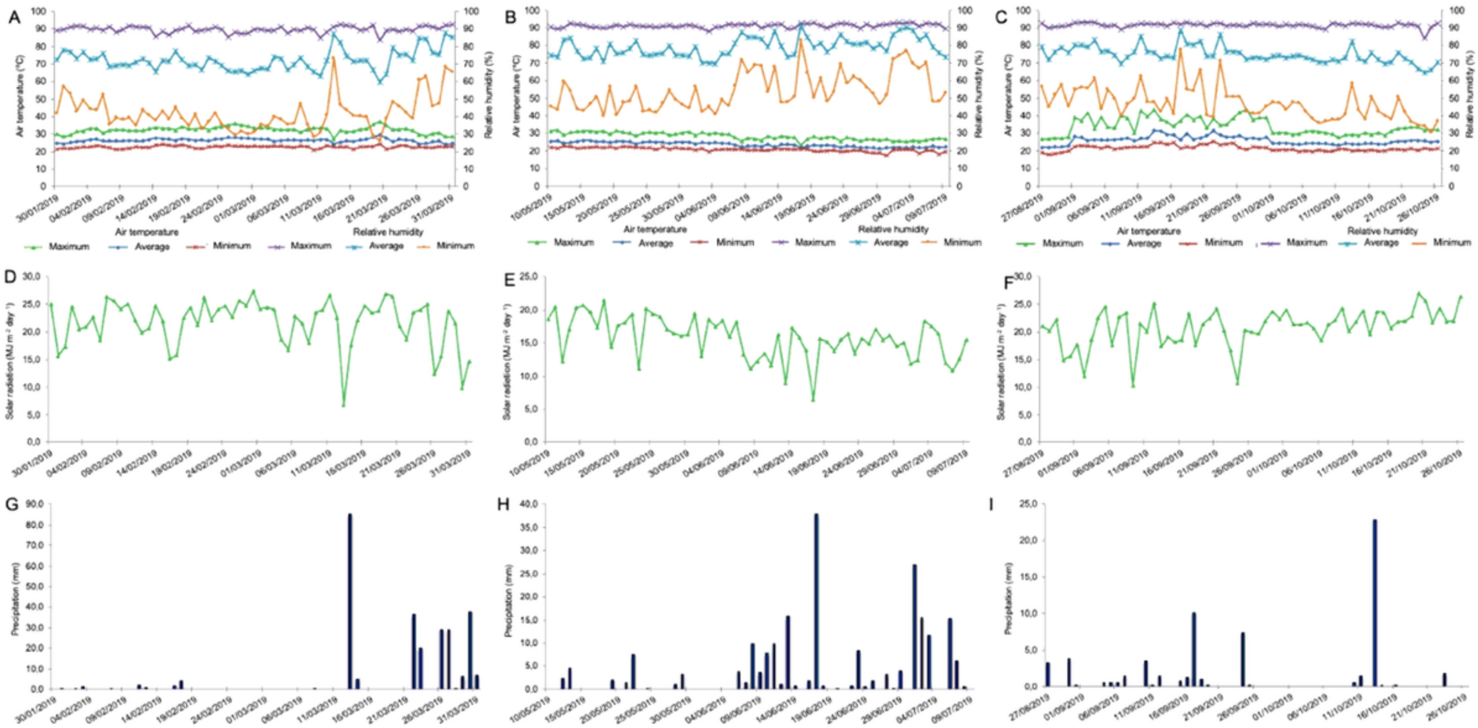

Figure 1

Minimum, average and maximum temperatures, relative humidity, solar radiation and precipitation for the 1st, 2nd and 3rd harvest

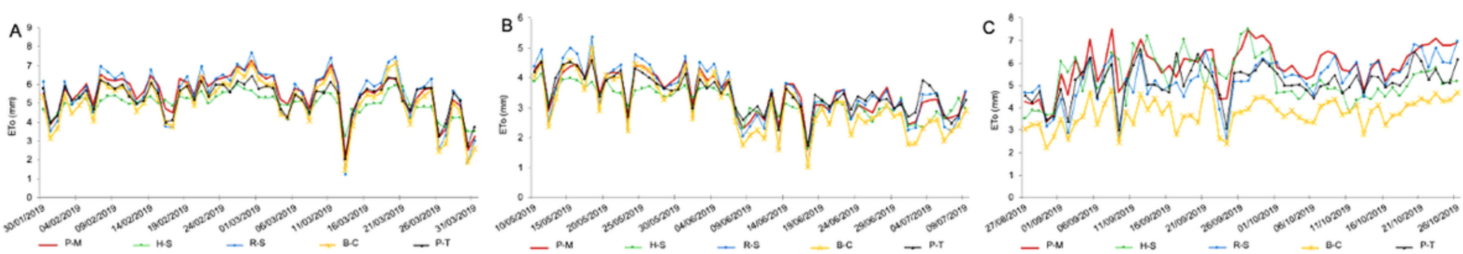

Figure 2

Temporal variation of reference evapotranspiration estimated by the Penman-Monteith, Hargreaves-Samani, Solar Radiation, Blaney-Criddle and Priestley-Taylor methods referring to the 1st, 2nd and 3rd growing season

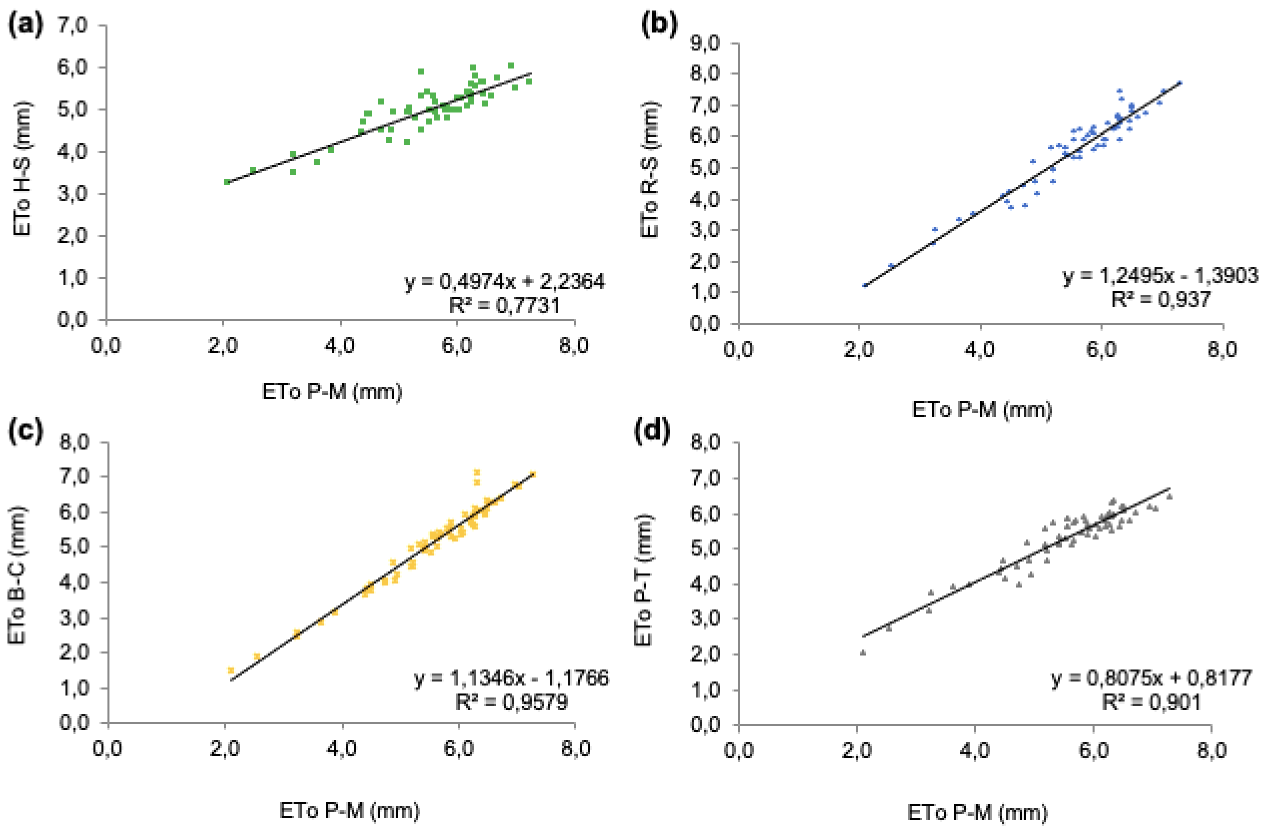

Figure 3

Correlation of reference evapotranspiration estimation between the Penman-Monteith method and the Hargreaves-Samani (a), Solar Radiation (b), Blaney-Criddle (c) and Priestley-Taylor (d) methods for the 1st growing season

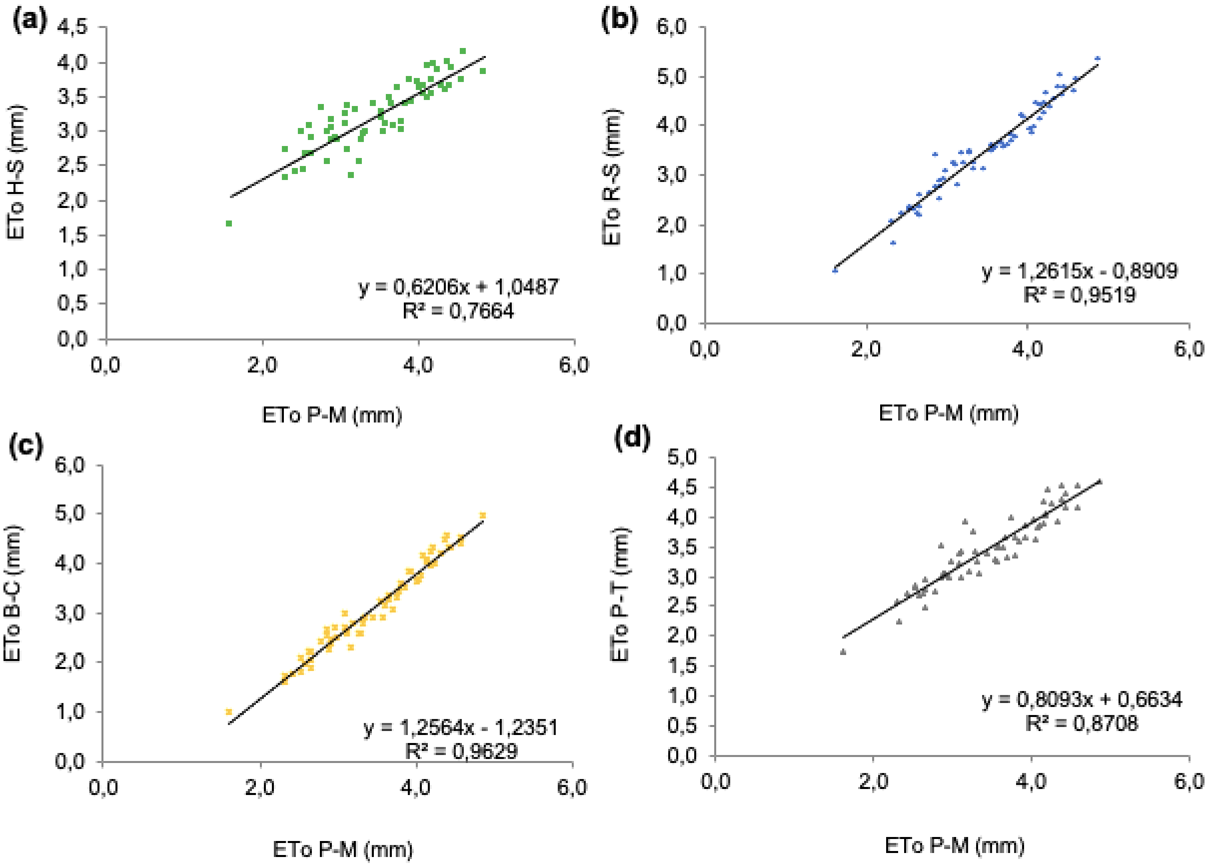

Figure 4

Correlation of reference evapotranspiration estimation between the Penman-Monteith method and the Hargreaves-Samani, Solar Radiation, Blaney-Criddle and Priestley-Taylor methods for the 2nd growing season

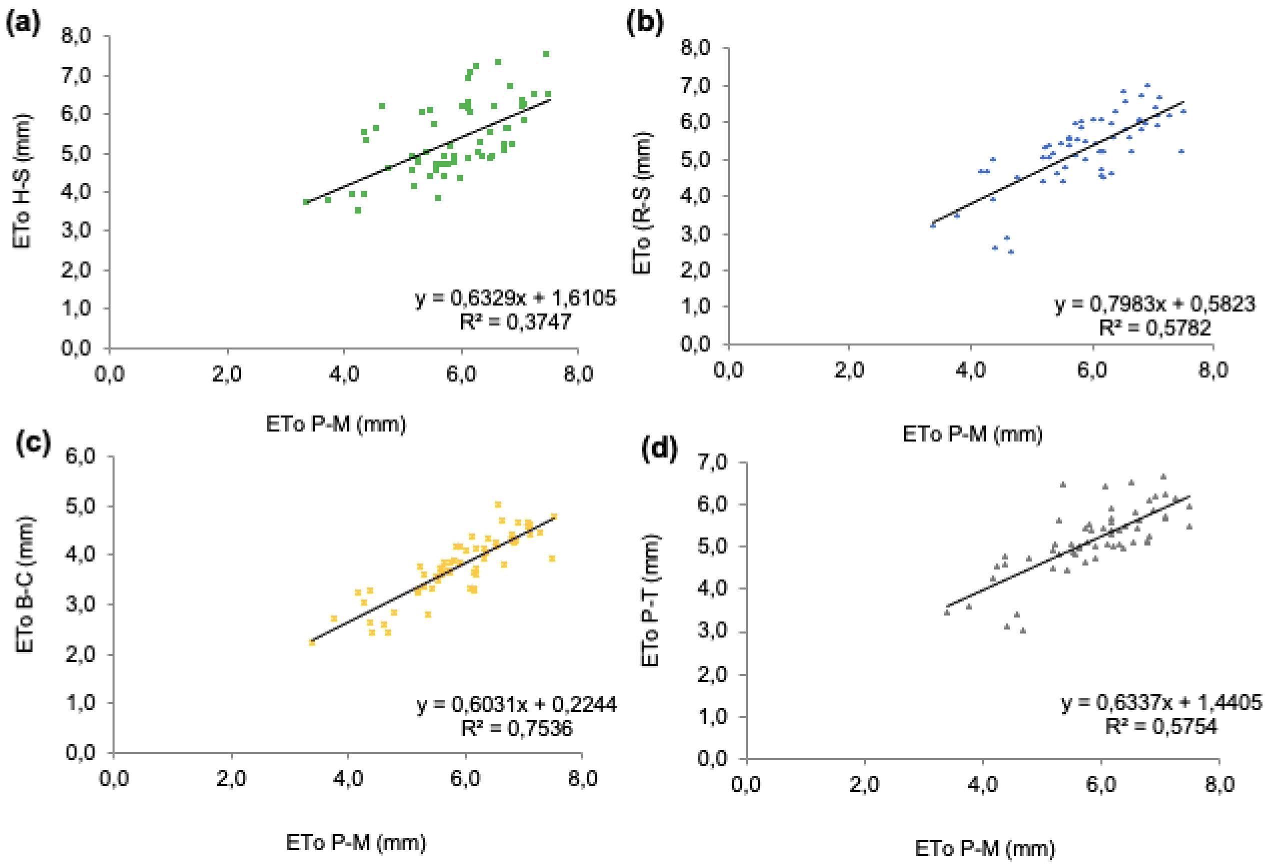

Figure 5

Correlation of reference evapotranspiration estimation between the Penman-Monteith method and the Hargreaves-Samani, Solar Radiation, Blaney-Criddle and Priestley-Taylor methods for the 3rd growing season

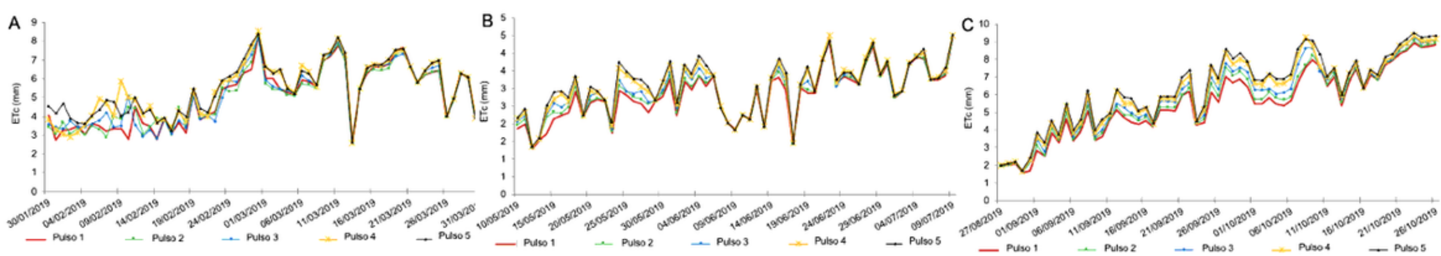

Figure 6

Crop evapotranspiration for pulse 1, pulse 2, pulse 3, pulse 4 and pulse 5 referring to the 1st (a), 2nd (b) and 3rd (c) growing season

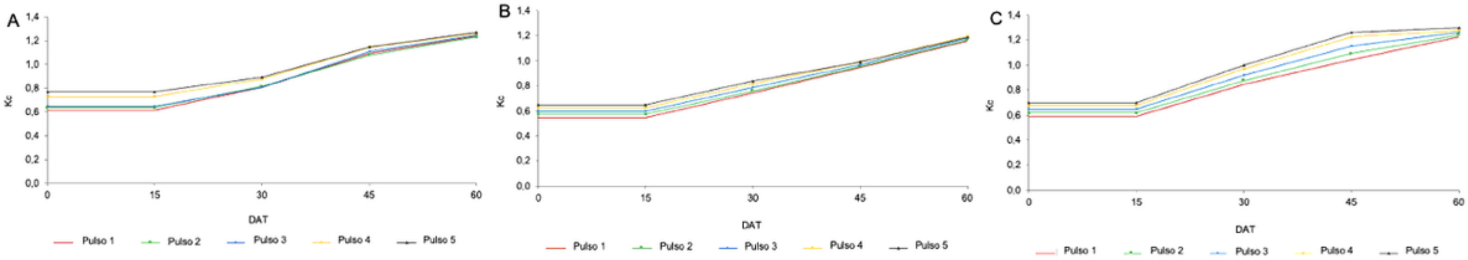

Figure 7

Crop coefficients of bell pepper, obtained by the Penman-Monteith method, for each of the irrigation pulses as a function of days after transplanting during the 1st, 2nd and 3rd growing season