Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 8, Issue, 08, pp.35537-35542, August, 2016

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

SPECIFIC ADJUSTMENT FUNCTIONS FOR DAILY CROP COEFFICIENT IN BRAZIL

*,[1]Bruno César Gurski, [1]Jorge Luiz Moretti de Souza, [1]Daniela Jerszurki, [2]Adão Wagner Pêgo Evangelista and [1]Robson André Armindo

[1]Department of Soil Science and Agricultural Engineering, Federal University of Paraná, Brazil
[2]Department of Agronomy, Federal University of Goiás, Brazil

ARTICLE INFO

Article History:
Received 14th May, 2016
Received in revised form
05th June, 2016
Accepted 10th July, 2016
Published online 20th August, 2016

Key words:

Water relations,
Crop evapotranspiration,
Days after planting, Models.

ABSTRACT

Crop coefficient (K_c) has a key role in order to reach high precision crop evapotranspiration data. This study aimed to obtain functions to estimate the daily crop coefficient (K_c) in specific locations and check advantages in its use compared with grouped and generalized values. For that purpose,daily values of K_c based on days after planting named "K_c(DAP)"were estimated by specificadjustment functions and compared to field measured crop coefficient values of peanut, sugarcane, bean, corn and soybean. Estimated crop responses were compared and quatitatively analyzed through linear regression, index "d" of performance, index "c" of agreement and statistical deviation technique. It was possible obtain functions for setting daily crop coefficient for both studied crops and sites. Daily crop coefficient functions improved the accuracy of estimated crop evapotranspiration when compared to widely used values, by better reflect local climate and soil conditions of the crops; and, also for grouped values, because the curve decreases the variability of the data estimated daily.

Copyright©2016, Bruno César Gurski et al. *This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.*

Citation: Bruno César Gurski *et al.* 2016. "Specific adjustment functions for daily crop coefficient in Brazil", *International Journal of Current Research,* 8, (08), 35537-35542.

INTRODUCTION

The crop coefficient (Kc) is widely used to estimate crop evapotranspiration (ETc), being used in various activities of water and soil engineering, as water balance calculation. Doorenbos and Kassam (1979) and Allen *et al.* (1998) established experimentally average values of Kc for several crops, divided into different developmental stages. Since then, these values have been used widely. However, many studies comparing Kc values used in the literature to local experimental values were performed and found large differences, especially over time (Liu and Luo, 2010; Zhang *et al*., 2011; Arif*et al*., 2012; Zapata *et al*., 2012). One solution would be the determination of Kc fordaily periods, but it is a costly process with need for special facilities such as evapotranspirometers or lysimeters. In addition, even when determined daily, the experimental Kc data is usually grouped into stages of development, due to its high temporal variability, may this procedure decrease accuracy of the results. In this context, the use of adjustment functions to describe the tendency of Kc throughout the crop cycle is a great alternative, due in parts to consider specific local environmental conditions and temporal continuity of data. Also, this feature could optimize water use efficiency, especially in regions that do not have instrumental, financial and scientific resources to obtain a measured Kc (Toledo *et al*., 2010; Zhang *et al*., 2011). In addition, in order to choose the best models to estimate Kc, the ones based on the polynomial of third degree equations generally had lower error values relating to the development stages of some crops, being closest to trends of water consumption by plants throughout their cycle (Leal and Sedyiama, 2004; Setiyono*et al*., 2007). This study aimed to obtain the best fit functions to estimate the daily Kc crops in specific locations and check the advantage in its use compared to both grouped and generalized values.

Corresponding author: Bruno César Gurski,
Federal University of Paraná, Curitiba, Brazil, brunogurski@ufpr.br.

MATERIALS AND METHODS

Measured crop coefficient (K_{cm}) for peanut, sugarcane, bean, corn and soybean were obtained in previous studies regarding water relations for crops (Table 1). Those crops were chosen to verify the *Kc* behavior in different cycles. As a reference, to be very employed in the literature, were used K_c values recommended by Doorenbos and Kassan (1979) and Allen *et al*. (1998) for the development stages of crops, called K_{cDK} e K_{cA}, respectively. All K_{cm} values were determined by the authors of Table 1from comparisons between crop and reference evapotranspiration:

$$K_{cm\,j} = \frac{ETc_j}{ETo_j}$$

Where: $K_{cm\,j}$ – crop coefficient in j-th development stage (dimensionless); ETc_j – crop evapotranspiration in j-th development stage (mm stage^{-1}); ETo_j – reference evapotranspiration of j-th development stage (mm stage^{-1}).

$K_c(DAP)_k = K_{c\,fin} + \frac{K_{c\,med} - K_{c\,fin}}{DAP_4 - DAP_3}(DAP_4 - DAP_i)$ for $DAP_3 < DAP_i \leq DAP_4$(4)

Where: $K_c(DAP)_k$ – crop coefficient obtained as a function of days after planting (dimensionless); K_{cini}, K_{cmed} and K_{cfin} – initial crop coefficient, middle or final (dimensionless); DAP_i – *i-th* day after planting (day); DAP_1, DAP_2, DAP_3, DAP_4 – days after planting of thedevelopmentstages:initial, growth, middle and final, respectively (Figure 1).

Table 1. Experimental areas in Brazil and methodologies for determining the measured crop coefficient values (K_{cm})

Author	Crop	City	Precipitation + irrigation (mm)	Soil	Climate type[1]	ETc measurement	ETo estimate
Silva and Rao (2006)	Peanut	Rodelas	648	Entisol	BSwh	Evapotranspirometer	Class A tanker
Silva *et al*. (2012)	Sugarcane (ratoon)	Juazeiro	1710	Vertisol	BSwh	Latentheat	Penman-Monteith
Medeiros *et al*. (2000)	Bean	Campinas	302	Oxisol	Cfa	Evapotranspirometer	Penman
Detomini *et al*. (2009)	Corn	Piracicaba	600	Oxisol	Cwa	Lysimeter	Penman-Monteith
Mendes (2006)	Soybean	Brasília	850	Oxisol	Aw	Tensiometer	Penman

[1]Obtained with the classification of Köppen

Daily values of K_c, determined as function of days after planting called "$K_c(DAP)$", to each analyzed crop, were estimated from the measured values called "$K_c(DAP)_m$", and recommended by Doorenbos and Kassan (1979) and Allen *et al*. (1998), represented by "$K_c(DAP)_{DK}$" and "$K_c(DAP)_A$", respectively, in their respective periodicities. The functions $K_c(DAP)_m$, $K_c(DAP)_{DK}$ and $K_c(DAP)_A$ were estimated by second and third-degrees polynomial equations, obtained by the comparison between K_c of each evaluated crop versus days after planting (DAP). Regression analyzes were performed establishing the intersection condition at zero. The establishment of crop coefficient functions considering climate data, named $K_c(DAP)_k$(Figure 1, Equations 1-4), was performed according to K_{cini}, K_{cmed} and K_{cfin}, estimated with Eqs. 5-8, proposed by Allen *et al*. (1998), and adapted to specific climate and soil conditions of the site and studied crop.

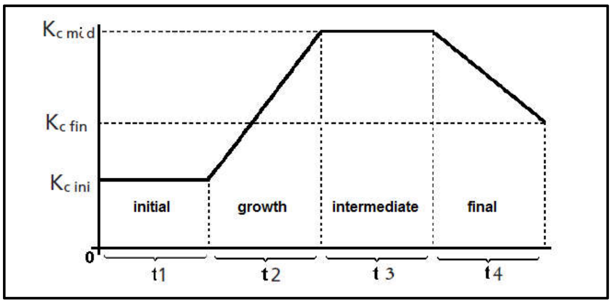

Figure 1. Alignment of the crop coefficient through out the developmental stages of a non-perennial crop (adapted from Allen *et al*., 1998)

$K_c(DAP)k = K_{c\,ini}$ for $DAP_i \leq DAP_1$(1)

$K_c(DAP)_k = K_{c\,ini} + \frac{K_{c\,med} - K_{c\,ini}}{DAP_2 - DAP_1}(DAP_i - DAP_1)$ for $DAP_1 < DAP_i \leq DAP_2$(2)

$K_c(DAP)_k = K_{c\,med}$ for $DAP_2 < DAP_i \leq DAP_3$(3)

Soil and crop data were obtained from Table 1. In order to test the models previously chosen, climate data were obtained for the year of 2015, from automatic weather stations of the Brazilian National Institute of Meteorology (INMET, 2015) and other research institutions located where the previous experiments of Table 1 were carried out (Table 2). Only the city of Rodelas had no weather station, which is why the data were obtained from the nearest station in the neighboring city of Paulo Afonso.

Table 2. Automatic weather stations used to estimate crop coefficient functions considering climate data

City	Coordinates (degrees)	Altitude (m)	Source
Brasília	15.79S 47.93W	1.20	INMET (2015)
Piracicaba	22.70S 47.62W	566	INMET (2015)
Paulo Afonso	09.38S 38.23W	255	INMET (2015)
Campinas	22.82S 47.06W	620	UNICAMP (2015)
Juazeiro	09.45S 40.52W	356	UNIVASF (2015)

The loss of water to the atmosphere in the initial development stage occurs predominantly in the form of evaporation. Therefore, the estimated K_{cini} was considered moisture and soil damping frequency of the period (Allen *et al*., 1998), according to the equations:

$K_{cini} \leq 1{,}15$(initial condition)

$$K_{c\,ini} = \frac{TEW - (EEW - TEW)\cdot \exp\left(\frac{-(t_w - t_1)\cdot Eso \cdot \left(1 + \frac{EEW}{TEW - EEW}\right)}{TEW}\right)}{t_w \cdot ETo}$$

, for$t_w \geq t_1$(5)

$$K_{c\,ini} = \frac{Eso}{ETo}$$, for$t_w < t_1$(6)

Where: K_{cini} – initial crop coefficient (dimensionless); TEW – total evaporable water (mm); EEW – easily evaporable water (mm); t_w – average interval between rain events (days); t_1 – time to complete the first stage (days); Eso – potential evaporation rate (mm day^{-1}); ETo – reference evapotranspiration (mm day^{-1}).

– Tocalculatet$_w$:

$$t_w = \frac{DAP_{ini}}{n_w + 0.5}$$

Where: DAP_{ini} – duration of the initial growth stage (days); n_w – number of times there was precipitation in the initial stage of development (dimensionless).

– To calculate Eso and t_1:

Eso = 1.15 .ETo

$$t_1 = \frac{EEW}{Eso}$$

– To calculate TEW:

$$TEW = 1000 \cdot (\theta_{CC} - 0.50 \cdot \theta_{PMP}) \cdot z_e \text{ for ETo} \geq 5 \text{ mm day}^{-1}$$

$$TEW = 1000 \cdot (\theta_{CC} - 0.50 \cdot \theta_{PMP}) \cdot z_e \cdot \sqrt{\frac{ETo}{5}} \text{ forETo<5 mm day}^{-1}$$

Where: θ_{CC} – water content corresponding to field capacity (m^3 m^{-3}); θ_{PMP} – corresponding water content at wilting point (m^3 m^{-3}); z_e– top soil depth being dried by evaporation (m), recommended to be equal to 0.10 m when not specified.

The equation for the adjustment of K_{cmed} and K_{cfin} and consisted of:

$$K_{c\,med} = K_{c\,med(Allen)} + [0.04 \cdot (u_2 - 2) - 0.004 \cdot (RH_{\min} - 45)] \cdot \left(\frac{h}{3}\right)^{0.3} \quad (7)$$

$$K_{c\,fin} = K_{c\,fin(Allen)} + [0.04 \cdot (u_2 - 2) - 0.004 \cdot (RH_{\min} - 45)] \cdot \left(\frac{h}{3}\right)^{0.3} \quad (8)$$

Conditions for using the equations:

$1 \text{ m s}^{-1} \leq u_2 \leq 6 \text{ m s}^{-1}$; $20\% \leq RH_{min} \leq 80\%$; $0.1 \text{ m} \leq h \leq 10 \text{ m}$

Where: K_{cmed} and K_{cfin}– middle crop coefficient or final (dimensionless); $K_{cmed(Allen)}$ or $K_{cfin(Allen)}$– middle crop coefficient or final recommended by Allen *et al.* (1998) (dimensionless); u_2 – average wind speed at 2 m height in the period (middle or final) (m s^{-1}); RH_{min} – minimum daily average relative humidity over the period (middle or final) (%); h – average plant height (m). In order to verify accuracy and precision of the functions, the comparison between the different functions of K_c for the crops of peanut, sugarcane, bean, corn and soybean, was performed using the coefficient of determination (R^2), index "d" of Willmott *et al.* (1985), index "c" of Camargo and Sentelhas (1997): c > 0.85 = great accuracy; c from 0.85 to 0.76 = very good; c from 0.75 to 0.66 = good; CI from 0.65 to 0.61 = average; c from 0.60 to 0.51 = tolerable; c from 0.50 to 0.41 = bad; and c ≤ 0.40 = very bad; mean error (ME) and mean absolute error (MAE), was performed through linear regression, index "d" of performance by Willmott *et al.* (1985), index "c" of agreement by Camargo and Sentelhas (1997), mean error (ME) and mean absolute error (MAE). The $K_c(DAP)_m$ values were adopted as reference for comparison.

$$d = 1 - \left[\frac{\sum_{i=1}^{n} (E_i - O_i)^2}{\sum_{i=1}^{n} \left(\left| E_i - \bar{O}_i \right| + \left| O_i - \bar{O}_i \right| \right)^2} \right]$$

$$c = d \cdot r$$

$$ME = \frac{1}{n} \cdot \sum_{i=1}^{n} (E_i - O_i)$$

$$MAE = \frac{1}{n} \cdot \sum_{i=1}^{n} (| E_i - O_i |)$$

Where: d – index of performance of Willmott *et al.* (1985); E_i– estimated value in the i-th day; O_i– observed value in the i-th day;c – indexof agreement ofCamargo and Sentelhas (1997); *r* – coefficient of correlation; *ME*– mean error (dimensionless); *MAE* – mean absolut error(dimensionless); *n* – number of observations (dimensionless);

RESULTS AND DISCUSSION

For all functions proposed there was the possibility of estimating the daily K_c values along the development stages of the crop. The K_c regressions versus DAP that originated the functions $K_c(DAP)_{DK}$, $K_c(DAP)_A$, $K_c(DAP)_k$ and $K_c(DAP)_m$, indicated that the third-degree polynomial function set closely to the DAP data for crops studied (Figure 2). The same was found by Leal and Sediyama (2004) for banana, carrots, bean and melon; and, Lopes *et al.* (2011) for rosemary peppermint obtained in drainage lysimeter. The polynomial function of fourth-degree was not analyzed in this study, because itdid not correspond to the real trend of K_c over the crop development stages, as demonstrated by Doorenbos and Kassam (1979) and Allen *et al.* (1998), due to the multiple inflection points, and do not represent the physiological behavior of the studied crops. Correspondence analysis and error committed in the use of established functions, in relation to $K_c(DAP)_m$ function, indicated what functions could be used to estimate K_c with less error possible when there is not K_c's measured in the area of interest (Table 2). Overall, there were differences among the best functions for each studied culture. For corn in Piracicaba, the most corresponding values to $K_c(DAP)_m$ were K_{cm}, because the function of tuning parameters came from K_{cm}. In second, the $K_c(DAP)_k$, indicating that the use of local climatic data favors estimates of daily K_c values, with smaller absolute error(0.1978), compared with values obtained by weighting lysimeter.

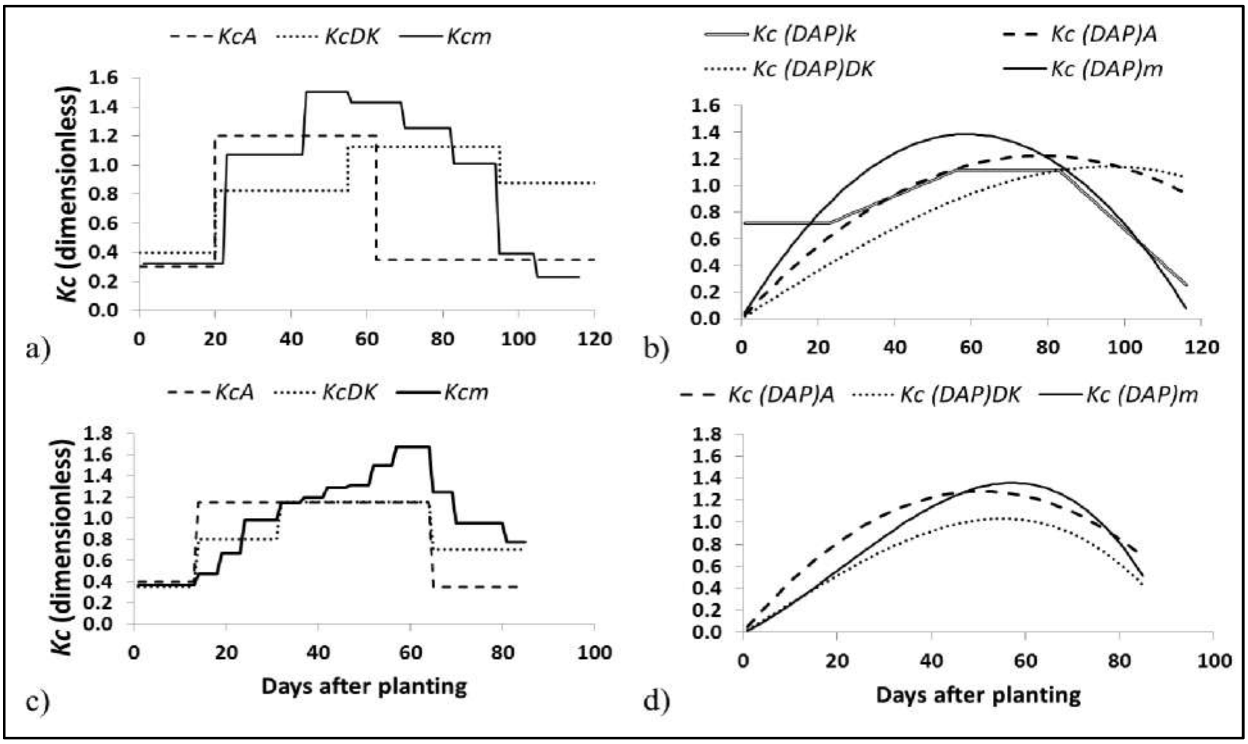

Figure 2. Variation of the crop coefficient (K_c) during the days after planting (DAP), as follows: (A) and (B) K_{cA}, K_{cDK} and K_{cm} values for corn (Detomini *et al*., 2010) and bean(Medeiros *et al*., 2000), respectively, and; (C) and (D) $K_c(DAP)_A$, $K_c(DAP)_{DK}$, $K_c(DAP)_m$ and $K_c(DAP)_k$ values for corn and bean, respectively

Table 2. Correspondence analysis and error committed in relation to $K_c(DAP)_m$for crops analyzed in different locations and climatic types

Parameter	Crop coefficient (dimensionless)					
	Kc_m	Kc_{DK}	Kc_A	$Kc(DAP)_{DK}$	$Kc(DAP)_A$	$Kc(DAP)_k$
Peanut in Rodelas-BA - ClimateBSwh						
R^2 (1)	0.8052	0.0145	0.1438	0.3359	0.0017	-
"d" (2)	0.9079	0.4009	0.1892	0.6542	0.3308	-
"c" (3)	0.8147	0.0483	0.0717	0.3792	0.0136	-
Performance	Very good	Terrible	Terrible	Terrible	Terrible	-
ME(4)	0.1054	–0.1419	–0.0820	–0.1788	–0.2089	-
MÃE(5)	0.1379	0.1777	0.2984	0.1672	0.2064	-
Sugarcane in Juazeiro-BA – ClimateBSwh						
R^2	0.5802	0.5527	0.6090	0.8164	0.0080	0.3215
"d"	0.6392	0.7034	0.6679	0.9405	0.3630	0.6470
"c"	0.4869	0.5229	0.5212	0.8498	0.0325	0.3668
Performance	Bad	Tolerable	Tolerable	Verygood	Terrible	Terrible
ME	0.9780	0.2242	0.3134	0.0569	0.7834	0.2436
MÃE	0.9784	0.2386	0.3332	0.1276	0.8366	0.3143
Bean in Campinas-SP – ClimateCfa						
R^2	0.8953	0.6564	0.1491	0.9883	0.9230	-
"d"	0.9548	0.8671	0.6646	0.9141	0.9595	-
"c"	0.9035	0.7025	0.2566	0.9087	0.9218	-
Performance	Great	Good	Terrible	Great	Great	-
ME	0.1094	–0.0405	–0.0452	–0.1742	0.0674	-
MÃE	0.1384	0.2022	0.3566	0.1776	0.1277	-
Corn in Piracicaba-SP – ClimateCwa						
R^2	0.8599	0.3893	0.1250	0.2909	0.3913	0.7824
"d"	0.9519	0.7792	0.6047	0.6921	0.7317	0.8498
"c"	0.8827	0.4862	0.2138	0.3733	0.4577	0.7517
Performance	Great	Bad	Terrible	Terrible	Bad	Verygood
ME	–0.0538	–0.0156	–0.1452	–0.2815	–0.0737	–0.0817
MÃE	0.1450	0.2677	0.4009	0.3654	0.2678	0.1978
Soybeanin Brasília-DF – Climate Aw						
R^2	0.7837	0.7656	0.5725	0.3755	0.8583	0.7703
"d"	0.9317	0.7750	0.8014	0.5636	0.8892	0.7632
"c"	0.8248	0.6781	0.6064	0.3454	0.8238	0.6699
Performance	Verygood	Good	Median	Terrible	Verygood	Good
ME	0.0320	–0.2419	–0.1383	–0.3725	0.0401	–0.1747
MÃE	0.1036	0.2511	0.2213	0.3874	0.2091	0.1956

(1) Coefficient of determination; (2) Index d of correspondence;(3) Index c of performance;(4) Mean Error;(5) Mean Absolute Error.

With the exception of sugarcane, the values of K_{cDK} and K_{cA} had very different trend of K_{cm} values for crops analyzed, mainly due to the fact that increased the number of measured periods. The results are interesting, because the K_{cDK} and K_{cA} values are recommended and widely used in numerous studies in the literature. The lack of greater agreement between the periodic values of K_c indicated that climatic and cultural aspects change and decisively influence the K_c values achieved throughout the production cycle (Zhang *et al*., 2011; Arif *et al*., 2012; Zapata *et al*., 2012). It was found for all analyzed crops, that the $K_c(DAP)_A$ functions estimated K_c values higher than $K_c(DAP)_{DK}$ functions, in the most of crop cycle. This finding shows, on average, the crop evapotranspiration values (ETc) estimated from K_{cA}or $K_c(DAP)_A$ will overestimate the ETc values estimated with K_{cDK} or $K_c(DAP)_{DK}$. Therefore, only in an author's choice of data or other alternative it is possible to make mistakes in estimating ETc(Liu and Lou, 2010).The adoption of a K_c for each development stage of corn, according to Fancelli (1986)scale (10 stages;K_{cm}), proposed by Detomini *et al*. (2009), improved the estimate of K_c for periods, throughout the crop cycle, compared to the K_{cDK} (4 stages) and K_{cA}(3 stages). The $K_c(DAP)_{DK}$ and $K_c(DAP)_A$ functions, proposed for corn, showed maximum point for further DAP relative to $K_c(DAP)_m$, indicating that different climate and soil conditions can actually cause great differences between K_{cm} and K_c'sr ecommended (K_{cDK} and K_{cA}). The Cwa climate of Piracicaba-SP, characterized by high average temperatures, decreased the amount of DAP required to complete the crop cycle, and the maximum vegetative development occurred around 70 days (Fancelli, 1986). The result shows the importance of establishing K_c's locations that reflect the soil and climate conditions of the area, shown in $K_c(DAP)_k$, which uses local weather data, presenting closer trend to $K_c(DAP)_m$. TheK_{cm}values for soybean were higher than K_{cDK} and K_{cA}, indicating again that the warmer climate of Brasília-DF (Aw) provides distortion in relation to the proposed values. The result agreed with Farias *et al*. (2001), who also found higher values of K_c regarding recommended ($K_{cDK}$and K_{cA}) to several regions. The $K_c(DAP)_k$was the best function that fits to $K_c(DAP)_m$, because it better reflected the local climate. The $K_c(DAP)_A$function also stood out and, if there was no weather station to provide data on Aw climate, it could be use this function with small absolute error (0.2091).The $K_c(DAP)_{DK}$ and $K_c(DAP)_k$ functions had very similar trend to $K_c(DAP)_m$ for sugarcane. The $K_c(DAP)_A$ function presented high K_c values for the crop, even to the climate type of BSwh.

The third-degree polynomial function did not adjust well to K_c values of peanut, as proposed by Allen *et al*. (1998). The result damaged the comparison between the K_c(DAP) functions obtained. Adverse weather conditions occurred in the experimental period, causing the K_{cm} in the maturation phase was high, probably precipitation and temperature well above of average led high ETc and sharp increase in K_c. It is important to note that K_c values obtained in atypical climatic conditions should be avoided for establishing K_c(DAP) functions for a given region. The trends of third-degree polynomial function was found by Silva and Amaral (2008) in the region of Cariri Brazil, and the K_{cm} values greater than $K_{cDK.}$ The study of these authors was not used in this study due to unavailability of data to perform the analyzes. The $K_c(DAP)_k$ function has not been estimated for peanut or bean due to the lack of reliable weather data in regions. This was a major obstacle found to use Eqs. 1-8, since they require daily data from weather stations, which often are not present in the regions of interest. The trend of K_c(DAP) functions for bean crop was very similar. Although limited in their use due to the need for specific climate data, it was observed that $K_c(DAP)_k$ had good results for leguminous crops. The adjustment K_c(DAP) functions to obtain daily K_c values proved to be a good alternative, however, dependent on several factors. Zhang *et al*. (2011) consider that the K_c values also vary with the variety of the crop, crop management, irrigation system, soil and coverage type and estimation method of ETo. Although more complete or complex models provide more accurate estimates of climate variations, having the inconvenience of lower spatial applicability due to lack of data for many regions (Farias *et al*., 2001).Compared to the use of periodic values of K_c, it is believed that the K_c(DAP) functions can improve the daily estimated ETc and, respectively, the other components of the daily agricultural water balance. However, analyzes demonstrated the impossibility of obtaining K_c(DAP) functions generic for each crop, being necessary the adjustment of functions for each crop condition (Table 3). The best would be that works involving studies with K_c submit the periodic K_c values, but were to conduct the adjustment of K_c(DAP) functions, considering weather, physiological and cultivation aspects. The proposition of K_c(DAP) functions was aimed precisely improving and overcoming the lack of existing data in some Brazilian regions. The lack of resources, such as weather stations and collection of crops data, should not serve as a justification for an agriculture without planning or inefficient (Arif *et al*., 2012).

Table 3. K_c(DAP) functions of best fit, obtained for different crops and locations

Crop/Location	Function		R²
Peanut (Rodelas-BA)	$K_c(DAP)_m =$	$6 . 10^{-6} .DAP^3 - 5 . 10^{-4} .DAP^2 + 0.0087 .DAP + 0.8179$	1.00
	$K_c(DAP)_{DK} =$	$-1 . 10^{-6} .DAP^3 - 4 . 10^{-5} .DAP^2 + 0.0230 .DAP$	0.86
	$K_c(DAP)_A =$	$-3 . 10^{-4} .DAP^2 + 0.0343 .DAP$	0.71
Sugarcane(Juazeiro-BA)	$K_c(DAP)_m =$	$-2 . 10^{-8} .DAP^3 - 3 . 10^{-5} .DAP^2 + 0.0083 .DAP + 0.4163$	1.00
	$K_c(DAP)_{DK} =$	$-2 . 10^{-6} .DAP^3 - 3 . 10^{-5} .DAP^2 + 0.0334 .DAP + 0.1146$	1.00
	$K_c(DAP)_A =$	$-3 . 10^{-5} .DAP^2 + 0.0157 .DAP$	0.98
Bean (Campinas-SP)	$K_c(DAP)_m =$	$-8 . 10^{-6} .DAP^3 - 5 . 10^{-4} .DAP^2 + 0.0214 .DAP$	0.95
	$K_c(DAP)_{DK} =$	$-4 . 10^{-6} .DAP^3 - 1 . 10^{-4} .DAP^2 + 0.0254 .DAP$	0.99
	$K_c(DAP)_A =$	$-5 . 10^{-4} .DAP^2 + 0.0506 .DAP$	0.89
Corn (Piracicaba-SP)	$K_c(DAP)_m =$	$-2 . 10^{-6} .DAP^3 - 3 . 10^{-5} .DAP^2 + 0.0334 .DAP$	0.86
	$K_c(DAP)_{DK} =$	$-6 . 10^{-7} .DAP^3 - 1 . 10^{-5} .DAP^2 + 0.0184 .DAP$	0.98
	$K_c(DAP)_A =$	$-2 . 10^{-4} .DAP^2 + 0.0313 .DAP$	0.89
Soybean (Brasília-DF)	$K_c(DAP)_m =$	$-6 . 10^{-8} .DAP^3 - 2 . 10^{-4} .DAP^2 + 0.0286 .DAP$	0.60
	$K_c(DAP)_{DK} =$	$-1 . 10^{-6} .DAP^3 + 1 . 10^{-4} .DAP^2 + 0.0037 .DAP$	0.95
	$K_c(DAP)_A =$	$-1 . 10^{-4} .DAP^2 + 0.0217 .DAP$	0.60

Thus, attempts to adjust functions from published and simplified data can maximize the efficiency of water use in agriculture and avoid waste, especially in areas where the resource is so scarce. When increasing the length of developmental stages sections to obtain the K_c of a crop, the obtained curve was less consistent with the values of K_{cDK} and K_{cA}. Therefore, the estimate of a daily K_c improved adjustment of K_c(DAP) functions, making it more sensitive to physiological changes of crops (Zapata *et al*., 2012).Referring to $K_c(DAP)_k$ functions, although it has been obtained performance "very good" and "good" for corn and soybean, respectively, using the equations proposed by Allen *et al*. (1998)proved to be very complex, requiring large amounts of climate and soil data. Besides these and getting questionable results, positive relations obtained did not provide a physical explanation of the evapotranspiration phenomenon. Thus, it is also believed that the adjustment of K_c(DAP) functions for estimating daily ETcis an intermediate solution. The methodology involving the use of K_c to find ETc is widely used for several decades, but present some problems, especially when the K_c values used have not been determined for the period and region studied. Therefore, it would be interesting to intensify studies to directly obtain ETc, similar to what is done for the EToby Penman-Monteith method, where the function relies on physical and not empirical explanation to the phenomenon.

Conclusion

It was possible obtain functions for setting daily crop coefficient for both studied crops and sites. Daily crop coefficient functions improved the accuracy of estimated crop evapotranspiration when compared to widely used values, by better reflect local climate and soil conditions of the crops; and, also for grouped values, because the curve decreases the variability of the data estimated daily.

REFERENCES

Allen, R.G., Pereira, L. S., Raes, D., Smith, M. 1998. Crop evapotranspiration: guidelines for computing crop water requirements. 1.ed. Rome: FAO.

Arif, C., Setiawan, B. I., Sofiyuddin, H. A. Martief, L. M., Mizoguchi, M., Doi, R. 2012. Estimating crop coefficient in intermittent irrigation paddy fields using Excel Solver. *Rice Science*, 19: 143-152.

Camargo, A. P., Sentelhas, P. C. 1997. Performance evaluation of different potential evapotranspiration estimating methods in the state of São Paulo, Brazil. *Revista Brasileira de Agrometeorologia*, 5: 89-97.

Detomini, E. R.,Massignan, L. F. D.,Libardi, P. L., Dourado Neto, D. 2009. Water consumption and crop coefficient for hybrid DKB 390. *ActaScientiarum Agronomy*, 31: 445-452.

Doorenbos, J., Kassam, A.H. 1979. Yield response to water. Rome: FAO. 193p. Irrigation and Drainage Paper, 33.

Fancelli, A. L. 1986. Alimentary plants: guide for study and discussion. Piracicaba: CALQ.

Farias, J. R. B., Assad, E. D., Almeida, I. R., Evangelista, B. A.Neumaier, N., Nepomuceno, A. L. 2001. Characterization of the water deficit for Brazilian soybean producing regions. *Revista Brasileira de Agrometeorologia*, 9:415-421.

INMET – Instituto Nacional de Meteorologia. 2016. Meteorological database for education and research (BDMEP). [internet] [acess in 22 jan. 2016]. Disponible in: <http://www.bdmpe.inmet.br/>.

Leal, B. G.,Sediyama, G. C. 2004.Mathematical model for determining the crop coefficient curve, Kc. *Engenhariana Agricultura*, 12:124-133.

Liu, Y.,Luo, Y. 2010. A consolidated evaluation of the FAO-56 dual crop coefficient approach using the lysimeter data in the North China Plain. *Agricultural Water Management*, 97: 31–40.

Lopes, O.D., Kobayashi, M.K., Oliveira, F.G., Alvarenga, I.C.A., Martins, E.R.,Corsato, C.E.2011.Determination of crop coefficient (Kc) and water use efficiency for irrigated rosemary peppermint. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 15: 548–553.

Medeiros, G. A., Arruda, F. B., Sakai, M.,Fujiwara, M., Boni, N. R. 2000. Vegetative growth and bean crop coefficient as related to accumulated growing-degree-days. *Pesquisa Agropecuária Brasileira*, 35:1733-1742.

Mendes, R. S. 2006. Determination of evapotranspiration by direct and indirect methods and the soybean crop coefficients for the Federal District. Masters dissertation. Brasília: UnB.

Setiyono, T. D., Weiss, A.,Specht, J., Bastidas, A. M., Cassman, K. G., Dobermann, A. 2007. Understanding and modeling the effect of temperature and day length on soybean phenology under high-yield conditions. *Field Crops Research*, 100: 257–271.

Silva, L.C., Rao, T.V.R.2006.Evaluation of the methods of estimating the peanut crop coefficients. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 10: 128–131.

Silva, M. T., Amaral, J. A. B. 2008. Evapotranspiration and crop coefficients for peanut irrigated under edafoclimatic condition the cariri area of Ceará State, Brazil. *Revista de Biologia e Ciências da Terra*, 8: 76-84.

Silva, T. G. F., Moura, M. S B., Zolnier, S., Soares, J. M., Vieira, V. J. S., Júnior, W. G. F. 2012. Water requirement and crop coefficient of irrigated sugarcane in a semi-arid region. *Revista Brasileira de Engenharia Agrícola e Ambiental*,16:64–71.

Toledo, N. T., Muller, A. G., Berto, J. L., Mallmann, C. E. S. 2010. Adjustment of the photothermic model to estimate soy bean development and leaf area index. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 14:288–295.

UNICAMP – Campinas University. 2015.Climatological data series of the Centre for Weather and Climate Research Applied to Agriculture. Campinas: UNICAMP.

UNIVASF– Federal Universityof Vale do São Francisco. 2015.Climatological data series of campus Juazeiro. Juazeiro: Laboratório de Meteorologia.

Willmott, C. J., Ackleson, S. G., Davis, R. E., Feddema, J. J., Klink, K. M., Legates, D. R., O’donnell, J., Rowe, C. M. 1985. Statistics for the evaluation and comparison of models. *Journal of Geophysical Research*, 90: 8995-9005.

Zapata, N., Chalgaf, I., Nerilli, E., Latorre, B., López, C., Martínez-Cob, A.,Girona, J., Playán, J. 2012. Software for on-farm irrigation scheduling of stone fruit orchards under water limitations. *Computers and Electronics in Agriculture*,88:52–62.

Zhang, K., Hilton, H. W., Greenwood, D. J., Thompson, A. J. 2011. A rigorous approach of determining FAO56 dual crop coefficient using soil sensor measurements and inverse modeling techniques. *Agricultural Water Management*, 98:1081–1090.

****