TECHNICAL PAPER

EVAPOTRANSPIRATION AND CROP COEFFICIENT FOR POTATO IN ORGANIC FARMING[1]

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ABSTRACT: The aim of this study was to quantify the water consumption and the crop coefficients (Kc) for the potato (*Solanum tuberosum* L.), in Seropédica, Rio de Janeiro (RJ), Brazil, under organic management, and to simulate the crop evapotranspiration (ETc) using the Kc obtained in the field and the ones recommended by the Food and Agriculture Organization (FAO). The water consumption was obtained through soil water balance, using TDR probes installed at 0.15m and 0.30m deep. At the different stages of development, the Kc was determined by the ratio of ETc and reference evapotranspiration, obtained by Penman-Monteith FAO 56. The crop coefficients obtained were 0.35, 0.45, 1.29 and 0.63. The accumulated ETc obtained in the field was 109.6 mm, while the ETc accumulated from FAO's Kc were 142.2 and 138mm, respectively, considering the classical values and the values adjusted to the local climatic conditions. The simulation of water consumption based on meteorological data of historical series from 1961 to 2007 provided higher value of ETc when compared with the one obtained in the field. From the meteorological data of historical series, it was observed that the use of Kc recommended by FAO may overestimate the amount of irrigation water by 9%, over the same growing season.

KEYWORDS: *Solanum tuberosum* L., time domain reflectometry, irrigation.

EVAPOTRANSPIRAÇÃO E COEFICIENTE DE CULTIVO DA BATATA EM SISTEMA AGROECOLÓGICO DE PRODUÇÃO

RESUMO: O trabalho foi desenvolvido visando a quantificar, sob manejo agroecológico, o consumo hídrico e os kcs para a cultura da batata (*Solanum tuberosum* L.), em Seropédica (RJ), e a simular a evapotranspiração da cultura (ETc), utilizando os kcs obtidos e os kcs preconizados pela FAO. O consumo hídrico foi obtido por meio do balanço hídrico do solo, utilizando sondas de TDR instaladas a 0,15 e 0,30 m de profundidade. Nas diferentes fases de desenvolvimento, o kc foi determinado pela razão entre a ETc e a evapotranspiração de referência, obtida por Penman--Monteith FAO 56. Os kcs obtidos foram 0,35; 0,45; 1,29 e 0,63. A ETc acumulada obtida em campo foi de 109,6 mm, enquanto as ETcs acumuladas a partir dos kcs FAO foram de 142,2 e 138,0 mm, respectivamente, considerando os valores clássicos e os corrigidos para as condições climáticas locais. A simulação do consumo hídrico com base nos dados meteorológicos da série histórica de 1961 a 2007 proporcionou valor maior de ETc quando comparado ao obtido em campo. A partir dos dados meteorológicos obtidos na série histórica, observou-se que a utilização de kcs preconizados pela FAO pode superestimar a quantidade de água na irrigação em 9%, considerando o mesmo período de cultivo.

PALAVRAS-CHAVE: *Solanum tuberosum* L., reflectometria no domínio no tempo, irrigação.

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INTRODUCTION

The irrigated agricultural production consumes 70% of drinking water from rivers and groundwater (Comprehensive Assessment of Water Management in Agriculture, 2007), and, in Brazil, the irrigation consumption is in the range of 61% of fresh water available (FAO, 2009). Given the worldwide concern with the shortage of drinking water due to global climate changes, pollution, population growth, among other problems, procedures to increase the efficiency of water use in irrigation should be adopted.

The irrigation efficiency may be increased by using drip systems (ONDER et al., 2005; SHOCK et al., 2.007; STARR et al., 2008). Additionally, one can optimize the use of water with a correct handling of irrigation, based on the actual water requirements of culture in local cultivation conditions.

For the determination of water consumption, or of crop evapotranspiration (ETc), it is necessary to know the crop coefficients (Kc), which are influenced by developmental stages and physiological attributes of the plant (albedo, aerodynamic properties, height, resistance of vegetative canopy), and also by conditions which affect the evaporation of water from the soil (ALLEN et al., 1998). FAO assigns Kc for various crops under conditions of sub-humid climate, as for example potato (*Solanum tuberosum* L.). However, these coefficients need to be adjusted according to local conditions, since the crop coefficients recommended by FAO do not consider the variability of climate, cultural practices and soil and water management (MEDEIROS et al., 2005).

For determination of adjusted Kc, ALLEN et al. (1998) recommend the use of empirical equations that include the frequency of rainfall, wind speed, minimum relative humidity and plant height. Otherwise, it is possible to determine Kc by field tests (MIRANDA et al., 2004; AMAYREH & AL-ABED, 2005), in which one determine the demand evapotranspirometric by direct quantification of humidity variations of the soil.

Several authors have different values of Kc for potato (PEREIRA et al., 1995; FRANKE & KONIG, 1994; KASHYAP & PANDA, 2001). Thus, from the ratio of these values with the reference evapotranspiration (ETo), it can be obtained estimates of ETc with greater precision to every culture environment. The use of values of ETc more concise allows better scaling of irrigation systems, in addition to quantify correctly the depths that suit the need of the culture (SOUZA et al., 2009; OLIVEIRA et al., 2010).

Water is the most important factor in potato production, and it is possible to increase their productivity levels through proper programs of irrigation management throughout its growth phase (YUAN et al., 2003). However, many farmers do not adopt an optimized management of irrigation, resulting in losses on plant growth and consequent decreases in productivity and quality of tubers (SILVA et al., 2007).

Based on the above, this study was developed in order to quantify the water consumption of potato (*Solanum tuberosum* L.) in Seropédica-RJ through the soil water balance, and to determine the crop coefficients for stages of culture development. Moreover, the scope of this study was to compare the Kc obtained with the ones recommended by FAO, adjusted and unadjusted according to the local climate conditions, and to confront the ETc obtained and calculated with these coefficients. And lastly, we simulated the ETc, estimated by Kc obtained and recommended by FAO, through historical series of ETo and effective rainfall (mm) for the period from 1961 to 2007.

ISSUE DESCRIPTION

The study was conducted in the experimental area of the Integrated System of Agroecological Production, located in Seropédica-RJ (22°45'06" S and 43°40'25" W), from May 7th to August 2nd, 2010. The area has an average height of 33.0 m and the soil was classified as moderate Dystrophic Red Argisols A (Ultisols), medium/sandy texture (EMBRAPA, 2006).

Potato culture (*Solanum tuberosum* L. "Opaline") was grown on an area of 80 m², using plots with dimensions of 5.0 m long by 3.2 m wide. The plots consisted of 2 seedbeds formed by 2 rows each, with 50 plants, spaced by 0.8 m between rows and 0.4 m between plants. Before planting, the field was fertilized with manure in the amount of 62.1 kg ha^{-1} of nitrogen and 100 kg ha^{-1} of potassium sulphate (50% K_2O). At 30 days after planting (DAP), It was realized ridging and fertilization with a compound of castor bean cake, equivalent to 90 kg ha^{-1} of N.

It was used an irrigation system composed of pressure-compensating over-line drippers of nominal flow rate of 6.05 L h^{-1}, spaced by 0.2 meters from each other. After tests realized in field, it was found a mean flow of the drippers of 6.87L h^{-1}, to a working pressure at the beginning of the line of 100 kPa. Under these conditions, we obtained a average distribution uniformity of about 90%. The system was installed in single rows, consisting of a PVC derivation line of 50 mm and lateral lines with polyethylene tubing of 16 mm. In order to maintain suitable conditions of pressure in line for better uniformity, irrigations were performed simultaneously in two rows of plants in each plot.

Irrigation management was based on monitoring of soil humidity, and, for this, five TDR probes batteries were installed at depths referring to 0-0.15 and 0.15-0.30 m, whose readings were performed every 2 days. Initially, irrigation management was done based on the amount of humidity for the field capacity (θcc) of 0.214 cm³ cm^{-3} (value obtained directly in the field at 15 cm depth). Later, it was adopted θcc of 0.26 cm³ cm^{-3}, value related to the depth of 0-30 cm.

The water balance in the soil was accomplished counting the irrigation depths applied (I), the variation of soil storage (ΔSW) and effective precipitation (Pe) (Equation 1). As GARCIA & GARCIA et al. (2009), other variables such as water balance as superficial drainage, deep drainage, capillary rise, and variation of subsurface flows of input and output were considered null, having in mind the characteristics of the area and the irrigation system used.

$$\mathrm{ETc} = \mathrm{I} + \mathrm{Pe} \pm \Delta\mathrm{SW} \qquad (1)$$

To evaluate the effective precipitation (Pe), it was considered the precipitated water blade (mm) which provided changes in soil humidity, via TDR, and which was effectively available for the culture.

The irrigation depth was calculated by the average of plot humidity, determined by TDR readings. Initially, it was adopted the percentage of wetted area of 50%, due to the increased representation of the operation area of drippers in the rows of cultivation. Due to the increase in the percentage of shading of the potato under the cultivation area, the percentage of shaded area (PSA) started to be used in the calculation of the depth, considering an application efficiency of 90% (MANTOVANI et al., 2009).

From the water balance in the soil, it was possible to estimate the crop evapotranspiration (ETc) during the 88 days of culture, the same being divided into four sub-periods, denominated: from planting (PL) to the emerging (EM) (1-17 DAP); from emerging (EM) to the beginning of tuber (BT) (18-33 DAP); from the beginning of tuber (BT) to the beginning of senescence (BS) (34-77 DAP); and from the beginning of senescence (BS) to harvest (HA) (78-89 DAP).

For the estimation of crop coefficients (Kc) of potato, it was adopted the values of ETc obtained by water balance in the soil, and daily values of reference evapotranspiration (ETo), estimated by the Penman-Monteith-FAO 56 (PMF) method (ALLEN *et al.*, 1998). The ETo was calculated using meteorological data collected in an automatic station installed in the experimental area.

The Kc values obtained were then compared to those recommended by FAO: $kc_{beg} = 0.50$; $kc_{med} = 1.15$ e $kc_{end} = 0.75$, which have also been adjusted to local climatic conditions. For this, it was used the eqs.(2) and (3) (ALLEN et al., 1998) for determining the intermediate and final Kc, respectively.

$$kc_{med(adj)} = kc_{med(tab)} + [0.04(u2-2) - 0.004(RH_{min} - 45)]\left(\frac{h1}{3}\right)^{0.3} \quad (2)$$

In which,

$kc_{med(adj)}$ - intermediate Kc ajusted;
$kc_{med(tab)}$ - intermediate Kc tabulated;
RH_{min} - mean of minimum relative humidity, %, and
h1 - mean of plant height at intermediate stage, m.

$$kc_{end(adj)} = kc_{end(Tab)} + [0.04(u2-2) - 0.004(RH_{min} - 45)]\left(\frac{h2}{3}\right)^{0.3} \quad (3)$$

In which,

$Kc_{end(adj)}$ - final Kc ajusted, and
h2 - mean of plant height at final stage, m.

The adjustment of Kc for the initial phase was carried out with the aid of the graph shown in FAO-56 bulletin (ALLEN et al., 1998).

The coefficients of FAO were estimated daily from the method proposed by ALLEN et al. (1998), considering the duration of the culture phases found in the field. For this, it was considered constant the crop coefficients of the PL-EM and BT-BS phases, and it was adopted the kc_{end} as that observed on the last day of the BS-HA phase. The crop coefficients of the EM-BT and BS-HA stages were determined by the eq.(4) (ALLEN et al., 1998).

$$kc = kcfase(previous) + \left[\frac{kcfase(next) - kcfase(previous)}{Lstage}\right] NDC \quad (4)$$

In which,

Lstage - number of days in the developmental stage considered, and
NDC - position of the representative day duration of the phenological stage considered.

From the relation of Kc adjusted and unadjusted of FAO (DOORENBOS & KASSAM, 1979) to ETo estimated daily by PMF methodologies, it was carried out a simulation of water consumption of potato in the realized period. The effective precipitation occurred during the development of the potato was subtracted by the simulated ETc in order to better represent the actual conditions of cultivation.

It was also simulated the water requirement of potato under weather conditions relating to a historical series from 1961 to 2007. With the daily data of maximum and minimum temperatures, mean relative humidity and wind speed, it was estimated ETo by PMF, using the coefficients "a" and "b" of Angström-Prescott equation calibrated locally (SILVA et al., 2010) for estimating the solar radiation. The probable precipitation was calculated using the Gamma Distribution method of probability (RIBEIRO et al., 2007), considering the level of 75% of probability.

Climatic conditions and water demand of potato (*Solanum tuberosum* L.) during cultivation

Figure 1 shows the values of temperature, radiation and precipitation during the 88 days of culture, as well as the depths of accumulated evapotranspiration. It is observed that the mean temperature showed values ranging from 16 to 26 ºC. The maximum temperature found was 34 ºC, which occurred on the day of planting, while the minimum was 11 °C, which occurred on June 14th.

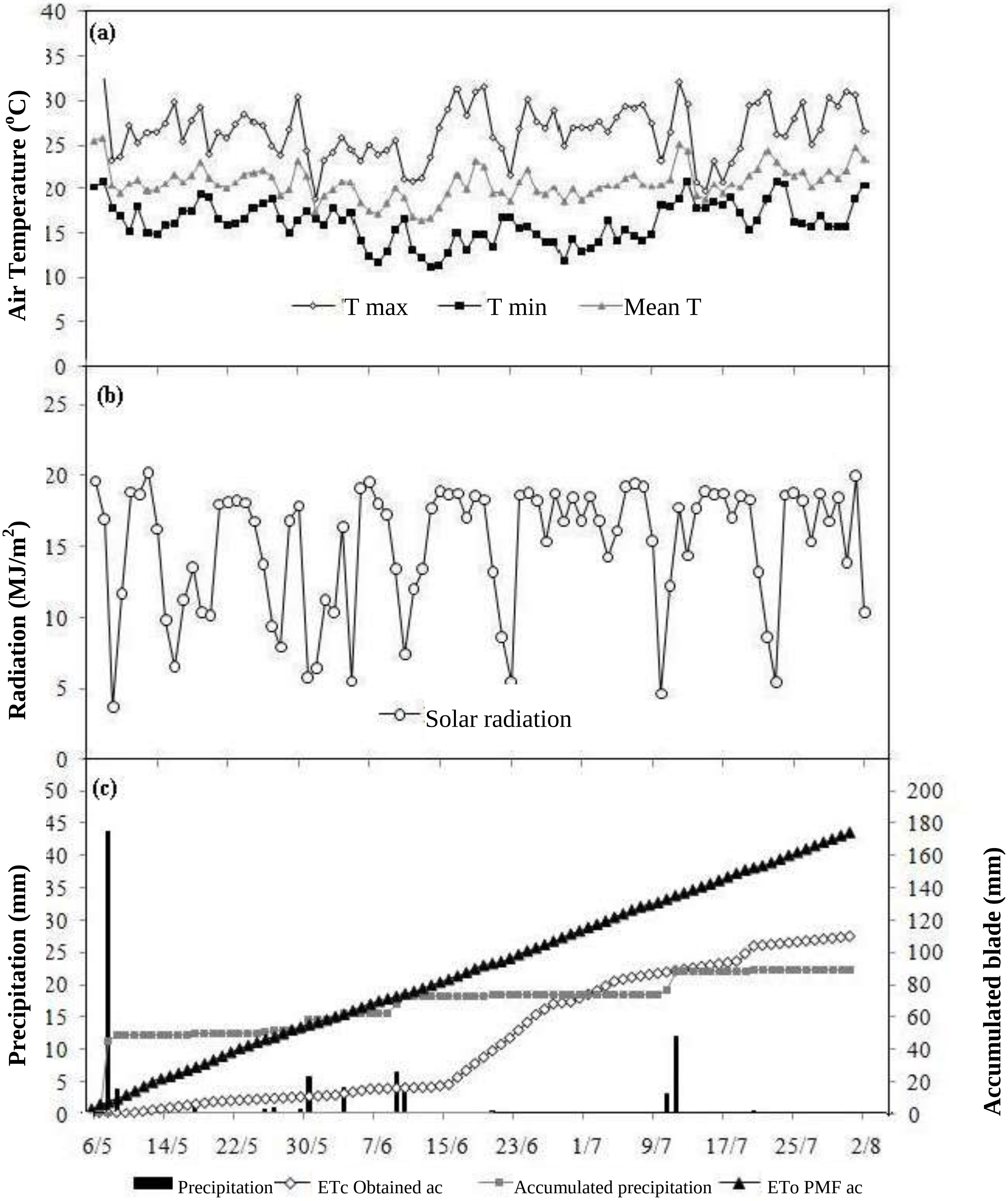

FIGURE 1. Climatic conditions over the crop period: (a) air temperature; (b) solar radiation; (c) precipitation, accumulated precipitation, accumulated reference evapotranspiration by PMF methodology (ETo PMF ac); and crop evapotranspiration accumulated (ETc Obtained ac).

Solar radiation was significantly lower in rainy periods, ranging from 4 to 8 MJ m^{-2}, while in drier periods, radiation was up to 21 MJ m^{-2}, directly reflecting the evaporative demand of the atmosphere. It is possible to note that the rainiest day coincided with the initial phase of cultivation (up to 32 DAP), in which the precipitated depth amounted to 57% of the precipitation occurred throughout the period.

The reference evapotranspiration totaled 174.0 mm, with a daily mean of 1.98 mm. The maximum value was 3.0 mm day^{-1} (in May 7th), while the minimum was 1.02 mm d^{-1} on July 10th.

BARROS et al. (2009) observed that both the method of Class "A" Tank (CAT) as the PMF are considered suitable for estimating ETo on the region of Seropédica-RJ. The authors found good performance for both methods when compared to the weighing lysimeter in estimating ETo for periods of 3 and 5 days.

Crop evapotranspiration totaled 109.6 mm (Figure 1), and, from this, 19.35 mm the portion related to the effective precipitation. The depth of 90.25 mm was applied to 15 irrigation events in response to soil humidity monitoring by TDR.

Determination of crop coefficients (Kc) and subsequent adjustments to Seropédica-RJ

Table 1 shows the crop coefficients for the cultivation of potato at different stages of development. The Kc's obtained comprise the mean values in the respective stages of development, based on the water balance in soil. Table 1 also shows the values of Kc adjusted based on equations 2 and 3, from those proposed by ALLEN et al. (1998). The values in PL-EM, BT-BS and BS-HA phases refer, respectively, to kc_{beg}, kc_{med} and kc_{end}. For kc_{beg} , there was no variation between the corrected value and the one proposed by FAO.

TABLE 1. Crop coefficient (Kc) for potato (*Solanum tuberosum* L.) obtained in field conditions and Kc's recommended by FAO and adjusted according to climatic data (Kc FAO adjusted).

Phase	Date	Duration (days)	Kc obtained	Kc FAO ajusted
PL-EM	7th/05 to 23rd/05	17	0.35	0.50
EM-BT	24th/05 to 8th/06	16	0.45	*
BT-BS	09th/06 to 22nd/07	44	1.29	1.12
BS-HA	23rd/07 to 02nd/08	11	0.63	0.69

*obtained by graphical method

It is seen in Table 1 that the value obtained in the field was higher than the one recommended by FAO only during BT-BS phase, which corresponded to the period from June 09th to July 22nd. Until the beginning of this period, monitoring of soil moisture with the TDR was being held in the layer of 0-15 cm. From June 17th, due to the development of the root system of the potato, monitoring started to be performed in the profile corresponding to 0-30 cm, providing higher irrigation depths and hence higher ETc/Eto relation. In this period, the ETo presented mean value of only 1.91 mm day^{-1}. In the early stage of cultivation (PL-EM), a lower value of Kc was obtained in relation to FAO due to the occurrence of precipitation of 49.9 mm (Figure 2), and, from this, only 8.7 mm was considered effective. Therefore, ETc/ETo relation remained low, having in mind a mean ETo of 2.24 mm day^{-1} (Figure 2).

Figure 2 shows curves of Kc constructed from the values shown in Table 1, as well as the original values provided by FAO. For the presented methodology, the curve provides a daily value for Kc. Adjusted values of kc_{med} e kc_{end}, corresponding to the phases BT-BS and BS-HA, were lower than those proposed by FAO.

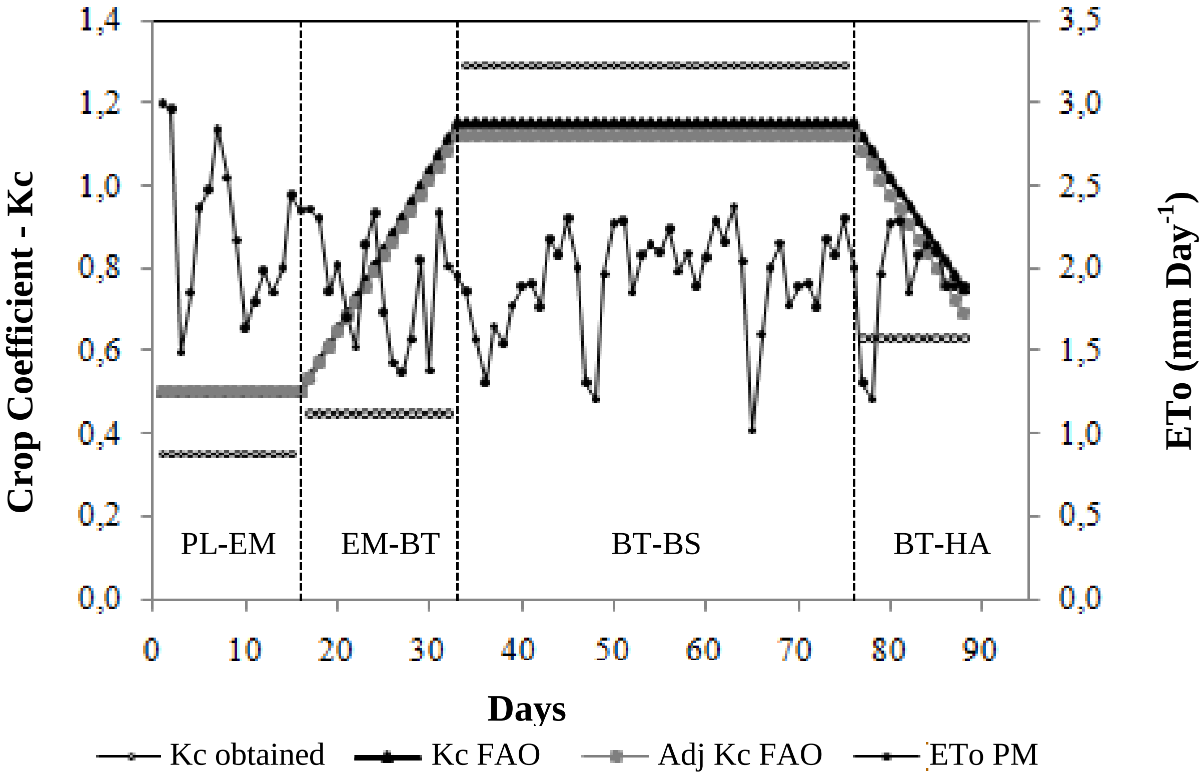

FIGURE 2. Crop coefficients for potato culture.

The Kc's for winter cultivation of potato in Botucatu, state of São Paulo (SP), Brazil, were 0.53, 0.85, 1.55 and 1.33, respectively, for the PL-EM, EM-BT, BT-BS and BS-HA phases (PEREIRA et al., 1995). KASHYAP & PANDA (2001), in a sub-humid climate, obtained values of 0.42, 0.85, 1.27 and 0.57, respectively, for the same phases.

The differences of Kc found in this study, in relation to the coefficients of FAO and of other studies, may be explained by the parameters used in the determination of phenological phases, which were based on local observations, taking into account the cultivar, climatic conditions and practices of cultures adopted. According to ALLEN et al. (1998), these stages must be determined locally so that evapotranspiration, and, consequently, the irrigation to be applied, may be inferred with increased accuracy.

Crop evapotranspiration (ETc) from Kc's obtained, recommended by FAO and adjusted according to weather conditions

Figure 3 shows evapotranspiration accumulated for each phase of development and throughout the entire cycle, according to the methodologies previously described. According to DOORENBOS & KASSAM (1979), the water requirement of potato ranges from 500 to 700 mm, for a cycle of 120 to 150 days in humid sub-regions. The lowest accumulated ETc found in this study is attributed to the shorter duration of the cycle of potato (cv. Opaline, considered early), to the reduction of evaporation of water provided by dripping (MIRANDA et al., 2004) and the low evaporative demand of atmosphere.

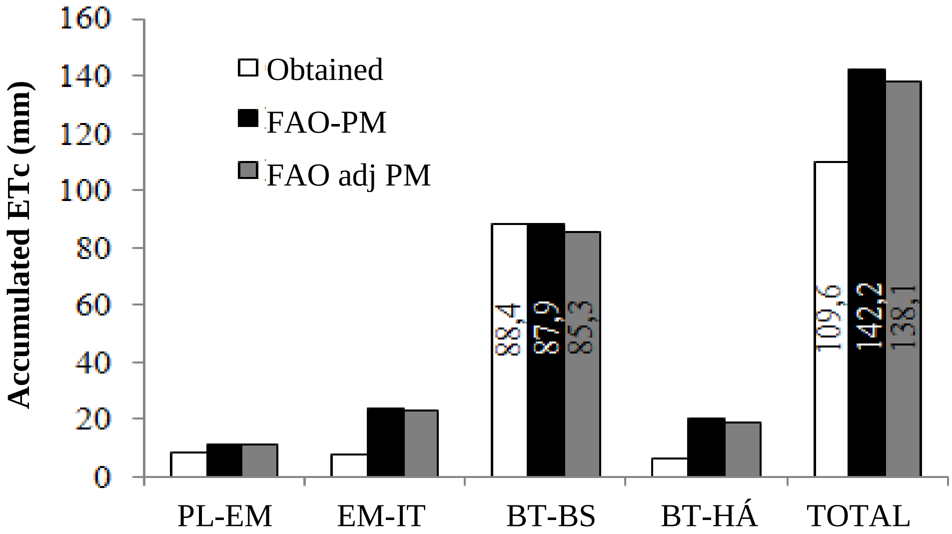

FIGURE 3. Acumulated evapotranspiration obtained in the field and from coefficients recommended by FAO, at different stages of development of potato.

The values of accumulated ETc in the PL-EM phase were 8.1 and 11.1mm, respectively, to the methodology of field and simulated by Kc of FAO. As shown in Figure 4, the Kc obtained in field for this stage was lower than the one shown by ALLEN et al. (1998), providing an accumulated ETc 27.2% lower than the simulated. In the EM-BT phase, the accumulated ETc values were more discrepant, reaching 7.24, 23.31, and 22.82 mm, respectively, for the field methodology, FAO-PMF and FAO adj PMF. It is worth noting that, at this stage, irrigation management was still being performed considering effective depth of root system of 0.15 m, associated with the fact that mean ETo of the period hit its lowest values (1.86mm day^{-1}) throughout the cycle.

In BT-BS phase, the methodologies used provided similar results in accumulated ETc of potato culture (Figure 3). The values simulated by FAO-PMF and FAO adj PMF were lower, respectively, 0.6% and 3.4% compared to ETc obtained in the field. For BS-HA phase, as observed in the EM-BT, the accumulated ETc was higher by 3.4 (FAO-PMF) and 3.2 (FAO adj PMF) times the amount of water required (obtained from field). At this stage of crop development, implementation greater than necessary may compromise the quality of the tubers produced and delay the harvest (FONTES et al., 2007).

As to total ETc, it has been found that the use of Kc's recommended by FAO, adjusted or not, imply application of water greater than necessary, equivalent to 29.7% (FAO-PM) and 26% (FAO adj PM), which would result in low efficiency in the use of irrigation, considering the maximum yield was obtained when applying a depth corresponding to, approximately, 100% of ETc (PATEL & RAJPUT, 2007; KING & TARKALSON, 2010).

Considering the values obtained in the field, the average water consumption varied between different developmental stages of potato, being 0.51, 0.42, 2.0 and 0.49 mm day^{-1}, respectively, for PL-EM, EM-BT, BT-BS and BS-HA. In addition to greater root growth, the BT-BS phase is characterized as one in which the photoassimilates are translocated to the formation of stolons, shoot growth, development and filling of tubers, which requires more water (FABEIRO et al., 2001).

Simulation of water consumption from Kc obtained and adjusted of FAO under weather conditions relating to historical series

The ETc estimated from the historical series of ETo and probable precipitation showed that the simulation from Kc's obtained would also imply lower cumulative total water consumption in relation to consumption simulated from Kc's recommended by FAO (Figure 4). Furthermore, it is observed that the accumulated ETc from Kc's obtained in this study was greater than that shown in Figure 4. This fact is explained by the weather conditions from the historical series used, which allowed the estimation of ETo greater than the conditions observed during the experimental period. Using the data in the historical series, the mean ETo was 2.28mm day^{-1}.

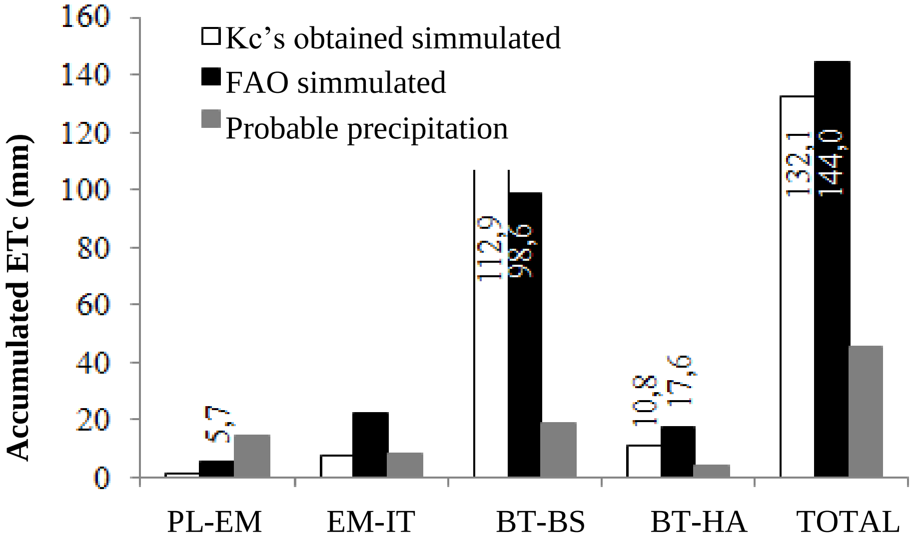

FIGURE 4. Simulation of ETc from the coefficients "obtained" and recommended by FAO, in the period from May 7th to August 2nd, 2010, based on historical series from 1961 to 2007.

The simulated ETc from Kc obtained during the PL-EM was 0.90 mm. During this time, the probable precipitation and ETo had values, respectively, of 14.3mm and 2.34 mm day^{-1}. Thus, with the significant increase in the effective precipitation, it is expected that irrigation at this period is low. However, one must evaluate the appropriate choice of Kc, since, if we adopted the Kc recommended by FAO, it would apply excessive water (5.7 mm) for the cultivation of potatoes, at edaphoclimatic conditions considered.

For the period of EM-BT, where the probable precipitation was 8.1mm and mean ETo of 2.17 mm day^{-1}, the simulated ETc from Kc "obtained" and recommended by FAO was, respectively, 7.56 and 22.23 mm. These simulated values were closer to those obtained in the period considered, in which it is expected a significant increase in demand for irrigation by using the Kc of FAO.

Under the conditions simulated in the period of BT-BS, it was found that when using the KC recommended by FAO the amount of water necessary for this stage would be underestimated by 14.4 mm. However, the value of ETc was higher than the one obtained, due to ETo, which showed the mean and maximum values, respectively, of 2.32 and 3.09 mm day^{-1}. Moreover, during the BS-HA phase, it was simulated a higher water consumption when using Kc recommended by FAO, which in turn was higher than the ETc obtained under the experimental conditions. In BS-HA phase, average of ETo simulated from the historical series presented a mean value of 2.18 mm day^{-1} and effective probable precipitation of 4.3mm, which resulted in simulated ETc higher than the value obtained.

CONCLUSIONS

The management of the irrigation system based on information obtained in field allowed an adequate supply of water for the cultivation of potato. Kc values obtained in the field provided lower water demand for potato culture compared to the simulated values using Kc's recommended by FAO.

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