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Producing *Chrysanthellum indicum* DC. (1836) on organic amended soil in dry-season: crop coefficient K_c and growing stages determination

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Abstract
An important concern has risen about the over exploitation of both timber and non-timber products in West African Soudano-Sahelian countries. This study focused on the determination of the crop growing stages and coefficient K_c allowing the irrigation of Chrysanthellum indicum, an herbaceous threatened plant frequently used in herbal medicine against heart and kidney diseases. To obtain the K_c, three steps were undertaken. First, a weather station provided the variables needed to calculate the reference evapotranspiration ET_0. Secondly, to ascertain scientifically the results, the experiment runs nine lysimeters to determine the crop maximum evapotranspiration ETM. A well-drained loam with 8.1±1.6% of organic matter content was used within the replications. The water-balance providing ETM used irrigation I and drainage D measured every two days. Finally, the definition $ETM_{loc} = K_c{\cdot}ET_0$ was applied after the transformation of ETM into local ETM_{loc}. The results showed that the triplet {stage name; stage duration (days); crop coefficient (K_c)} values are respectively {initial; 28; 0.7±0.1}; {development; 17; 0.7-1.4±0.2}; {mid-season; 20; 1.4±0.2} and {late-season; 14; 0.7±0.04}. The total growing period was found as 79 days. These results offer the possibility for a water-efficient production of Chrysanthellum indicum in the dry season.
Keywords: *Crop coefficient, Evapotranspiration; Forest irrigation; Lysimeter; Tropical Savannah*

1 INTRODUCTION

Over-exploitation of timber and non-timber forest resources in the tropics is a threat to their sustainability. Today, species such as *Milicia excelsa Welw., Khaya senegalensis Desr., Afzelia Africana Sm., Pterocarpus erinaceus Poir*., have been identified as endangered and deserve special attention (Schmidt et al., 2015). The wood of woody species have many applications in carpentry, production of charcoal, or are simply used as firewood for cooking (Eklu-Natey et al., 2012a). On the other hand, the overexploitation for consumption of non-timber forest products – including root, bark, leaves, flowers, and almonds in herbal medicine and cosmetics – has become a major concern. This overexploitation, without any counterpart for the regeneration of the species, constitutes a threat to forests, which constitute carbon stores, and thus climate change alleviators. Many Sahelian countries including Niger, Burkina Faso, Mali, Mauritania or Senegal are experiencing a worrying advance towards desertification (UN-SD).

To assist in regenerating most over-exploited forest species, forest irrigation is one of the most credible solutions. Irrigation supposes the knowledge of natural plants water requirements, needs that depend closely on the knowledge of the crop coefficients K_c. The crop coefficient K_c (Doorenbos and Pruitt, 1977) has been proposed as the factor containing the intrinsic attributes of the plant, most independent of climate and contributing to its maximum evapotranspiration (*ETM*). The second competing factor at the *ETM* is the reference evapotranspiration ET_0, which contains climate attributes independently of the plant under investigation. Since the 1970s, research has carried out intensive activities for the determination of K_c for many food crops such as tomatoes, onions, wheat, etc. (Allen et al., 1998; Tyagi et al., 2000). Surprisingly, for forest crops that man exploits no less, efforts have been very limited. In order to contribute to the reduction of this scientific and technological gap, ASMA (Keïta and Sanou, 2016) proposed to open a research axis dealing with the determination of K_c of the most useful forest plants to permit their irrigation.

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This study focuses on the case of an Asteraceae, *Chrysanthellum indicum DC.* (1836) (Syn. *Chrysanthellum indicum var. afroamericanum*), an herbaceous annual plant growing only during the rainy season in the Soudano-Sahelian zone (Eklu-Natey et al., 2012b; Keïta and Sanou, 2016). This plant is currently under intense exploitation as herbal medicine – with positive effects on the human heart and the kidneys – necessitatitng the determination of its production parameters under irrigation in the dry season.

2 MATERIAL AND METHODS

2.1 The study site

On the research site, the poor temporal rainfall distribution impacts on the rhythm of plant growth. The investigations were implemented at 2iE/Kamboinse, located 20 km northwest of Ouagadougou, the capital of Burkina Faso (Figure 1). The area is under the influence of the Soudano-Sahelian climate – also called Tropical Savannah in the international climate classification (Peel et al., 2007; SOGETHA, 1963) – with two well separated seasons. The rainy season runs from June to September (four months) and is the real period during which food and forest plants undertake a significant growth. The dry season, which lasts eight months from October to May, is composed of a cold period from November to February where a minimum of 15 °C is common, followed by a much hotter period from March to May. The peak outdoor temperature may reach 42°C in the later one. The average yearly rainfall amounts to 860 mm and possesses a poor monthly distribution (Keïta, 2015). The month of August is the rainiest; with often more than 250 mm. Therefore, it is not surprising that most of the traditional crop production is done during the rainy season. Irrigation was introduced in the early 1960s for food crops (SOGETHA, 1963). Irrigation of natural forest plants – the object of the current research – therefore presents itself as an innovation.

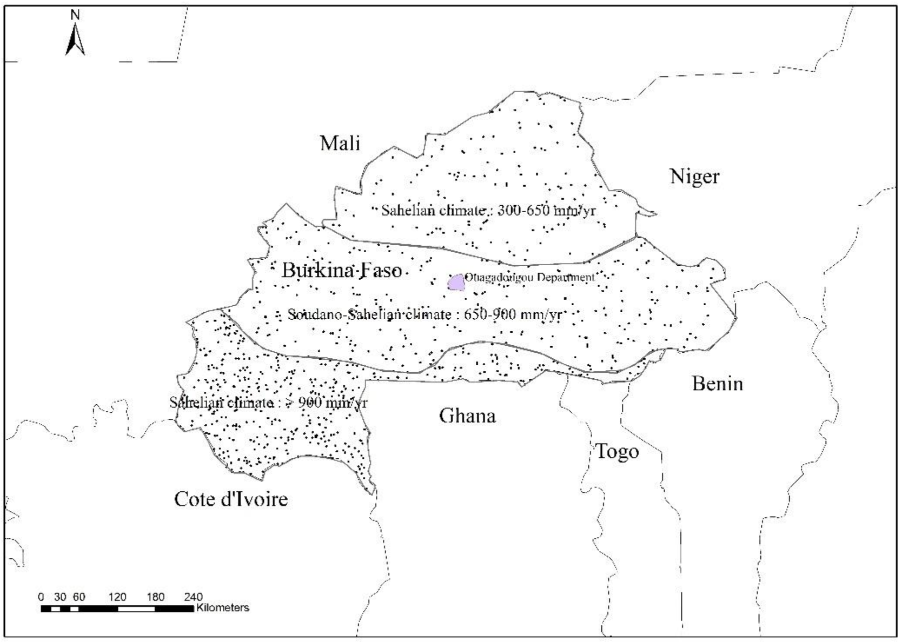

Figure 1: Study site location and climate zone

2.2 The experimental units

2.2.1. The lysimeters

To meet the statistical requirements for replications in design, nine lysimeters (Figure 2) were constructed to resist temperature changes and to offer a space convenient for the full crop growth (Keïta, 2015). With these nine lysimeters, the law of Student can be applied to check the normality of the variables and compute the confidence intervals (Montgomery and Runger, 2011).The material used is reinforced concrete to prevent cracks due to temperature variation – from 15 °C to 45 °C – following the alternation of the rainy and dry seasons in Burkina Faso. A special chemical substance called *Sikalite* (BODCOLTD, 2011) was incorporated in the mortar in order to ensure the impermeability of the walls. In addition, based on a maximum rooting depth of 50 cm for young crops, the dimensions were chosen as follows: height (H) = 1.50 m, width (W) = 1.16 m, Length (L) = 1.16 m. The wall thickness was 0.08 m with bottom thickness (B_m) = 0.15 m resulting in a total internal volume V_{tot} (m3) = 1.51 m3. One of the walls was affixed two taps: the first – connected to Φ50 mm PVC perforated drainage pipe –placed at 1.15 m above the lysimeter bottom whilst the second tap – used for subsurface drainage D – was set at 0.30 m above the bottom.

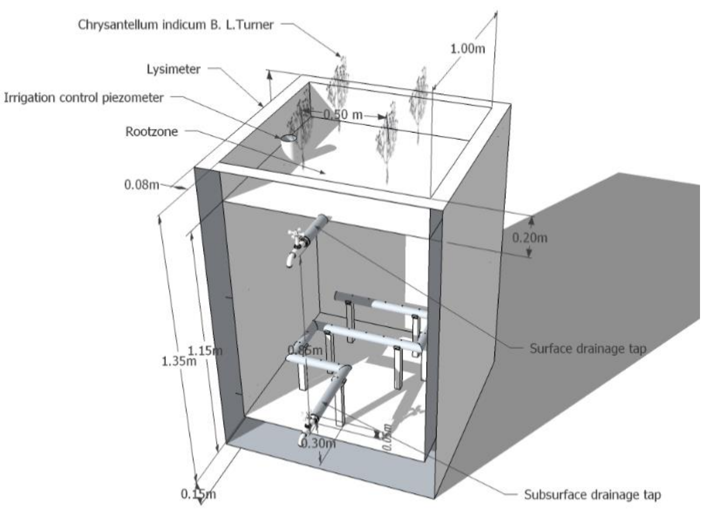

Figure 2: Schematic diagram of the experiment lysimeter

The details of the lysimeter designed (Keïta, 2015) and used are shown in Figure 2. The space between the two drainage taps was filled with three layers of materials: gravel at the bottom (40 cm), sand (35 cm), and 40 cm of loam at the top with 8% of organic matter content. Four plants of *Chrysanthellum. indicum* were transplanted in each lysimeter, with a crop spacing of 50 cm. Irrigation was introduced on the top, and drainage flowed into the subsurface drainage pipe with measurements undertaken every two days. At any irrigation, the water level – measured in the irrigation control piezometer – is restored to nullify the stock variation ΔS in the soil.

2.2.2. The properties of the experimental soil media

In order to implement the experiment in nine replicates, the soil introduced in the lysimeters was strictly checked for its homogeneity. To achieve that, two parameters were used: the organic matter content OM(%), and the saturated hydraulic conductivity K_{sat}, which allows the use of the software Soil Water Characteristic (Saxton and Rawls, 2006) for the determination of the soil available moisture (AM). The criterion for homogeneity is to obtain a coefficient of variation (CV), the ratio of the average to the standard deviation, not more than 10%. The soil was taken from the same site in Kamboinse and mixed with poultry compost at a ratio of 30 kg over the lysimeter surface of 1 m² and a soil layer of 30 cm.

The hydraulic conductivity (K_{sat}) was measured using the double ring infiltrometer method (Boivin, 1990) to derive data as close as possible to the real-world infiltration process. The runs were performed randomly over the nine lysimeters in the field with infiltration depth and time the variables measured. Although K_{sat} could be deduced from the infiltration rate (not directly measured in the field), the current experiment used the cumulative infiltration curve, which is the antiderivative of the infiltration rate equation:

$$I_t = k_{sat} \cdot t + \frac{1}{b}(i_0 - k_{sat}) \cdot (1 - e^{-bt}), \quad (1)$$

where t is the time elapsed since initial instant t_0 (equal to 0) in h; b is an adjusting parameter of the regression curve, k_{sat} is an adjusting parameter of the regression curve or saturated hydraulic conductivity in mm/h; i_0 is the initial infiltration rate in mm/h; $i_t(t)=(I_t-I_0)/(t-t_0)$ is the instantaneous infiltration rate at instant t, in mm/h; I_t is the cumulative infiltration since the initial instant t_0 in mm; and I_0 the preliminary infiltrated water (often equal to 0) , in mm.

To avoid data loss, the measurements of the cumulative infiltration depth were performed by a group of increments. During the first hour, the increment between two measurements was 10 minutes, 20 minutes in the second hour, 30 minutes in the third hour, etc. Data were processed using the software Minitab 17 for a non-linear regression and drawing the two parameters of eq.(1), i.e., K_{sat} and b. The nine K_{sat} values obtained were introduced into the software Soil Water Characteristics (Saxton and Rawls, 2006) for the determination of the soil type.

2.2.3. Climatic data

With regard to climate, an Alecto WS-5000-Pro automatic weather station was used to measure daily the variables used in ET_0's Penman-Monteith calculation (Jensen ME and Haise HR, 1990). These measured variables were: i) min and max temperatures, ii) wind speed 2 m above ground, iii) saturation and current vapor pressures, iv) relative humidity, v) solar radiation. The procedure developed for the current study and described in Figure 3 was introduced in an MS Excel worksheet to calculate the values of ET_0.

2.3 Methods

The crop coefficient (K_c) determination, for the key crop growing stages of the *Chrysanthellum indicum*, requires knowing two important variables that are the maximum evapotranspiration ETM (mm·day-1) and the reference evapotranspiration ET_0 (mm·day-1) according to eq.(2) (Doorenbos and Pruitt, 1977):

$$ETM = K_c \cdot ET_0 \Rightarrow K_c = \frac{ETM}{ET_0}. \quad (2)$$

Hence, to compute K_c, three important procedures were followed: the first was the determination of the maximum evapotranspiration ETM, the second was computing the reference evapotranspiration ET_0, and the third the calculation of K_c on the lysimeters.

2.3.1. Procedure 1: Determination of ETM

ETM was obtained by developing a water balance equation in which all the five variables– excluding *ETM* – were measured in nine lysimeters designed to meet this objective (Figure 2). The water balance equation – including runoff O (mm), drainage D (mm), rainfall R (mm), irrigation I (mm) and the stock variation in the lysimeter soil ΔS (mm) –is as follows:

$$ETM = (R + I) - (O + D) - \Delta S \quad (3)$$

Considering the conditions of the experiment, three important simplifications were made from eq.(3). First, the operations took place during the dry season during which there is no rainfall, hence $R = 0$. Secondly, the lysimeters had five centimeters of freeboard and irrigation was carried out to produce no runoff, therefore $O = 0$. Finally, the stock variation ΔS within each of the nine lysimeters was nullified by bringing the water level at the reference depth five centimeters below surface (thus restoring the moisture at field capacity) as measured in the irrigation control piezometer (Figure 2) at each irrigation, and calculating the water balance on a decadal cycle basis. Therefore, *ETM* was determined by using eq.(4):

$$ETM = D - I \quad (4)$$

2.3.2. Procedure 2: Determination of ET_0

The procedure shown in Figure 3 based on six measured variables – i) daily temperatures T_{min}, T_{max} (°C), ii) day length n, iii) daily mean solar radiation R_s (W·m^{-2}·day^{-1}), iv) daily relative humidities RH_{min}, RH_{max}, (%), v) the atmospheric pressure p_a (kPa) and vi) 2m-height wind speed u_2 (m·s^{-2}) – was applied to calculate the following Penman-Monteith (Allen et al., 1998) formula for the reference evapotranspiration :

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \frac{\gamma \cdot 900}{T+273} u_2 \cdot (e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\, u_2)} \tag{5}$$

where ET_0 is the reference evapotranspiration (mm·day^{-1}); R_n the net radiation at the soil surface (MJ·m^{-2}·day^{-1}); G the soil heat flux density (MJ·m^{-2}·day^{-1}) which is about zero for a cycle (day or 10 day periods for example); T=(T_{min}+T_{max})/2 is the mean daily air temperature (°C); u_2 is the wind speed at 2 m height (m·s^{-1}); e_s is the saturation vapour pressure (kPa); e_a is the actual vapour pressure (kPa); e_s-e_a is the saturation vapour pressure deficit (kPa); the slope of the saturation vapor pressure curve is Δ (kPa·°C-1), and the psychrometric constant is γ (kPa·°C^{-1}).

The full procedure is described in Figure 3. The procedure reads from left to right while running from top to bottom. In the left column, the parallelogram-shaped boxes enclose six variables that were measured with the experimental automatic weather station Alecto WS-5000 Pro. These were: daily temperatures T_{min}, T_{max} (°C), day length $_n$, daily mean solar radiation R_s (W·m-2·day-1), daily relative humidities RH_{min}, RH_{max}, (%), 2m-height wind speed u_2 (m·s^{-2}), and the atmospheric pressure p_a(kPa). The altitude Z (m) was measured with a GPS. The first column remaining 4variables are either constant – the Stefan-Boltzmann constant σ (Wm^{-2}·K^{-4}), the albedo or reflection coefficient α-0.23 for grass, the daily soil heat flux density G ≈ 0 (W·m^{-2}·day^{-1}) – or read from a table – daily sunlight maximum duration N (h) (Allen et al., 1998). The net outgoing long wave radiation R_{nL} (W·m^{-2}·day^{-1}) and the soil surface net radiation R_n (MJ·m^{-2}·day^{-1}) were calculated in the 2nd and 3rd columns. Finally the eight generated variables – saturation vapor pressure e_s (kPa), actual vapor pressure e_a (kPa), saturation vapor pressure curve slope Δ (kPa·°C^{-1}), R_n, G, psychrometric constant γ (kPa·°C^{-1}), daily mean temperature T, the wind speed u_2 – were used to calculate the reference evapotranspiration ET_0 as presented in the last column.

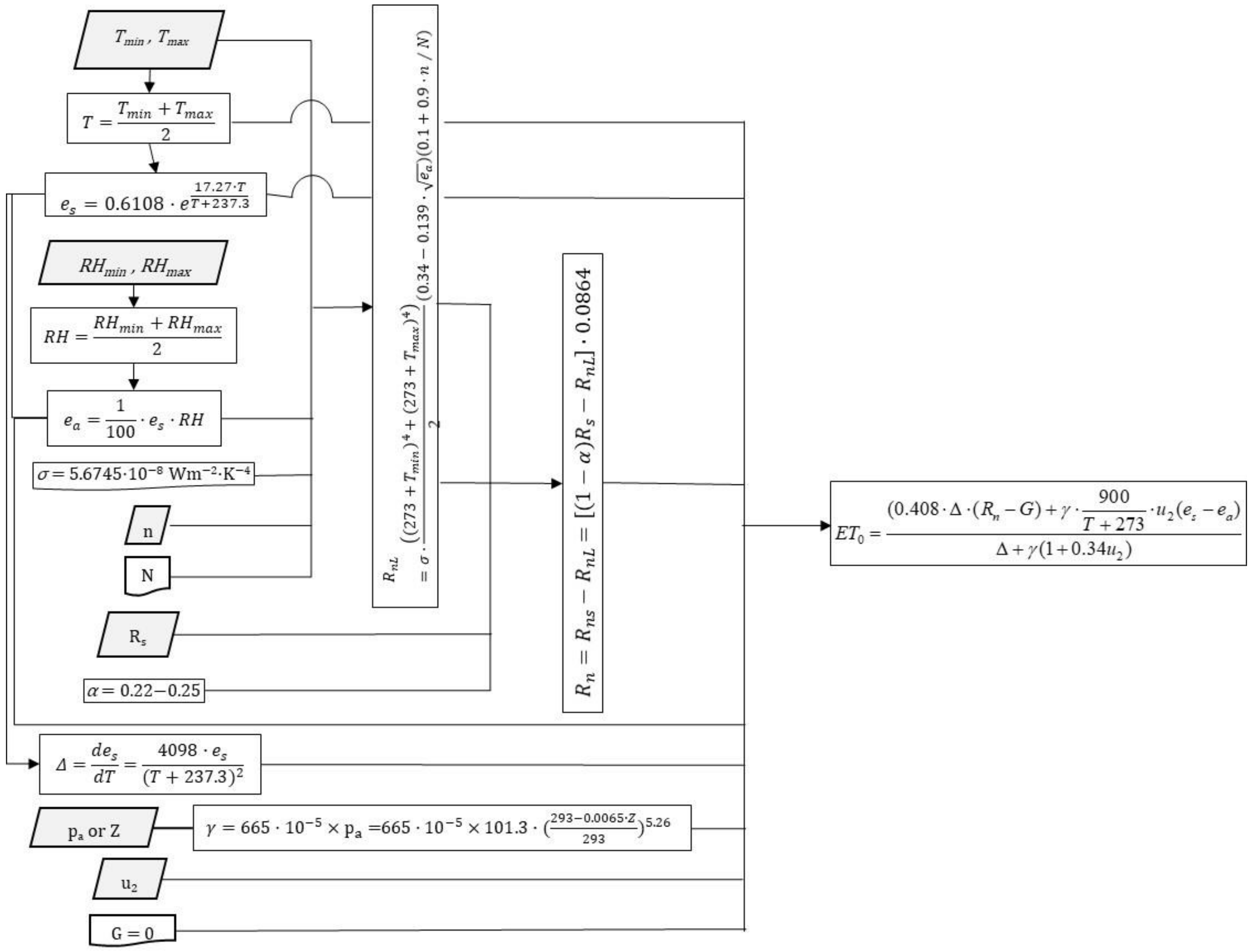

Figure 3: ET0 calculation procedure

2.3.3. Procedure 3: computation of K_c

To obtain the crop coefficient K_c values, the procedure shown in

Figure 4 introduced a very important variable beside *ETM* and ET_0 previously determined in the procedures 1 and 2. This key parameter is the ground cover GC_i, where "*i*" is the lysimeter number. In effect, the plant foliage in a lysimeter – though expanding gradually – remained local. Therefore, the Karmeli and Keller (David Karmeli, 1975) foliage reduction factor *Kr* using the ground cover *GC*(%) was applied. At any stage of growth, the ground cover – the ratio of the sum of all the *k* individual crop foliage area a_k by the lysimeter maximum canopy area A_i given by the maximum foliage development– was determined by making top-view photos of the lysimeter surface in order to capture the crop foliage areas a_k. The application of this reduction factor leads to the expression of K_c (eq.(6)) as it follows:

$$K_c = \frac{ETM_{Loc}}{ET_0} = \frac{0.1 \cdot \sqrt{GC_i} \cdot ETM}{ET_0} \quad (6)$$

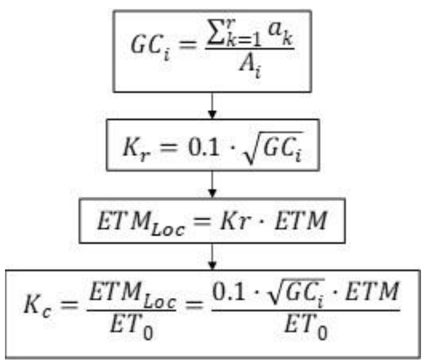

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Figure 4: Kc calculation procedure

Figure 4 explains the full procedure. The procedure reads from top to bottom. The ground cover GC_i for each i^{th} lysimeter is calculated by summing all individual crop foliage projected area a_k for all the r crops and dividing this sum by A_i. The K_c value obtained takes into account the localized growth of the plants.

2.4 The experiment design characteristics

2.4.1. Measurement Maximum evapotranspiration factors

To produce crop coefficients K_c values of the *Chrysanthellum indicum DC.* with a claim of accuracy of 95% confidence interval, replication and randomization principles were necessary (Keïta, 2017; Mathews, 2005). Hence, nine lysimeters – exact replications of each other (Figure 1) – were constructed and contained the same type of soil. For each lysimeter's basic experimental unit, replication referred to all factors with potential impact on the response variable, namely the maximum evapotranspiration *ETM*. If any factor cannot be randomized, it must be blocked (Montgomery and Runger, 2011). It immediately comes from eq.(4) that the two key factors or variables are irrigation *I* and drainage *D*. These two variables were measured concomitantly in each of the lysimeters from *P1.1* to *P3.3* but at 25 different dates D_t along the crop-growing period. Therefore, even though the date D_t cannot be randomized, it does count as a factor. On the other hand, since irrigation I and drainage *D* are measured within the same lysimeter *Pi.j*, the measurements were randomized by order of the lysimeters at each new date. Hence, this experiment was a randomized blocked design. The Design matrix is shown in Table 1.

2.4.2. Identifying the crop growing stages

The K_c is subject to variation during the crop growing stages, the knowledge of which is very important. The curve of variation of K_c is represented by a segmented curve introduced initially by Doorenbos and Pruitt (1977). Three values of K_c for a crop grown under standard conditions (Allen et al., 1998) correspond to four line segments within the crop growing period in the following order: horizontal during initial stage (K_c is constant); ascending during crop development stage (K_c increases), horizontal again during the mid-season (K_c is constant), and descending during the late season stage (K_c decreases). Therefore, in practice, only three values of K_c are determined: the constant values at the initial and mid-season, and the final value at the end of the late season. The growing stages were defined as follows (Doorenbos and Pruitt, 1977): i) Initial: from planting to a foliage ground cover *GC* of 10%; ii) Crop development: from ground cover 10% to maximum ground cover GC_{max} (not necessarily 100%); iii) Mid-season (maturing): from the maximum ground cover GC_{max} to the apparition of the beginning of yellowing/drop of leaves and; iv) Late-season : from the beginning of leaf yellowing to the harvest. The experiment observed these visual observations in the nine lysimeters.

Table 1 : Design matrix of the irrigation and drainage measurements for the first 10 days

	Real dates Dt	27/10/2017	30/10/2017	01/11/2017	03/11/2017	06/11/2017
	Days after planting	**0**	**3**	**5**	**7**	**10**
N°	**Run standard order**	**Randomized operation order in the 9 lysimeters**				
1	P1.1(I,D)	P1.3(10.0; 0.5)	P3.1(10.0; 4.2)	P1.1 (30.0; 3.0)	P1.1 (30.0; 9.2)	P1.2(30.0; 2.3)
2	P1.2(I,D)	P3.3(10.0; 5.0)	P2.2(10.0; 0.2)	P1.2(30.0; 4.1)	P1.3(30.0; 0.1)	P1.3(30.0; 5.0)
3	P1.3(I,D)	P2.2(10.0; 3.0)	P3.2(10.0; 4.8)	P2.3(30.0; 5.1)	P2.3(30.0; 5.5)	P2.3(30; 10.8)
4	P2.1(I,D)	P3.1(10.0; 2.0)	P3.3(10.0; 0.2)	P3.2(30.0; 3.0)	P2.2(30.0; 8.0)	P2.1(30.0; 6.0)
5	P2.2(I,D)	P1.2(10.0; 5.2)	P1.1 (10.0; 3.0)	P2.2(30.0; 1.5)	P3.2(30.0; 5.6)	P2.2(30.0; 8.5)
6	P2.3(I,D)	P3.2(10.0; 7.0)	P1.2(10.0; 4.8)	P3.1(30.0; 3.0)	P3.3(30.0; 6.5)	P3.3(30.0; 9.0)
7	P3.1(I,D)	P1.1 (10.0; 6.5)	P2.1(10.0; 5.2)	P2.1(30.0; 4.0)	P3.1(30.0; 4.0)	P3.1(30; 3.50)
8	P3.2(I,D)	P2.3(10.0; 9.0)	P1.3(10.0; 3.5)	P1.3(30.0; 1.5)	P2.1(30.0; 1.5)	P1.1 (30.0; 2.0)
9	P3.3(I,D)	P2.1(10.0; 4.8)	P2.3(10.0; 6.0)	P3.3(30.0; 3.0)	P1.2(30.0; 3.5)	P3.2(30; 10.8)

Pi.j = lysimeter's identifier; *I* = irrigation in mm; *D* = drainage in mm

2.5 Statistical analysis of the experiment

To ascertain the expected results, the statistical processing used by this research covered three main aspects: i) accuracy, ii) homogeneity of the replicates, and iii) rightness. Nine replications of the experimental units were constructed (Figure 2), thus legitimating the use of 95%confidence interval statistic (eq.(7)) based on the Student law (Keïta, 2017; Mathews, 2005) in order to check the accuracy the response variables, namely *ETo*, *ETM*, and K_c. On the other hand, to certify how homogeneous the nine replicates were, the coefficient of variation statistic *CV* (eq.(8)) was applied to the response variables *OM*, K_{sat} and *ETM*. Finally, simple comparisons were performed between the results and those obtained from similar studies to assess their rightness. Therefore, the main equations (eqs. (7) and (8)) used were:

$$95\%CI = \pm\, t_{\alpha/2,n-1} \cdot \delta = \pm t_{0.05,n-1}\,(s/\sqrt{n}) \quad (7)$$

$$CV(\%) = \frac{s}{\bar{x}} \quad (8)$$

where 95%CI is the 95% confidence interval, corresponding to a significance level α = 0.05; t is the Student distribution statistic ($t_{0.05}$=1.96); *n*, *s* and $\bar{x}$ are respectively the sample size, standard deviation and mean. The *CV* is the coefficient of variation

3 RESULTS AND DISCUSSION

3.1 Homogeneity of the nine lysimetric replicates

The soils used in the lysimeters showed homogeneity and a clear typology. As presented in Table 2 the coefficients of variation were less than 10% for all the nine replicates for the organic matter content (*OM*) and the saturated hydraulic conductivity K_{sat}. With an average *CV* of 8.1% versus the common value of 2.0% of Soudano-Sahelian soils (Hillel et al., 2004), the lysimeters were holding rich soils in organic matter. Such concentration in *OM* aimed to satisfy the *Chrysanthellum indicum* mineral needs so that this factor will not cause any restriction in crop maximum evapotranspiration *ETM*. In addition, the mean value of the saturated hydraulic conductivity K_{sat} of 22.7 mm/h classifies the soil on the textural triangle as a loam (Saxton and Rawls, 2006). The subsequent successful development of *Chrysanthellum indicum* during the experiment proves that the crop grows better on well-drained soils. Observations of the crop in a natural environment support this conclusion: the plant often grows on gravel soils.

Table 2 : Soil homogeneity in the nine lysimetric replicates

Lysimeter	OM (%)	K_{sat} (mm/h)
P11	8.0	21.3
P12	10.0	23.8
P13	8.1	24.5
P21	8.2	18.1
P22	7.9	22.7
P23	8.1	23.1
P31	8.0	23.9
P32	7.9	23.8
P33	6.9	22.7
Mean	8.1	22.7
Stdev s	0.8	2.0
Coef. of Var. CV	9.9%	8.7%

3.2 Crop growing stages and ground cover development

Chrysanthellum indicum growth, which lasts 79 days, shows remarkable properties in four areas (Table 3). The first area deals with the vegetative stage durations. The "initial" period is the longest, with 28 days, almost 1 month. The crop was sown on 03/10/2017 and transplanted on 25/10/2017, after a nursing time of three weeks. This long period of dormancy before germination and the young crop develops 3-4 leaves may mislead the conclusion of the seeds being unfertile. In effect, many vegetables have a shorter “initial” period, e.g., *Lactuca. sativa* (lettuce); 20 days and *Phaselus vulgaris* L. (beans), 15 days (Brouwer and Heibloem, 1986). A second area is worth of notice. *C. indicum* started flowering from October 30, at the beginning of the “crop development” stage while the ground cover GC was 10%, and continues flowering throughout the “development” and the “mid-season” stages. Hence, the flowering lasts at least 40 days. This flowering went along with grain formation, and the flowers produce a rather nice smell that makes the crop an excellent candidate from home gardening. The third area of interest is that, as shown in Table 3, the figure 20.0 % of maximum ground cover achieved with the crop spacing of 50 cm suggests the crop spacing can be reduced to, for example, 20 cm. Such spacing would lead to a greater biomass yield. The last point to notice is that the ground cover measured at the harvest is 15% while it could be 20% as noted to result from the time of harvest of the mature seeds notably; when many leaves have already fallen. In practice, phytotherapists, for example, are rather interested in harvesting the leaves at their maximum development (Eklu-Natey et al., 2012a).

Table 3 : Chrysanthellum indicum development stages

Dates	**Stages**	**Duration (days)**	**Ground cover GC(%)**	**Mean GC(%)**	**Karmeli & Keller *Kr***
3/10-30/10	Initial	28	0.0-10.0	5.0	0.2
31/10-16/11	Development	17	10.0-20.0	15.0	0.4
17/11-06/12	Mid season	20	20.0-20.0	20.0	0.4
07/12-20/12	Late season/harvest	14	20.0-15.0	15.0	0.4

3.3 ETM Determination

The determination of *ETM* from the water balance equations (Procedure 1) led to an important observation (Table 4). The validity of the decade-based water balance within the lysimeters. While the daily and 2-days water balance led to important levels of fluctuation of *ETM* across the nine lysimeters, with the decadal computation, the mean *ETM* values are much centralized around a mean for a given period. For example, for the decade 27/10-06/11, the mean *ETM* found is 8.7±0.6 mm/days^{-1} with a coefficient of variation of 8.7%. It was noted that at any of the five decades of water balance computation, the coefficient of variation is smaller than 10% across the nine lysimeters (Table 4), pointing to a homogeneous process within these nine replicates. This also confirms what was drawn from the homogeneity of organic matter content within the replicates.

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Table 4 : ETM measurements per decade in the nine lysimeters

	Decade Mean ETM (mm·day^{-1})				
Lysimeters	**27/10-06/11**	**08/11-17/11**	**20/11-29/11**	**01/12-12/12**	**13/12-22/12**
P11	8.63	11.8	9.2	7.7	4.3
P12	9.01	13.2	9.1	8.3	4.8
P13	9.94	11.5	9.3	7.5	5.0
P21	8.85	11.4	8.3	6.9	4.4
P22	8.88	12.6	9.0	8.2	4.3
P23	7.36	12.3	9.2	8.2	4.5
P31	9.33	12.6	9.2	7.9	4.5
P32	7.88	11.3	8.1	7.4	4.7
P33	8.6	11.7	8.2	7.2	4.0
Mean ETM (mm·day^{-1})	8.7	12.0	8.8	7.7	4.5
Stdev *s*	0.8	0.6	0.5	0.5	0.3
Variance	0.6	0.4	0.3	0.3	0.1
95% Conf. Interval	0.6	0.5	0.4	0.4	0.2
Coef. of Var.	8.7%	5.4%	5.7%	6.6%	6.4%

3.4 ET0 Determination

The experiment data processing provided accurate daily ET_0 validly transformable into a decade or monthly values. Table 6 uses the six variables that the weather station directly measured to yield ET_0 in the case of the month of October 2017 (Procedure 2). The data at the end of the month of October showed a slight decrease in ET_0 values, due to the weather change from the warm rainy season to cold, dry season in the Soudano-Sahelian climate. Furthermore, as Figure 5 shows, the Pettit's statistical test of homogeneity (Pettit, 1979) of the time series for the only month of October leads to the conclusion that two segments made this extract of data (p-value = 0.002). Two averages – μ_1 = 4.7 mm day^{-1} and μ_2 = 4.0 mm·day^{-1} – are required. Even the correction of the drop in the ET_0 observed on 29/10/2017 – due to weak solar radiation of 129.7 MJ·m^{-2}·day^{-1} – does not solve this constraint. Despite these observations, the descriptive values of the data at the bottom of Table 6 support that the monthly mean ET_0 value of 4.4±0.3 represents a good accuracy of the reference evapotranspiration of the month of October 2017. The similar analysis led to the same conclusion for ET_0 decade values (Table 5) for the months of October, November, and December of the *Chrysanthellum* indicum growing period.

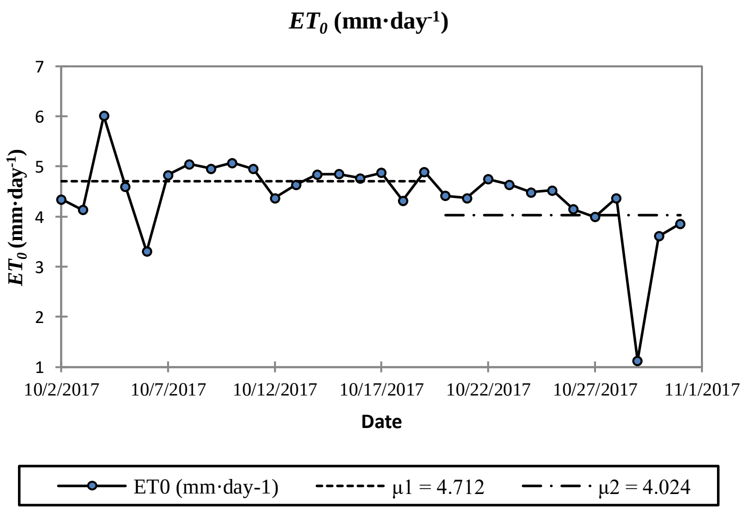

Figure 5 : Pettit's test of homogeneity of ET_0 in October 2017

Table 5 : Reference evapotranspiration ET_0 decade values from October 2017

Month	**October**			**November**			**December**	
Date start	02/10/2017	11/10/2107	21/10/2017	31/10/2017	11/10/2017	21/11/2017	01/12/2017	11/12/2017
Date end	09/10/2017	20/10/2017	30/10/2017	10/11/2017	20/11/2017	30/11/2017	10/12/2017	20/12/2017
Decades	1	2	3	1	2	3	1	2
ET_0(mm·day^{-1})	4.7	4.7	4.0	3.8	3.1	3.6	3.7	3.6
95% Conf. Interval	0.5	0.2	0.7	0.3	0.6	0.5	0.3	0.6

Table 6 : Reference evapotranspiration ET_0 values for the month of October 2017

Date	T_{max}(°C)	Tmin (°C)	T_{mean} (°C)	Rh_{max} (%)	Rh_{min} (%)	RH_{mean}(%)	Sunshine hours n (h)	Maxi sunshine duration N (h)	Rs (MJ·m^{-2}·day^{-1})	U_2 (m/s)	ET_0 (mm·day^{-1})
02/10/2017	38.7	23.0	28.7	98.0	42.0	77.2	10.0	12.0	253.7	0.4	4.3
03/10/2017	34.9	21.7	27.8	95.0	49.0	76.8	10.0	12.0	247.3	0.3	4.1
04/10/2017	39.3	25.1	29.9	94.0	28.0	70.6	10.0	12.0	332.1	0.2	6.0
05/10/2017	39.4	25.1	29.6	87.0	34.0	66.5	10.0	12.0	275.5	0.0	4.6
06/10/2017	35.1	23.6	28.9	87.0	43.0	69.8	10.0	12.0	204.9	0.3	3.3
07/10/2017	37.6	24.8	30.5	87.0	39.0	66.3	10.0	12.0	270.8	0.4	4.8
08/10/2017	37.7	25.8	29.9	83.0	42.0	66.9	10.0	12.0	267.6	1.1	5.0
09/10/2017	38.1	23.5	29.0	99.0	40.0	74.8	10.0	12.0	279.6	0.6	5.0
10/10/2017	40.0	24.3	30.5	98.0	30.0	68.4	10.0	12.0	282.0	0.4	5.1
11/10/2017	40.8	25.2	31.2	87.0	29.0	62.0	10.0	12.0	278.3	0.3	4.9
12/10/2017	40.5	26.0	31.3	84.0	33.0	62.3	10.0	12.0	250.6	0.3	4.4
13/10/2017	40.3	24.2	31.4	80.0	13.0	52.6	10.0	12.0	268.7	0.3	4.6
14/10/2017	39.3	23.1	31.3	93.0	14.0	49.7	10.0	12.0	260.6	0.7	4.8
15/10/2017	38.6	20.6	29.7	96.0	15.0	54.4	10.0	12.0	263.1	0.8	4.8
16/10/2017	39.4	20.8	29.5	95.0	14.0	53.8	10.0	12.0	268.2	0.6	4.8
17/10/2017	39.9	21.4	29.3	84.0	13.0	49.3	10.0	12.0	277.1	0.6	4.9
18/10/2017	40.1	19.3	28.8	88.0	12.0	47.8	10.0	12.0	259.7	0.5	4.3
19/10/2017	39.0	18.7	28.1	90.0	11.0	50.9	10.0	12.0	281.4	0.7	4.9
20/10/2017	39.6	19.0	29.1	90.0	11.0	48.2	10.0	12.0	268.4	0.3	4.4
21/10/2017	40.8	18.9	29.3	89.0	12.0	46.3	10.0	12.0	259.4	0.5	4.4
22/10/2017	40.4	18.7	29.0	89.0	13.0	48.4	10.0	12.0	278.8	0.5	4.7
23/10/2017	41.4	19.3	29.1	86.0	12.0	50.7	10.0	12.0	273.0	0.5	4.6
24/10/2017	41.4	18.7	29.3	91.0	12.0	51.6	10.0	12.0	271.3	0.3	4.5
25/10/2017	39.7	19.4	29.7	80.0	14.0	46.3	10.0	12.0	269.5	0.4	4.5
26/10/2017	39.1	20.3	29.3	90.0	14.0	50.8	10.0	12.0	225.9	0.9	4.1
27/10/2017	38.7	18.0	27.8	81.0	12.0	45.5	10.0	12.0	217.9	1.1	4.0
28/10/2017	37.3	15.9	26.0	74.0	11.0	40.6	10.0	12.0	275.8	0.5	4.4
29/10/2017	40.0	16.2	25.6	75.0	12.0	45.5	10.0	12.0	129.7	0.2	1.1
30/10/2017	38.9	19.0	28.5	73.0	15.0	43.1	10.0	12.0	234.2	0.4	3.6
31/10/2017	39.9	21.0	29.5	71.0	14.0	42.0	10.0	12.0	223.5	0.7	3.9
Mean	39.2	21.4	29.2	87.1	21.8	56.0	10.0	12.0	258.3	0.5	4.4
Stdev S	1.5	2.9	1.3	7.6	12.6	11.1	0.0	0.0	34.2	0.3	0.8
NB n	30	30	30	30	30	30	30	30	30	30	30
95% Conf. Interval	0.6	1.0	0.5	2.7	4.5	4.0			12.2	0.1	0.3

Constants:					
Altitude Z(m)	295.0	α	0.23	σ (W m^{-2} K^{-4})	5.67E-08
pa (Kpa)	97.7	G (MJ·m^{-2}·day^{-1})	0.0	γ(kPa·°C^{-1})	0.065

3.5 The crop coefficients K_c

The variation and the values of *Chrysanthellum indicum* DC. features are similar to many other seasonal crops. The computation of *Kc* was based on Procedure 3, and particularly eq.(6) and the results are shown in Table 7. K_c values are – for the four stages initial, development, mid-season and late-season/harvest – respectively 0.7±0.13; 1.2±0.04; 1.4±0.18; and 0.7±0.04 with 95% confidence intervals. The value 1.4 is compatible with high mid-season values such as 1.9 found by (Triana et al., 2015) while and studying an herbaceous crop. As a common practice, the development stage K_c value is not generally provided by researchers since it can be deduced from the initial stage and mid-season values (Doorenbos and Pruitt, 1977). The classical data figure, used for example by the FAO software CropWat (Raes et al., 2009), is presented in Figure 6. Like for seasonal vegetables such as green beans, onions or lettuce (Brouwer and Heibloem, 1986), it appears that K_c value at mid-season (1.4) is double of that of the initial stage (0.7). Therefore, the net crop water requirement will double during the 20 days of the mid-season. It is also important to notice that the total growing period of *Chrysanthellum indicum* is 79 days for the crop sown at the beginning of October, which is the start of the cold, dry season in the Soudano-Sahelian area.

Table 7 : Chrysanthellum K_c values by growing stages

Stages	Initial	Development	Mid-season	Late-season/harvest
Period	3/10-30/10	31/10-16/11	17/11-06/12	07/12-20/12
Duration	28	17	20	14
Mean *GC(%)*	5.0	15.0	20.0	15.0
Mean K_r	0.2	0.4	0.4	0.4
Mean K_c*(%)*	0.7	1.2	1.4	0.7
Stdv K_c	0.5	0.3	1.2	0.3
Nb of values K_c	54	153	180	144
95% Conf. Interval	0.13	0.04	0.18	0.04

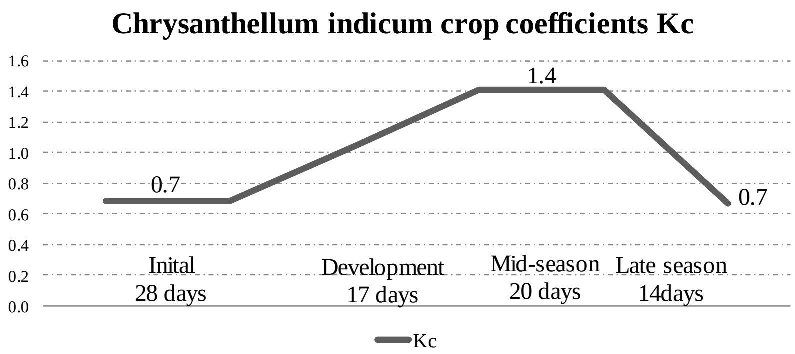

Figure 6 : *Chrysanthellum indicum DC.* crop coefficients

4 CONCLUSIONS

The study determined the crop coefficients of *Chrysanthellum indicum DC.* with several important results. It was found that, at the opposite of current common expectations, it is possible to grow the plant outside the rainy season and under irrigation. The plant was successfully produced on well-drained soil from October to December, during the cold, dry season in Soudano-Sahelian climate. The total growing cycle is 79 days. The three key values of K_c determined by the experiment are respectively for 0.7±0.1 in the initial, 1.4±0.2 in mid-season, and 0.7±0.04 in late-season The crop growing stage durations were also obtained. The results of the study serve as a platform for investigations into other useful natural plants found in the forest and thus lead to what the authors called 'forest irrigation.' A positive impact would be reforestation improvement in the framework of actions to mitigate climate change and promote the availability of forest crop throughout the year in tropical countries.

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