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Common bean evapotranspiration estimated by orbital images

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Evapotranspiration quantification is essential for water management in irrigated crops because it represents the crop water demand, and knowledge prevents water and energy waste, besides productivity breaks. This study aimed to estimate common bean actual evapotranspiration through orbital images, using the simple algorithm for evapotranspiration retrieving (SAFER) algorithm. In order to achieve this, actual evapotranspiration (ET) and crop coefficient (Kc) were estimated in a bean crop (BRS style) irrigated by center pivot at Distrito Federal (PAD/DF), Brazil. ETa was determined by SAFER energy balance model, using images from Landsat 8 (OLI/TIRS) and climatic variables. Evapotranspiration reference was also determined by Penman-Monteith method (FAO56). Assessments were conducted on five periods during crop development stages, coinciding with the passage of the satellite in orbit 221/71 (06/30; 07/16; 08/01; 08/17 and 09/02/2014). ET values equal to 1.69, 2.52, 3.21, 3.58 and 2.63 mm day^{-1} were found for 06/30, 07/16, 08/01, 08/17 and 09/02/2014 periods. ETa values obtained by the SAFER model were on average 4.19% lower than the estimated values from FAO-56 default method. Satellite images and SAFER algorithm use is recommended to estimate bean crops ET.

Key words: Energy balance, *Phaseolus vulgaris L*., SAFER, hydro demand.

INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is an agricultural product appreciated by Brazilians. It is considered staple food and one of the main protein sources in the population diet. Although this culture is characterized as one of the main crops in Brazil (Cunha et al., 2013), it is often grown as second harvest, which, in much of the country, is when the drought begins. Thus, irrigation use is essential for bean growth. Plant evapotranspiration rates knowledge is of fundamental importance for the rational management of water resources, contributing to the increasing agricultural production in irrigated areas. Evapotranspiration (ET) can

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be defined as the total water loss in the soil-plant system caused by the atmosphere, from the combination of evaporation and transpiration processes (Lopes et al., 2014).

There are different methods to estimate evapotranspiration (ET). Remote sensing techniques have been applied effectively (Teixeira, 2012b; Teixeira et al., 2012c), as they allow estimates over large areas without the need of quantifying other hydrological processes (Andrade et al., 2010). ET estimates can be obtained from remote sensing images, applying algorithms combined with physical models (Andrade et al., 2014; Lopes et al., 2014), highlighting surface energy balance algorithm for land (SEBAL) (Bastiaanssen et al., 1998), mapping evapotranspiration at high resolution with internalized calibration (METRIC) (Allen et al., 1998) and simple algorithm for evapotranspiration retrieving (SAFER) (Teixeira et al., 2013a).

SAFER is an algorithm whose non mandatory advantage is to use the thermal band, having the possibility of applying meteorological data from different station types (meteorological, conventional and automatic). Features such as these are important to enable energy balance, evapotranspiration and water productivity components historical trends assessment on a large scale over the years, given that automatic sensors are relatively recent advances in instrumental technology (Teixeira et al., 2013b). SAFER is highlighted as a simplified algorithm (Teixeira, 2012a). Thus, this study aimed to estimate bean actual evapotranspiration through orbital images, using the SAFER algorithm.

MATERIALS AND METHODS

The study was conducted in an 41 ha area irrigated by center pivot, in the period from 30 May, 2014 to 10 September of 2014, in a commercial farm at the Federal District Directed Settlement Program (PAD/DF, Brazil) (15° 56' 38.97'' S; 47° 28' 16.25'' W; 880 m). According to Koppen (Codeplan, 1984), climate is classified as Aw tropical, with rainfall concentrated in summer (October to April) and dry season in winter (May to September). The analyzed cultivar was of common beans (BRS Style), consisting of erect architecture and high yield potential. Sowing was mechanically held on 05.30.2014, with spacing of 0.50 m between rows and 11.4 seeds per meter. In order to estimate the actual evapotranspiration (ET), Landsat 8 satellite images (OLI/TIRS, orbit/point 222/71) were used, which were acquired from free stock images of the United States Geological Survey - USGS (2014). The OLI product consists of nine multispectral bands with spatial resolution of 30 m, in which data are collected with 30 m per pixel. TIRS instrument thermal bands show more accurate surface temperatures, and data are collected with 100 m per pixel. The images selected for the study were taken at 30 days after sowing (DAS) on 06.30.2014, at 46 DAS on 07.16.2014, at 78 DAS on 08.17.2014 and at 94 DAS on 02.09.2014.

Evapotranspiration reference (ET_0) was determined by the method of Penmanm Monteith, using climate data from weather stations provided by Irriger (Irrigation Management Engineering), which is located 20 km from the area. Raster function calculator was used as programming and calculation tool, being available on the System Manager software Geographic Information (GIS), which allows modeling calculation and application using raster data. In SAFER, albedo surface (αs) was estimated according to the albedo of the atmosphere on the top (α_0) (Equation [1]):

$$\alpha_s = a \cdot \alpha_0 + b \qquad [1]$$

Where a and b are regression coefficients corresponding to the values of 0.7 and 0.006, respectively (Teixeira, 2010). Surface temperature (T_0) was estimated by Equation 2, which is described by the equation:

$$To = \mathrm{a} * \mathrm{mean\ TKelvin} + \mathrm{b} \qquad [2]$$

Where a and b are correction coefficients, whose values are 1.11 and -31.89, respectively (Teixeira, 2010). Afterwards, normalized difference vegetation index (NDVI) was estimated by (Equation [3]):

$$\mathrm{NDVI} = \frac{IVP - V}{IVP + V} \qquad [3]$$

Where IVP is infrared light reflectance near V and reflectance in the red band. Subsequently, albedo surface data (α_0), surface temperature (T_0) and Normalized Difference Vegetation Index (NDVI) were used to calculate ET/ET0 ratio instantaneous values by (Equation [4]):

$$\frac{ET}{ET_0} = exp\left[a + b\left(\frac{T_0}{\alpha_0 * NDVI}\right)\right] \qquad [4]$$

The "a" coefficient was used with the value of 1.0 (Hernandez et al., 2012; Teixeira et al., 2013a), which was determined for São Paulo state Northwestern region (Noroeste Paulista), proving to be well adapted to the conditions of the studied area. The "b" coefficient was obtained by Teixeira (2010) and corresponds to the value of -0.008. ETo is the reference evapotranspiration, given in millimeters per day (mm d^{-1}) by Penman-Monteith method, according to FAO Bulletin N°. 56 (Allen et al., 1998).

$$ET_0 = \frac{0.408\ X\ (Rn - G) + \left[\gamma x \left(\frac{900}{T+273}\right) x\ u_2\ x\ (e_s - e_a)\right]}{\Delta + \gamma\ x\ (1 + 0.34\ x\ u_2)} \qquad [5]$$

Where Rn is the crop surface radiation balance (MJ m^{-2} day^{-1}), G is the heat flow density in the soil (MJ m^{-2} day^{-1}), T is air average daily temperature (°C), u_2 is the wind speed at 2 m (ms^{-1}), es is the air saturation vapor pressure (kPa) and air actual vapor pressure (kPa), es - ea is the air saturation vapor pressure deficit (kPa), Δ is the gradient of the air vapor pressure curve in the atmosphere (kPa °C^{-1}) and γ is the psychrometric constant (kPa °C^{-1}). Subsequently, ET/ETo ratio instantaneous values were multiplied by ET_0 daily values, obtaining the actual evapotranspiration (ET):

$$ET_a = \frac{ET}{ET_0} . ET_0 \qquad [6]$$

Bean crop potential evapotranspiration estimation was obtained according to the method in FAO Bulletin N°. 56 (Allen et al., 1998), by Equation 7:

$$ETc = ET_O \cdot Kc \qquad [7]$$

Where ETc is the crop evapotranspiration (mm/day); ET_0 is the reference evapotranspiration (mm/day) and Kc is the crop coefficient (dimensionless) - FAO N°. 56 (Allen et al., 1998).

Method performance when estimating evapotranspiration by the algorithm (SAFER) was evaluated by correlating the measured data

Table 1. Period of days for each bean crop development stage.

Stage/Period	Initial	Development	Intermediary	Finale	Amount
Beginning of stage	21/05/2014	10/06/2014	11/07/2014	29/08/2015	
Period (days)	20	31	49	20	120

Table 2. evapotranspiration bean (Phaseolus vulgaris L.) on the dates and points sampled on Landsat 8 images.

Dates	DAS	ETo (mm/day)	ETc (mm/day) (FAO)	ETa (mm/day) (SAFER)	Absolute error (mm/h)	Relative error (%)
30/jun	40	2.22	1.95	1.69	0.27	13.72
16/jul	56	2.19	2.52	2.52	0.00	0.04
1/augu	73	2.77	3.19	3.21	0.03	0.87
17/augu	88	3.11	3.58	3.58	0.00	0.00
02/sept	105	2.99	2.81	2.63	0.18	6.32

with the estimation, through simple linear regression. R-squared, Pearson "r" correlation coefficient and Willmott "d" index were considered statistical indicators. Willmott index is related to the removal of the estimated values from observed values, ranging from zero for no agreement to 1 for perfect agreement, being determined by Equation 8:

$$d = 1 - \left[\frac{\sum (Pi - Oi)^2}{\sum (|Pi - O| + |Oi - O|)^2} \right] \quad [8]$$

Where Pi is the estimated value; Oi is the observed value and O is the mean of the observed values. However, climatic conditions contain various weather parameter values, and research results are not applicable for other regions without specified ranges being determined for each weather parameter, even if climatic conditions are the same for both regions (Valipour, 2015).

Although FAO Penman-Monteith has been applied in various regions of the world, its application requires many parameters that are often difficult to be obtained. To this end, experimental models have been developed for potential evapotranspiration estimation using limited data (Valipour, 2014). Therefore, SAFER is an algorithm that has the advantage of applying meteorological data from different station types (agrometeorological, conventional and automatic). Algorithms are relatively recent technology advances in evaporation estimation.

RESULTS AND DISCUSSION

Based on the values obtained in the bean crop seeded in winter, May, and phenological differences monitoring, the duration of each crop development stage was determined, as seen in Table 1. Table 2 shows evapotranspiration reference (ETo) values, determined by conventional method (FAO-56), and actual evapotranspiration (ETa), using SAFER in five different periods throughout the crop development cycle. Data from weather stations, available by Irriger, were used as evapotranspiration reference (Penman-Monteith). From the relative error percentage, average data variation was estimated within the 4.19% area.

ETa in the months from June to September, 2014, for a defined study area, is observed in Figure 1. Note that, depending on crop development stage, ETa values vary. However, higher values were observed at the stage where the crop was in full development. The lowest ETa values were observed in the first and last periods, due to being the closest to the beginning and the end of the development period.

When comparing ETa values estimated by SAFER with ETc values, there is great similarity between data, especially in the phases in which the crop was in full development (07.16, 08.01 and 08.17). On the first period (30.06; 40 DAS), SAFER model estimated a value below the crop evapotranspiration value obtained by the standard method due to being closer to the beginning of the development period, with relative error of 13.72%, which is higher than reference evapotranspiration, as shown in Figure 2. This can be explained by soil surface moistening frequency effect, which is caused by uncovered surface or little vegetation, or by the irrigation frequency in the area.

Approaching the final stage of the cycle (02/09), the model underestimated the ETo value (Figure 2). This effect can be explained by the fact that the crop was entering the final stage of the growing season, which is a stage characterized by senescence, and beginning the maturation process, what has direct influence in NDVI determination, making NDVI values decrease to initial levels. It is observed in Figure 2 that Pearson "r" correlation showed a value of r = 0.99, which was very close to the Willmott "d" index, 0.97, and very close to the R-squared value, $R^2 = 0.98$, which indicates a strong relation between the analyzed variables, meaning good results.

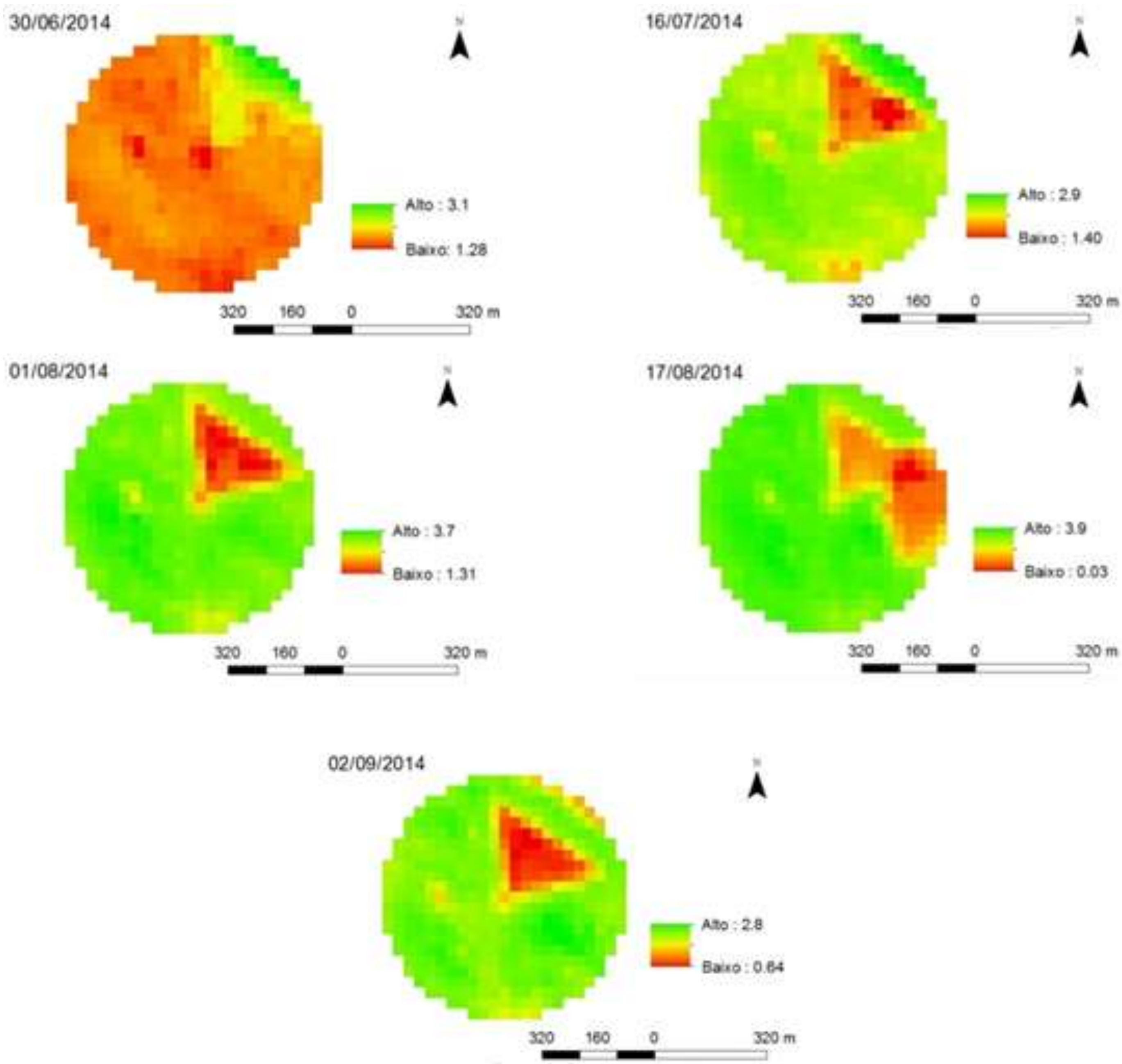

Figure 1. Actual evapotranspiration map for the period from June to September 2014, in the demarcated area of study.

Figure 3 illustrates the crop coefficient (Kc) curve obtained by the SAFER model and by the standard method in the satellite passage periods. Figure 3 also analyzes standard crop coefficient and SAFER model estimation differences. Higher values were observed to the standard crop coefficient at the stage where the crop was in early development and at the end of the growth period. This can be explained because the plant surface was uncovered or with little cover. Based on the obtained results, SAFER model was consistent in assessing water consumption and identifying potential problems in the uniformity of application of water by the irrigation system.

Conclusion

According to the results, it is concluded that SAFER is a very promising algorithm to estimate actual crop

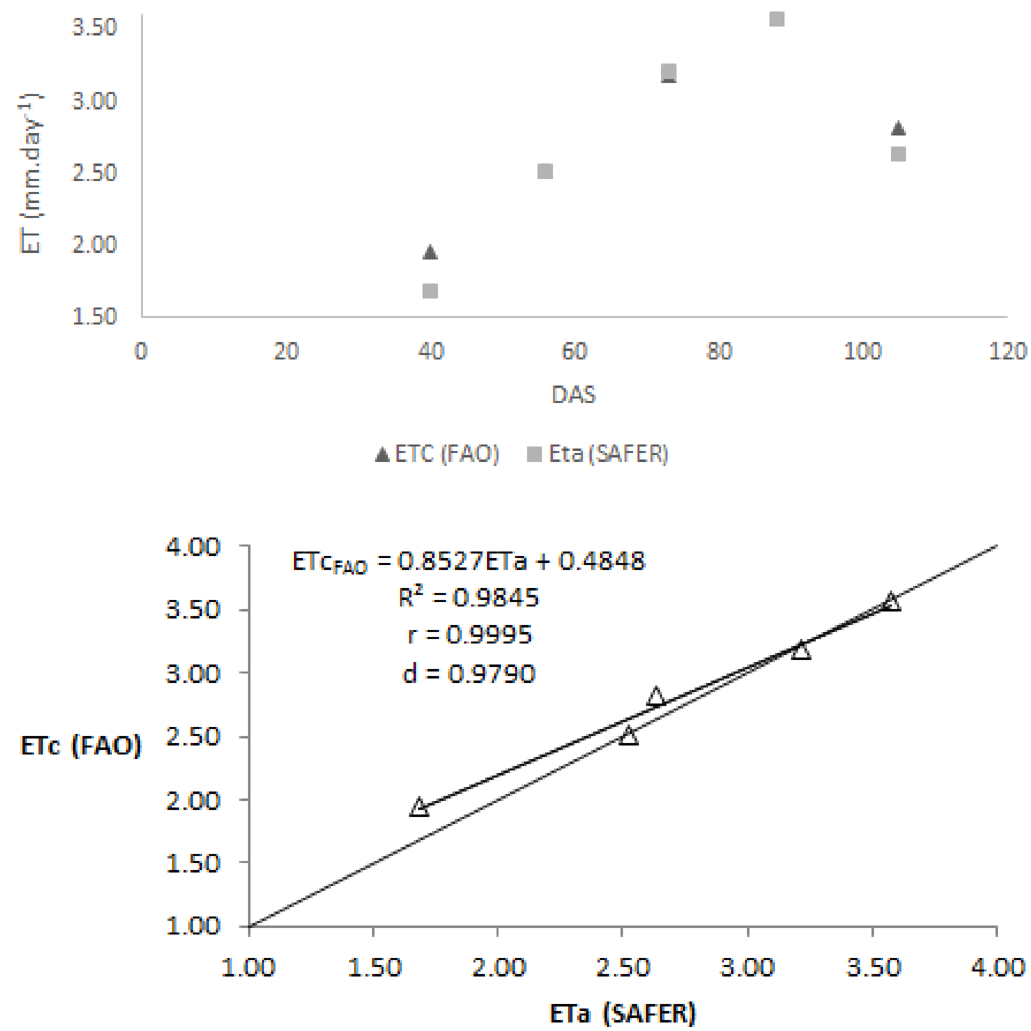

Figure 2. Comparative ET determined by standard method (FAO-56) and actual evapotranspiration (ET) using SAFER at different periods throughout the crop development cycle.

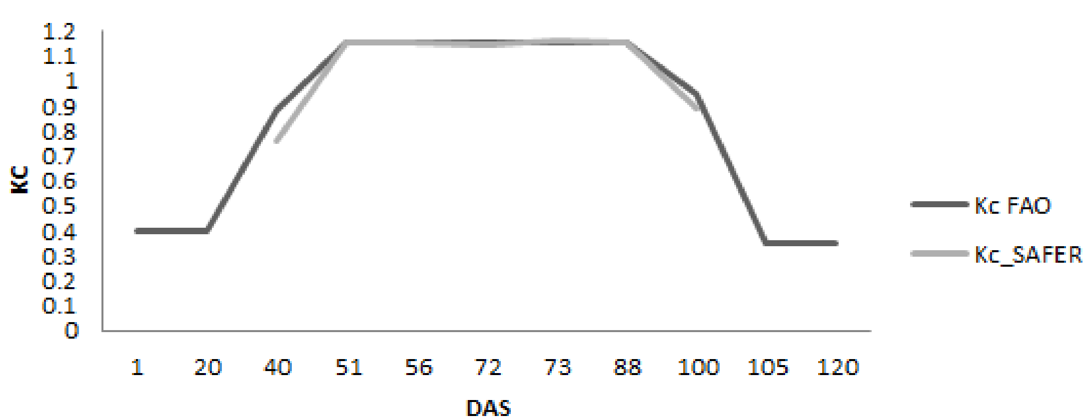

Figure 3. Comparison between bean crop Kc using FAO-56 report and Kc using SAFER in different periods throughout the crop development cycle.

evapotranspiration, highlighting the possibility of monitoring the timeline of large irrigation areas. Therefore, useful information to assist the producer in irrigation system planning and management decision-making can be obtained by SAFER.

Conflict of interest

The authors have not declared any conflict of interest

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