Single crop coefficients for agricultural irrigation in Guyana

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Irrigated agriculture is the activity that consumes the most water in the world. The crop coefficient (Kc) is widely used to estimate evapotranspiration (ETc), and is used in various water and soil engineering activities, as a component of the calculation. It is important to adjust the Kc values for the localized conditions in agricultural areas. Guyana is a country with abundant water resources and developing irrigation activities. However, as there is enough water, farmers and agricultural production systems do not pay special interest to the correct irrigation management, and therefore, the country lacks research results related to Kc values. Due to the above, a study was conducted in Guyana from 2014 to 2018 to adjust crop coefficients. For this, the growth stages of traditional crops such as rice and sugar and non-traditional crops such as cabbage, banana and others, were established. For each growth stage, meteorological variables were processed in order to determine the reference evapotranspiration. With these values, the crop coefficients were adjusted in the initial, middle and end stages (Kc_{ini}, Kc_{mid} and Kc_{end} respectively), using the FAO 56 method. The results showed that there is a tendency to overestimate the values of K_{ini} and underestimate Kc_{mid} and Kc_{end}, coinciding with some authors. A close relationship was found between the Kc_{mid} and Kc_{end} values according to FAO and the adjusted Kc_{mid} and Kc_{end} (ρ=0,99 - R^2=0,9848 - RMSE=0,049 and r=0.99 - R^2 = 0.9963 – 0.058 respectively), and accepted relationship with the FAO 56 Kc_{ini} values and Kc_{ini} adjusted (RMSE=0,358). It was concluded that with the adjusted Kc values, it is possible to determine the crop water requirements and the irrigation schedule in agricultural areas of Guyana.

Keywords: Crop coefficient, adjustment, crop evapotranspiration, wetting events, adjusted Kc

Irrigated agriculture is the activity that consumes the most water in the world. According to AQUASTAT (2016), irrigation represents 70% of the extractions of this resource. Two thirds of the world population will live in countries with water stress in 2025 if current consumption patterns are maintained (FAO 2019). Furthermore, FAO emphasizes that key decisions such as site selection, technology and suppliers are often made without taking into account the impact on water resources, especially when water is not a limiting factor either in quantity and / or in price. That is why this organization works with countries to ensure that the use of water in agriculture is more efficient, productive, equitable and respectful of the environment. Therefore, it is important to improve the efficiency in the use of water for irrigation of agricultural crops.

The crop coefficient (Kc) is widely used to estimate crop evapotranspiration (ETc), and is used in various water and soil engineering activities, such as soil water balance calculations (Cesar et al. 2016). Doorenbos and Kassam (1979) and Allen et al (1998) established experimental average Kc values for several crops, divided into different stages of development. However, several studies were conducted to compare the Kc values used in the literature with the local experimental values and large differences were found. The regions where these studies were conducted are: Yucheng in China, Wellesbourne in the United Kingdom, West Java in Indonesia and semiarid conditions in Spain. (Liu and Luo 2010; Zhang et al. 2011; Arif et al. 2012; Zapata et al. 2012).

Therefore, it is vital to determine the Kc based on the local agroclimatic conditions. López et al. (2015) state that Kc values should be calibrated for local weather conditions and

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crop management. This was based on a review of research carried out by other authors, where they agreed that the Kc values should be adjusted. Shukla et al. (2014) also support the previous statement, where they state that although the use of the FAO Penman-Monteith equation and crop coefficients (Kc), continue to be of the simplest and most economical methodologies, these have the disadvantage that Kc values must be obtained and validated for local conditions.

There are different techniques to estimate evapotranspiration, such as using Whirlpool Covariance, lysimeters, Bowen's ratio, ground water balance, Scintilometry and Remote Perception (Zhang et al. 2014), which have been presented as more precise methods.

Farg et al. (2012) estimated evapotranspiration and crop coefficient through an integrated FAO 56 approach (Allen et al. 1998) and remote sensing data in south Nile Delta, Egypt.

Thus there are several investigations related to the estimation and adjustment of the crop coefficients. However, in Guyana this type of research is very scarce despite the fact that this country presents a developing agriculture system, where research in this field is necessary to improve water use management.

Therefore, the objective of this article is to adjust the crop coefficients through the processing of meteorological data, as established by Allen et al. (1998).

Materials and methods

The study was carried out in the Agrometeorology Section of the Hydrometeorological Service of the Ministry of Agriculture, Guyana. A historical series of 5-year data (2014-2018) of climatic variables from nine synoptic weather stations was processed to determine reference evapotranspiration (ETo) and to adjust the crop coefficients (Kc). This period was considered because, according to the World Meteorological Organization (2019), the years 2015, 2016, 2017 and 2018, have been confirmed as the four warmest ever recorded, confirming the continuity of long-term climate change caused by atmospheric concentrations of greenhouse gases. For the analysis, seven climatic variables were considered namely; temperature (maximum and minimum), relative humidity, sunshine hours, wind speed, rainfall and rain-days. Table 1 shows the monthly average values for each station.

Table 1: Monthly average of climatic variables at each station from 2014 to 2018

Meteorological Station	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative Humidity (%)	Daily Sunshine (hours)	Wind Speed ($m \cdot s^{-1}$)	Rainfall (mm)	Rain Days
Mabaruma	31.0	22.3	89.2	5.1	1.4	231.0	17
Georgetown	30.3	24.3	83.3	7.0	1.2	175.2	14
Ogle	30.4	24.2	82.1	7.1	3.8	172.8	14
Timehri	31.8	21.6	89.8	6.0	0.9	212.4	16
New Amsterdam	31.4	24.1	83.0	6.7	0.8	152.4	13
Kamarang	30.1	20.5	91.2	5.7	0.3	184.7	18
Kaieteur Falls	28.9	21.5	93.9	6.1	0.4	351.0	21
Lethem	33.2	23.7	79.3	7.4	2.5	124.5	9
Ebini	32.2	22.6	88.7	6.5	1.5	169.1	14

Source: Hydrometeorological Service, Guyana

Data processing consisted of selecting periods of the year for each crop based on the country's agricultural production system. In each of these periods the calculations were carried out (Table 2). For the cultivation of rice and sugarcane, there are established production systems in agriculture in Guyana, but for the rest of the crops, planting is done at any time of the year. That is why the information was processed from January to December to obtain an annual average.

Determination of the Reference Evapotranspiration (ETo)

The FAO Penman-Monteith equation (Allen et al. 1998) was used:

$$ETo = \frac{0.408\Delta(R_n - G) + \Upsilon\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \Upsilon(1 + 0.34u_2)} \quad (1)$$

where:

ETo is the reference evapotranspiration (mm·d^{-1}),
Rn is the net radiation (MJ m^{-2} d^{-1}),
G is the heat flux in the ground (MJ·m^{-2}·d^{-1}),
T is the average daily air temperature (°C),
Δ is the slope of the saturation pressure curve (kPa·°C^{-1}),
ϒ is the psychometric constant (kPa·°C^{-1}),
e_s is the vapor saturation pressure (kPa),
e_a is the average daily vapor pressure (kPa),
u_2 is the average wind speed at 2 m elevation (m·s^{-1}).

The CROPWAT software was used to calculate the reference evapotranspiration values (Swennenhuis 2009).

Table 2: Periods analyzed for the adjustment of the crop coefficients

Crop	Period	Crop	Period
Rice*	May June-September September-October	Pepper	
Rice*	December January-April April-May	Watermelon	
Sugarcane (virgin)	June July-February February-April	Cucumber	
Sugarcane (ratoon)	December January-August August-October	Pumpkin	January-December
Corn		Lettuce	
Peanut		Neck pumpkin	
Bean		Tomato	
Haba		Eggplant	
Cowpea	January-December	Eddoe	
Celery		Sweet potato	
White spinach		Cassava	
Cabbage		Banana	
Chinese cabbage			

*There are two production systems for rice in Guyana

Adjustment of Kc_{ini}

This coefficient was determined by knowing the duration of the initial stage of the crop and obtaining the amount of rain events at that stage. Then the time interval between wetting events is calculated as follows:

$$I = \frac{L_{ini}}{N_e} \qquad (2)$$

where:

L_{ini}- is the duration of the first stage of crop growth in days.

N_e- is the amount of rain events within the crop growth stage in mm.

Knowing the value of interval between wetting events (***I***), two graphs of document FAO 56 (Allen et al. 1998, figures 29 and 30) are used to determine the adjusted Kc_{ini} for different wetting events and infiltration depths in the period.

Since the infiltration depths in all periods are within the range of 10 to 40 mm (Table 3), the following equation is applied that combines the use of both graphs.

$$Kc_{ini} = Kc_{ini\ (Fig.29)} + \frac{(I-10)}{40-10}\left[Kc_{ini\ (Fig.30)} - Kc_{ini\ (Fig.29)}\right] \qquad (3)$$

where:

Kc_{ini} (Fig. 29) - initial Kc value corresponding to Figure 29

Kc_{ini} (Fig. 30) - initial Kc value corresponding to Figure 30

I- infiltrated depth average in mm.

Table 3: Values of infiltration depths determined by each study period

Period	Infiltration depth (mm)
May*	14.9
June-September**	14.5
September-October***	11.9
December*	12.1
January-April**	10.9
April-May***	14.3
June*	16.2
July-February**	13.7
February-April***	10.8
December*	12.1
January-August**	13.3
August-October***	12.2
January-December	13.3

Items marked with (*) correspond to the initial crop growth stage, (**) middle stage, and (***) end stage.

Adjustment of Kc_{mid} y Kc_{end}

The following equations were used (Allen et al. 1998):

$$Kc_{mid(adjusted)} = Kc_{mid(FAO)} + [0,04(u_2 - 2) - 0,004(HR_{min} - 45)]\left(\frac{h}{3}\right)^{0,3} \qquad (4)$$

$$Kc_{end(adjusted)} = Kc_{end(FAO)} + [0,04(u_2 - 2) - 0,004(HR_{min} - 45)]\left(\frac{h}{3}\right)^{0,3} \qquad (5)$$

where:

$Kc_{mid\ (adjusted)}$ and $Kc_{end\ (adjusted)}$ - are the adjusted middle and end Kc values respectively.

Kc_{mid} (FAO) and Kc_{end} (FAO) - are the middle and end crop coefficients expressed by FAO 56 document.

u_2 - average daily wind speed value for both stages of growth, in $m \cdot s^{-1}$

HR_{min} - average daily value of minimum relative humidity for both stages of growth

h - average height of plants for both stages of growth

The conditions for equations 4 and 5 were:

- HR_{min} ranges between 20% and 70%,
- the average height (h) was taken from FAO 56 document.

To quantify the relationship that exists between the different Kc values of all the crops studied, the Pearson correlation coefficient (r) was determined, and linear regression was performed calculating the coefficient of determination (R^2). In addition, RMSE was determined as a goodness of fit test to evaluate the $Kc_{adjusted}$ values with respect to the Kc_{FAO} values.

Calculation of RMSE (Fox 1981):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P-O)^2}{n}} \qquad (6)$$

where:

P- $Kc_{adjusted}$ value
O- Kc_{FAO} value
n- number of values

Results

Table 4 shows the reference evapotranspiration (ETo) values in the three stages of growth for all crops. The values of Kc according to FAO 56 and the adjusted values are also shown. It can be seen with the exception of rice and sugarcane the values of ETo and adjusted Kc_{ini} for all other crops are repeated. This is because, as explained above, climatic variables were processed throughout the year, since these crops are sown at any time. Regarding the cultivation of rice and sugarcane, these have sowing periods and harvests established in the country, so there are variations of ETo and Kc.

In general, the adjusted Kc_{ini} values are overestimated with respect to the FAO 56 Kc_{ini} values. This is not the case with the adjusted Kc_{mid} and Kc_{end} values, where these are underestimated.

Table 4: Results of the reference evapotranspiration and the $Kc_{adjusted}$ for the three stages of crop growth

Crop	ETo (mm·d^{-1})			Kc FAO 56			Kc adjusted		
	ini	mid	end	ini	mid	end	ini	mid	end
Rice	3.52	4.00	4.69	1.05	1.20	0.75	1.02	1.14	0.70
Rice	3.58	3.88	3.77	1.05	1.20	0.75	0.88	1.15	0.69
Sugarcane (virgin)	3.30	3.73	3.96	0.40	1.25	0.75	1.08	1.17	0.67
Sugarcane (ratoon)	3.58	3.81	4.59	0.40	1.25	0.75	0.88	1.17	0.67
Corn	3.96	3.96	3.96	0.60	1.20	0.50	0.88	1.13	0.42
Peanut	3.96	3.96	3.96	0.50	1.15	0.60	0.88	1.11	0.55
Bean	3.96	3.96	3.96	0.40	1.15	0.35	0.88	1.11	0.30
Haba	3.96	3.96	3.96	0.50	1.15	0.30	0.88	1.10	0.24
Cowpea	3.96	3.96	3.96	0.40	1.05	0.50	0.88	1.01	0.45
Celery	3.96	3.96	3.96	0.70	1.05	1.00	0.88	1.01	0.95
White spinach	3.96	3.96	3.96	0.70	1.00	0.95	0.88	0.97	0.91
Cabbage	3.96	3.96	3.96	0.70	1.05	0.95	0.88	1.01	0.90
Chinesse cabbage	3.96	3.96	3.96	0.70	1.05	0.95	0.88	1.01	0.90
Pepper	3.96	3.96	3.96	0.60	1.05	0.90	0.88	1.01	0.84
Watermelon	3.96	3.96	3.96	0.40	1.00	0.75	0.88	0.96	0.70
Cucumber	3.96	3.96	3.96	0.60	1.00	0.75	0.88	0.97	0.71
Pumpkin	3.96	3.96	3.96	0.50	1.00	0.80	0.88	0.96	0.75
Lettuce	3.96	3.96	3.96	0.70	1.00	0.95	0.88	0.97	0.91
Neck pumpkin	3.96	3.96	3.96	0.50	1.00	0.80	0.88	0.96	0.75
Tomato	3.96	3.96	3.96	0.60	1.15	0.80	0.88	1.11	0.75
Eggplant	3.96	3.96	3.96	0.60	1.05	0.90	0.88	1.00	0.84
Eddoe	3.96	3.96	3.96	1.05	1.15	1.10	0.88	1.09	1.03
Sweet potato	3.96	3.96	3.96	0.50	1.15	0.65	0.88	1.11	0.60
Cassava	3.96	3.96	3.96	0.30	0.80	0.30	0.88	0.75	0.24
Banana	3.96	3.96	3.96	0.50	1.10	1.00	0.88	1.03	0.91

Figure 1 shows the relationship between crop coefficients established by FAO and those adjusted to Guyana conditions. For the initial stages (Figure 1a), no linear relationship was found because the determination of the adjusted Kc_{ini} values does not take into account the Kc_{ini} values of the FAO document. The correlation coefficient (r) proves it with almost zero value. This means that there is no linear relationship between both variables, but there may be a non-linear relationship. This is indicated by the non-elevated RMSE value, showing an accepted adjustment of the $Kc_{adjusted}$ value with respect to the Kc_{FAO} value.

However, in figures 1b and 1c there is a close linear relationship between both coefficients for the middle and end stages (R^2 = 0.9848 and R^2 = 0.9963 respectively), due to the Kc values of the FAO, and therefore follow the same trend. So also the r and RMSE values show an almost perfect correlation.

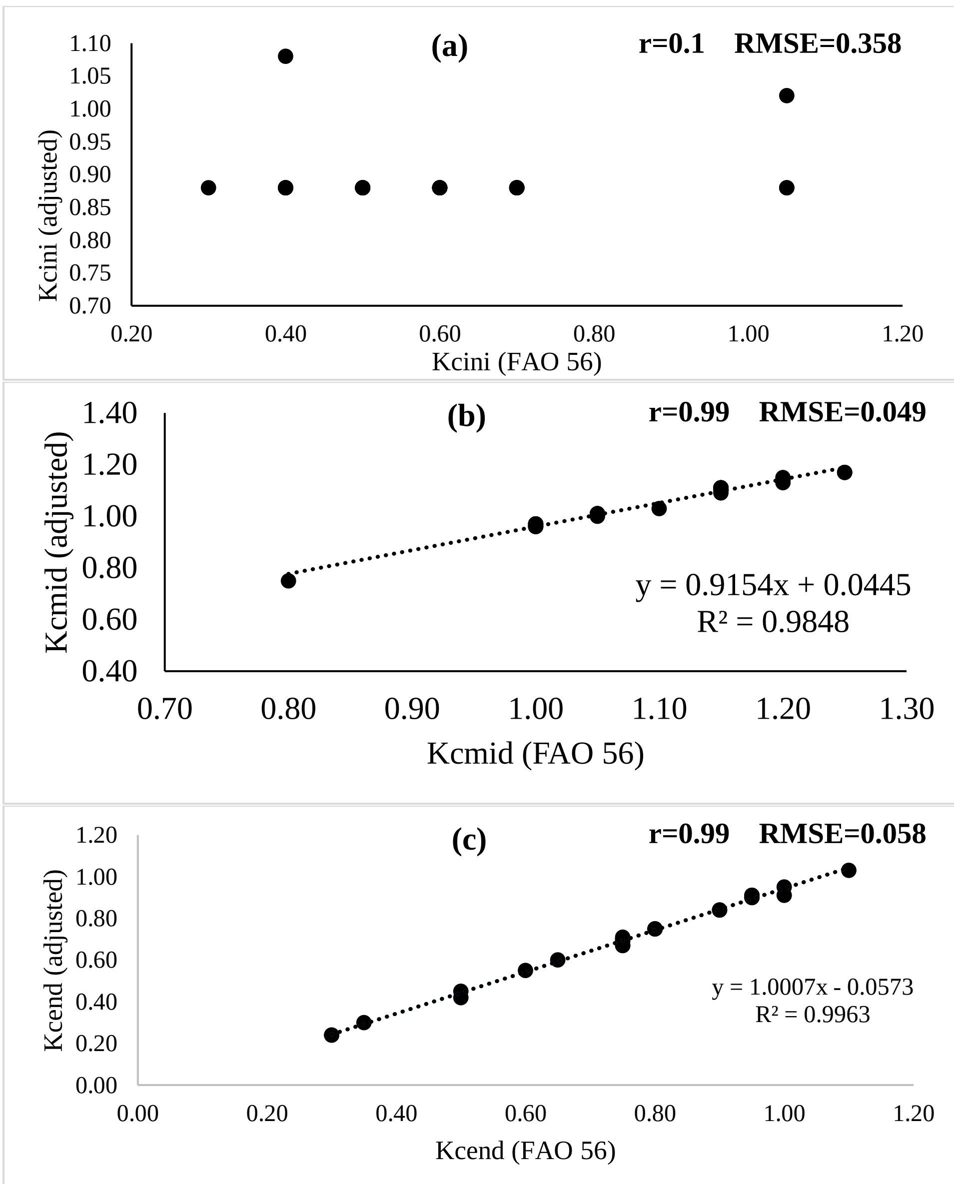

Figure 1: Relationship between the initial, middle and end crop coefficients proposed by FAO 56 and adjusted (a, b and c respectively).

Discussion

Cisneros et al. (2015) state that the crop coefficient varies depending on the reference evapotranspiration of the area, the variety of the crop, the method of application of water and soil type, so it is recommended that it be determined and adjusted for each specific condition.

Regarding the overestimation and underestimation of the values of Kc_{ini}, and Kc_{mid} and Kc_{end} respectively, it coincides with studies carried out by several authors on specific crops. For example, López et al. (2015) obtained estimated values of crop coefficients for banana Chile lower than those reported by Allen et al. (1998). Rodríguez et al. (2011) also obtained lower values of average and final crop coefficients compared to FAO 56 document for the same crop but in another region.

According to Allen et al. (1998), the Kc_{ini} FAO 56 values are only approximations, and should be used to estimate ETc only during preliminary or planning studies, for which the adjusted Kc_{ini} values are more precise. Therefore, this constitutes an alternative for the practice of agricultural irrigation. However, it is necessary to conduct research studies to obtain results in local conditions.

There is no scientific information in Guyana regarding the determination of crop coefficients under experimental conditions. Therefore, it is not possible to compare the adjusted Kc values with local investigations. On the other hand, no studies were found where relations were established between the adjusted Kc and the FAO 56 Kc. However, work has been done to relate the Penman Kc and the Penman-Montheith Kc. In this case, Della et al. (2004) related these coefficients finding a linear relationship of $R^2 = 0.949$.

Conclusion

Adjustments of the crop coefficients for the agroclimatic conditions of Guyana were established. With these values, the crop water requirements and the irrigation schedule in agricultural areas, can be determined. Nevertheless, it is necessary to conduct research studies to obtain more precise Kc values under experimental conditions.

Also, the adjusted Kc_{ini} values were overestimated with respect to the Kc_{ini} values of the FAO 56 document. As for the Kc_{mid} and Kc_{end} values, these are underestimated. There is a close relationship between the adjusted values of Kc_{mid} and Kc_{end} and those presented by Allen et al. (1998). While between the adjusted Kc_{ini} values and the FAO 56 document, accepted relationship was found.

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