



Bean Crop Coefficients Determined for Central Provinces Conditions of Cuba

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Received: January 10, 2023

Published: April 06, 2023

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Abstract

Introduction/ Context: The available irrigation water for crops is more limited quantitative as qualitatively, due to the increasing growth of demands for different uses, what makes more necessary the efficient use of water in irrigation systems. The water crop needs are determined by climate demand and crop type, these two parameters are interrelated through Crop Coefficient (Kc), it varies in time because of the factors that influence in the crop development.

Objective: The objective of the research was to determine bean Kc under the conditions of the Cuban central provinces.

Methodology: The study was carried out in the Cooperative Production Basic Unit (UBPC) "Victoria II", belonging to the Agricultural Enterprise Camagüey", located in Camagüey municipality in Camaguey province; using center pivot machine technology on red Ferralitic soil, where soil moisture samplings were made every five days with TDR-300, the crop evapotranspiration (ETc) was determined into account the irrigation made and the profitable rain during the cropping period, the results of Kc were calculated starting from the relationship of moisture balance every five days and the results were validated.

Results: The results obtained showed the increase in ETc during the flowering and pod formation stage with a value of 3.98 mm/day, the Kc obtained was 0.45 (Kc inic), 1.00 (Kc mid) and 0.38 (Kc end) and in results validation, a constant trend was observed in the behavior of the Kc results, while the variation in relation to the results of the research stage is maintained in a range of less than 10% of variation.

Conclusions: It was concluded that Kc parameters obtained can be used for bean irrigation scheduling under the conditions of the central provinces in Cuba.

Keywords: Irrigation Scheduling; Efficiency; Water Needs

Introduction

The available water for crop irrigation is increasingly limited both quantitatively and qualitatively due to the accelerated growth of domestic and industrial demands, which makes the efficient use of water in irrigation systems increasingly necessary. An efficient irrigation is one capable of keeping soil moisture within appropriate limits, which will depend on crops features, climate conditions and the environment management, all of which is expressed through evapotranspiration (ET) [1].

The correct water for irrigation scheduling based on an adequate balance implies knowledge of crop water needs and water availability in the supply source, crop water needs are determined

by climatic demand and crop type, these two parameters in turn, are related to each other through the so-called Crop Coefficient (Kc) which is a value obtained by relating the crop evapotranspiration (ETc) with the reference evapotranspiration (ETo), this coefficient varies over time due to factors influencing crop development [2].

The Kc integrates the effects of the characteristics that distinguish a reference crop, which has a uniform appearance and completely covers the soil surface, different crops will have different Kc values, the crop features that vary during its growth will also affect the Kc value [3].

In the Unit under study, the main problems related to irrigation scheduling in bean cropping in the province are referred to the poor knowledge of personnel in charge of the activity, due to lack of training, resulting in an inefficient management of irrigation water of bean with electric center pivot machines, affecting the crop by not applying the irrigation standards and frequencies necessary for its normal growth and development, that's why an irrigation schedule is necessary that guarantees the adequate use of the areas under irrigation and getting satisfactory productive results.

Objective

To determine crop coefficients (Kc) of beans under the conditions of the central provinces of Cuba.

Materials and Methods

The research was carried out during three campaigns (2019 - 2022) in areas of the Cooperative Production Basic Unit (UBPC) "Victoria II", belonging to the Agricultural Enterprise Camagüey, which is geographically located in the Camagüey municipality, at Camagüey province in Cuba, between coordinates N (310.00-315.00) and E (403.00-408.00) on the San Serapio map sheet (4680-II-A) at a scale of 1:25 000 (Figure 1).

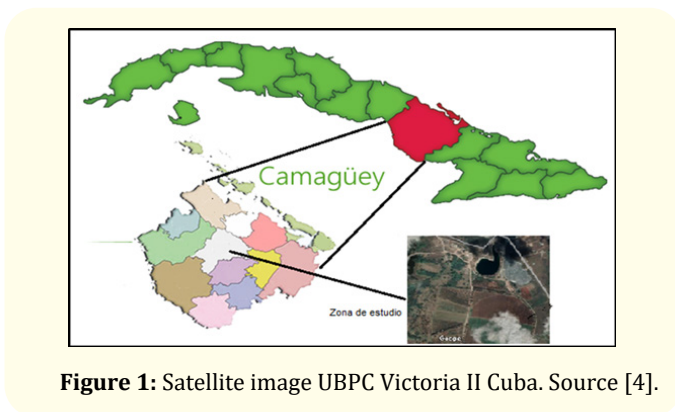


Figure 1: Satellite image UBPC Victoria II Cuba. Source [4].

The main activity of the Unit is aimed at the producing crops, including roots and tubers, vegetables, fruits and grains; being beans the most representative one.

Irrigation infrastructure

The UBPC has a total area of 403.0 ha distributed over 17 farms, of which 144.0 ha are under irrigation, including 82,0 ha with sprinkler irrigation linked to 6 semi-stationary systems (medium pressure) and 62.0 ha irrigation with 5 center pivot machines [5].

The UBPC has for irrigation a supply source of surface water (Borges micro dam), its main parameters occupying a total volume

1.102 MM m³ according to the information from the Hydraulic Exploitation Company in Camagüey (INRH Camagüey, 2018).

The irrigation system works from a main pumping station located in the reservoir, from which the water is pumped by a closed conductor to a regulating box located at a higher point in the area and then it is distributed by gravity towards the entire irrigation network using closed conductors, which feed the Pumping Stations of each of the irrigation systems installed in the unit.

Soils

From updating the study carried out by the Cuban Soil Research Institute [8], was specified there are six types of soils at the UBPC "Victoria II" (Figure 2).

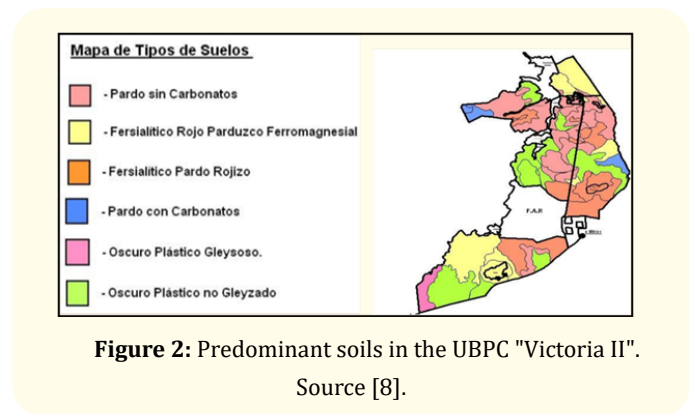


Figure 2: Predominant soils in the UBPC "Victoria II". Source [8].

Climate

The locality presents typical characteristics of tropical climate of seasonally humid equatorial savannah forests with humid summer and with a comparatively remarkable trend to continental character within the country; in its physical-geographical condition the plains predominate.

For the characterization of the UBPC "Victoria II" in 2019, the data corresponding to the meteorological station of Camagüey, Cuba (78355) were used, located at 21° 24' north latitude and 77° 51' west longitude, with a height of 118 m above sea level, being the closest and most representative station for the study area (Table 1).

Characterization of the experimental area

The research was carried out in areas of electric center pivot machine. The predominant soil in the research area is reddish brown Fersialitic whose main characteristics are shown in table 2.

Parameter	U.M.	Media
Temperature	°C	22.2
RH	%	77
Wind speed	km/h	8.6 a 13.7
precipitation	mm	1390.9
Insolation	light-hours/day	7.8
Cloudiness	eighths	4 a 5

Table 1: Average values of climatic parameters.

Depth (cm)	Densidad aparente (g/cm ³)	Porosidad (%)	Capacidad de Campo (% bss)	Velocidad Infiltración (mm/h)
00 - 10	1.26	52.4	31.4	21
10-20	1.26	52.4	30.0	21
20 - 30	1.26	52.4	34.9	21

Table 2: Characteristics of the predominant soil in the research area.

Genetic Classification: Reddish Brown Fersialitic, Cuba.

Source: [9].

Calculation of the application efficiency of the electric center pivot machine

The evaluation of the machine was carried out according to the procedure described in NC: 11545 [10], obtaining values of uniformity coefficient (Cu) and discharge efficiency (Ef) that were used to determine the working regime in each of the phases of crop development.

Pivot machine adjustment

From the soil and the crop features, the net irrigation standards to be applied by stage of physiological development were determined, which were used for the use of the pivot machine regulation table and the application efficiency obtained during the evaluation will determine the necessary regulation for the entire crop stage.

TDR-300 Calibration

For the determination of soil moisture, the digital soil moisture sensor was used, known as TDR-300 (Time Domain Reflectometer) (Figure 3).

The TDR-300 probe has proven to be an effective method that allows you to quickly and efficiently obtain volumetric moisture content readings in the soil to operate the irrigation system and keeping the level of available moisture between the upper and the lower limit of the reserve easily usable [12].



Figure 3: TDR 300 soil moisture meter. Source: [11].

Before starting the study, the TDR-300 equipment was calibrated using the gravimetric method to determine the moisture present, using a SORTORIOS Signum 1 digital scale with a weighing range of up to 35 kg and a precision of 0.1g (Figure 4).



Figure 4: SORTORIOS Signum 1 digital scale. Source: [13].

Calculation of crop evapotranspiration

To determine moisture soil to be used in the moisture balance, a control position was defined (Figure 5) occupying an area of 4 m²; in it, soil moisture sampling was carried out every five days.

From the moisture present, the moisture reserve was calculated.

$$W = 100 \times H \times Da \times Hp \text{ ----- (1)}$$

Where: W. Moisture reserve (mm); H. Depth to moisten (mm); Gives. Apparent density (mm); moisture present (mm).

From the soil moisture balance method, the initial and final reserve moisture of the period was calculated, considering the final reserve of one period as the initial reserve of the following period

$$Wf = Wi + R + LLa - ETc \text{ ----- (2)}$$



Figure 5: Location of the control position.

Where: W_f . Final reserve (mm); W_i - Initial reserve (mm); R. Net irrigation standard (mm); Ll_a . Usable rainfall (mm); Etc . Evapotranspiration (mm).

The value of the magnitude of the rainfall that occurred was measured with a rain gauge located in the research area, performing the daily reading at the same time. The calculation of usable rainfall during the period was carried out taking into account the rainfall (Ll) and the irrigation (R) applied, as well as the Etc of the crop during the decade evaluated in the period prior to the rain.

After calculating the final W_f , the Etc of the evaluated period is determined taking into account the irrigations carried out and the usable rainfall, according to the following equation

$$Etc = (W_i + R + Ll_a) - W_f \quad \text{----- (3)}$$

Where: Etc . Crop evapotranspiration (mm); W_i - initial moisture reserve (mm); W_f - final moisture reserve (mm); Ll_a - usable rainfall (mm); R- irrigation (mm).

Calculation of the Kc

During 2019 - 2020 and 2020-2021 campaigns, bean evapotranspiration behavior was calculated, the average results obtained are shown.

The methodology approved by the FAO for the study of crop evapotranspiration (Etc) is based on its calculation as the product of the reference evapotranspiration (ETo) and the crop coefficient (Kc) [14].

The Kc values were calculated from the relationship of the moisture balance of the period every five days knowing the Etc and the ETo according to the expression:

$$Kc = Etc/ETo \quad \text{----- (4)}$$

For this, the forecast of the behavior of the reference evapotranspiration (ETo) for the study area was obtained weekly from the Province Meteorological Center (CMP) in Camagüey, Cuba (Figure 6).



Figure 6: Daily reference evapotranspiration information.

Source: [15].

The Kc values obtained were transformed into the steps described in the Penman-Monteith method [3].

After performing the calculation, the Kc curve was prepared from the data obtained, determining the duration of the development stages and the value of the Kc corresponding to each one, the curve represents the changes along of their growth period.

Validation of Kc results

The validation of the results is aimed at verifying the results obtained under production conditions, it was carried out during 2021-2022 campaign, for which the Etc values were determined from the moisture balance, with this information and the ETo values obtained from the Meteorological Center of Camagüey, Cuba, the Kc were calculated, the values obtained were compared with those calculated during the research stage.

Results and Discussion

Electric center pivot machine evaluation

As a result of the evaluation of the electric center pivot machine, values of Uniformity Coefficient and Application Efficiency of 82% and 75%, respectively, were obtained; [16] considers that for this technology the Uniformity Coefficient is adequate in the range between 85 and 90%, [17] for which the value obtained can be classified as acceptable, while the Application Efficiency is low, which is attributed to prevailing wind speed that behaved in the range of 2.8 to 3.5 m/s, usual values during the operation of this irrigation system, so that in the development of the research one of the aspects

taking into account was to place the emitters at the same height to reduce the incidence of the wind, referring to the topic [15] one of the issues raised is height reduction of the emitter to the ground, to diminish losses due to evaporation and drag, without harm irrigation quality parameters and night irrigation also contributes to reducing these hindrances.

Pivot machine regulation

The results of the necessary regulation for the application of irrigation throughout the cropping stage are shown in table 3.

Physiological development stage	Net norm (mm)	Gross norm (mm)	Regulation (%)
Sowing - Germination	5.92	10.03	25
Germination - Establishment	5.92	10.03	25
Establishment - Flowering	5.92	10.03	25
Flowering - pod formation	11.34	19.22	15
Pod formation - Harvesting	11.34	19.22	15

Table 3: Pivot machine regulation.

TDR Calibration - 300

With the calibration of the TDR-300, values were obtained which reflect the relationship between the equipment reading and the soil moisture in the research area, as shown in table 4.

Reading TDR	CC BSS (%)	Reading TDR	CC BSS (%)	Reading TDR	CC BSS (%)
> 75	100	67	92	54	84
75	98	65	90	49	82
72	96	62	88	45	80
69	94	60	86	< 45	< 80

Table 4: Scale for irrigation programming based on the reading of the TDR-300.

Calculation of crop evapotranspiration

During the cropping cycle there were 6 rain events with a total magnitude of 62.5 mm and 51% utilization. Figure 7 shows their distribution.

16 irrigations were carried out, in total, the moisture inputs during the entire crop cycle were 263 mm, its distribution is shown in figure 8.

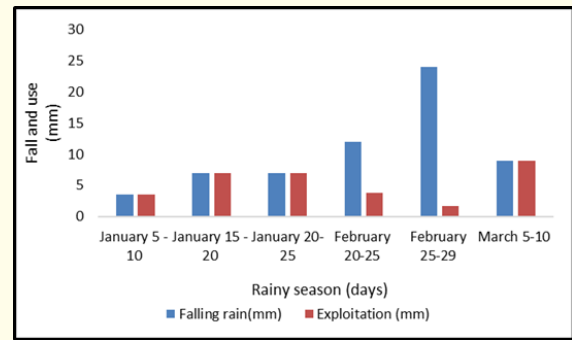


Figure 7: Total and usable rainfall.

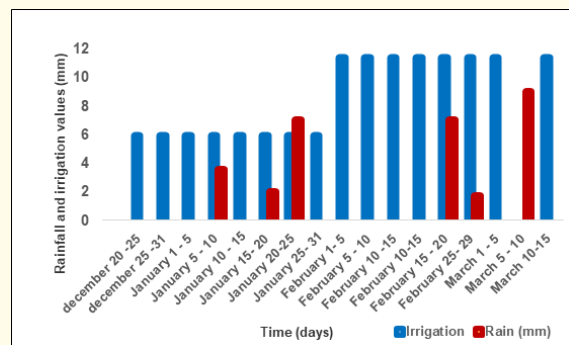


Figure 8: Moisture ingress.

The results of crop evapotranspiration (ETc) obtained from moisture balance by stages of physiological development are shown in table 5.

Physiological development stage	ETc (mm/day)
Sowing - Germination	1.61
Germination - Establishment	2.43
Establishment - Flowering	2.82
Flowering - Pod formation	3.98
Pod formation - Harvest	1.86

Table 5: Crop evapotranspiration values during the experimental stage.

The ETC values varied at all stages of crop development, increasing as the crop grows and develops, reaching its maximum value at the time of flowering and pod formation.

The results reported by different authors coincide in stating that beans are a crop susceptible to both excess moisture and its deficit during its development cycle [18].

The highest consumption is observed in the flowering and pod formation stage, a result that coincides with reports from [19] that identify the period during the flowering stage as critical for water demand.

Calculation of the Kc

A summary of the ETo information received from the Camagüey Meteorological Center, Cuba during the two campaigns of the experimental stage is shown in table 6.

Month	ETo (mm/día)		
	1ª Ten	2ª Ten	3ª Ten
December	3.50	3.72	3.50
January	3.69	3.41	3.75
February	3.71	3.88	3.80
March	4.02	4.25	4.20

Table 6: Mean values of ETo during the experimental stage.

The Kc integrates the effects of the characteristics that distinguish a reference crop, which has a uniform appearance and completely covers the soil surface, different crops will have different Kc values, the characteristics of the crop that varies during its growth will also affect the Kc value [17].

The factors that affect the values in the Kc are the characteristics of the crop, the development stage and the duration of the vegetative period; will have a seasonal variation: initial phase (germination and initial growth with 10% coverage), development phase (from the end of the initial phase and between 70% - 80% coverage), maturing phase (from full coverage to start maturation (leaf fall) and final phase (from the end of the previous phase to harvesting) [18].

The Penman-Monteith method recommended by the FAO [3] for calculating the Kc suggests the use of the graph in which the four stages are framed (Figure 9).

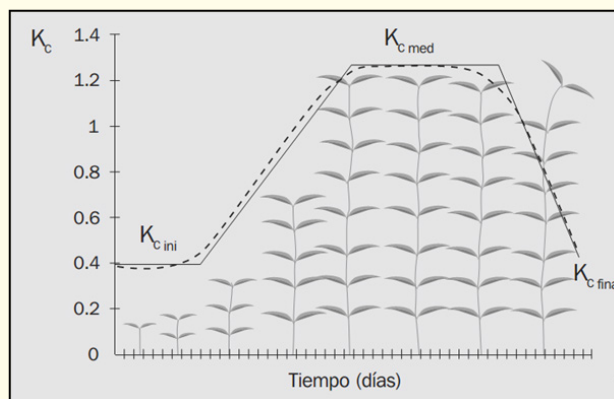


Figure 9: Crop Coefficient (Kc) during crop development.

Source: [3].

The values obtained were used to prepare the Kc curve (Figure 10).

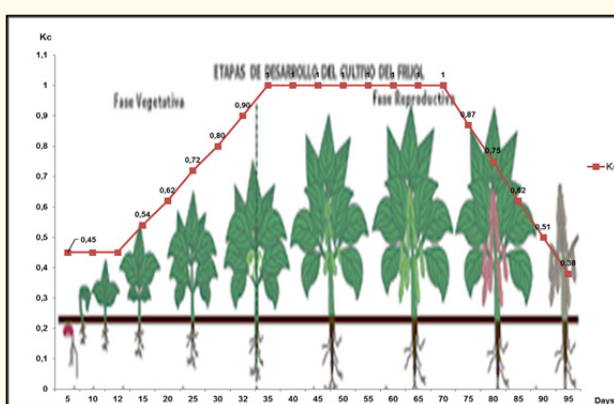


Figure 10: Kc curve obtained during the investigation.

The results obtained in the research were 0.45 (Kc init), 1.00 (Kc mid) and 0.38 (Kc end), which are similar to FAO reports (3) with values of 0.40; 1.15 and 0.35 and are far from those indicated in [20] which were 0.89; 0.90 and 0.57 respectively; In these last results, it is observed that the Kc values of the initial and middle stages are practically coincident, which is far from the behavior observed during the investigation stage.

The values shown in figure 10 are in correspondence with what was proposed by [21], who have pointed out that during the cropping growth period the variation of Kc expresses the changes in the vegetation and in the degree of soil cover, in the research was taken

into account from the physiological point of view when the plant was in the period of highest water demand shown in the results obtained.

Studies carried out by [22], report the possibility of applying Controlled Deficit Irrigation criteria in bean cropping, taking care not to create water stress conditions in the flowering stage and pod formation, which guarantees the highest irrigation water productivity.

While ETo represents an indicator of climatic demand, the value of Kc varies mainly depending on the particular characteristics of the crop and its stage of development, affected only to a small extent depending on the climate. This allows the transfer of standard values of the crop coefficient between different geographical areas and climates [23].

Validation of Kc results

During validation, the results shown in table 7 were obtained.

Stage	Days		Kc		
	A	B	A	B	C
Initial	12	10	0.45	0.50	0.90
Developing	23	20	0.45 - 1.00	0.50-0.96	0.99
Half	38	35	1.00	0.96	1.04
Final	22	27	1.00 - 0.38	0.96-0.42	0.90
Total	95	92	0.79	0.78	1.01

Table 7: Validation results of Kc values.

A: Research stage

B: Validation

C: Relationship between the results obtained during the experimental stage and the validation stage.

It is observed that the same trend is kept in the behavior of the Kc values, while the variation in relation to the results of the researching stage remains in a range of less than 10% variation, which confirms the wealth of the values calculated.

Conclusions

- The results of the evapotranspiration of the crop in the experimental stage obtained a value of 3.98 mm/day and the highest demand was obtained in the flowering phase grain formation.
- The values of crop coefficients varied as follows: 0.45 at the initial stage, 1.00 at the middle stage and 0.38 at the end.

- The Kc values determined can be used for bean irrigation scheduling under the conditions of the central Cuban provinces.

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