Assessing water demand with remote sensing for two coriander varieties

Determinación de las necesidades hídricas de dos variedades de cilantro mediante sensores remotos

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ABSTRACT

The use of remote sensing to determine water needs has been successfully applied by several authors to different crops, maintaining, as an important basis, the relationship between the normalized difference vegetation index (NDVI) and biophysical variables, such as the fraction of coverage (f_c) and the basal crop coefficient (K_{cb}). Therefore, this study quantified the water needs of two varieties of coriander (UNAPAL Laurena CL and UNAPAL Precoso CP) based on the response of f_c and K_{cb}, using remote sensors and a water balance according to the FAO-56 methodology. A Campbell Scientific meteorological station, a commercial digital camera and a portable spectro radiometer were used to obtain information on the environmental conditions and the crop. By means of remote sensing associated with a water balance, it was found that the water demand was 156 mm for CL and 151 mm for CP until the foliage harvest (41 d after sowing); additionally, the initial K_{cb} was 0.14, the mean K_{cb} was 1.16 (approximately) and the final K_{cb} was 0.71 (approximately).

Key words: UNAPAL, *Coriandrum sativa*, NDVI, water demand.

RESUMEN

El uso de la sensores remotos para determinar las necesidades hídricas ha sido aplicada exitosamente por varios autores en diferentes cultivos, manteniendo como base importante la relación existente entre el índice de vegetación de diferencia normalizada (NDVI) con variables biofísicas como la fracción de cobertura (f_c) y el coeficiente basal de cultivo (K_{cb}). Por esta razón, en este estudio se cuantificaron las necesidades hídricas de dos variedades de cilantro (UNAPAL Laurena CL y UNAPAL Precoso CP) basado en la respuesta de la f_c y K_{cb}, utilizando sensores remotos y empleando un balance hídrico según la metodología de FAO-56. Para la obtención de información de las condiciones ambientales y del cultivo, se utilizaron una estación meteorológica Campbell Scientific, una cámara digital comercial y un espectro radiómetro portátil. Se encontró, por medio de sensores remotos asociados a un balance hídrico, que la demanda hídrica para CL fue de 156 mm y 151 mm para CP, hasta la cosecha de follaje (41 días después de siembra). Ademas el K_{cb} inicial fue de 0.14, el K_{cb} medio 1.16 (aproximadamente) y el K_{cb} final 0.71 (aproximadamente).

Palabras clave: UNAPAL, *Coriandrum sativa*, NDVI, necesidades hídricas.

Introduction

Coriander (*Coriandrum sativa* L.) is an annual herbaceous plant that reaches between 60 and 90 cm in height during the flowering period; it belongs to the family Apiaceae (Umbelliferae) (Vallejo *et al.*, 2004). Its fruits are used for the elaboration of oils, fragrances and flavorings, while its leaves are used as a condiment (Usman *et al.*, 2003).

In Colombia, eight types of coriander varieties are sown (Estrada *et al.*, 1997), and around 2,431 ha are harvested, with Cundinamarca (36%) and Valle del Cauca (23%) being the larger producing departments (MADR, 2016).

In the departments of Valle del Cauca and Cauca, the UNAPAL Precoso (CP) variety is highly accepted because of its short vegetative period (28-35 d after sowing, DAS) and adaptation to climatic conditions (20-27°C) (Estrada *et al.*,

2004). On the other hand, the variety UNAPAL Laurena (CL) is a new variety that will be released soon, created from the genetic improvement of the CP variety. This variety preserves the favorable characteristics of its parent, with a capacity to generate a greater number of basal leaves and average yields in foliage of 40 t ha⁻¹ (Otero, 2016).

Adequate water availability at each phenological stage is decisive for achieving proper coriander production because it requires shallow sowing (5 mm), has a shallow root system (10-15 cm) and a short vegetative period. These characteristics make it a demanding crop that requires short and frequent irrigation, mainly in the early stages of establishment and development (Vallejo *et al.*, 2004). According to Mejía *et al.* (2014), in controlled trials in mesh houses, irrigation with less than 200 mm in the vegetative period reduced the number of leaves, the height, and the yield.

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However, higher irrigation can generate greater evapotranspiration (ET_c) of this crop without significant increases in yield. It is inferred that, in order to maximize the yield of coriander, an adequate estimation (or measurement) of the ET_c is necessary in order to accurately determine the water needs of this crop and the irrigation amount to be applied. Among the methods globally accepted to determine ET_c, two methods of water balance are noteworthy, as described by Allen *et al.* (2006): the single coefficient (Eq. 1) and the dual coefficient (Eq. 2); the latter separately analyzing the plant's transpiration component and soil evaporation (Wright, 1982).

$$ET_c = ET_o \times (K_c) \qquad (1)$$

$$ET_c = ET_o \times (K_{cb} + K_e) \qquad (2)$$

where ET_c is the evapotranspiration of the crop (mm), ET_o is the reference evapotranspiration (mm), K_c is the coefficient of cultivation or single coefficient, K_{cb} is the coefficient of transpiration and K_e is the coefficient of evaporation.

The implementation of one method or the other differs in terms of the timescale. Approximation with the single coefficient integrates two coefficients; therefore, it is designed for crops whose irrigation demand can be extended weekly or at even higher frequencies (Allen *et al.*, 2006). On the other hand, the dual coefficient is used for estimates of daily ET_c, allowing differentiation between the behavior of K_{cb} and K_e, especially in the days following irrigation or precipitation events (Hunsaker *et al.*, 2005), which makes this method the most suitable for the implementation of high frequency localized irrigation systems.

K_{cb} is directly related to the morphology and physiology of a plant, especially to the loss of water vapor through the opening and closing of stomata in response to environmental conditions, influenced by energetic, physiological and aerodynamic factors (González Piqueras, 2006). K_{cb} recommendations for various crops were given by Allen *et al.* (2006); however, these values are for crops under standard conditions, which on many occasions cannot be replicated because of local conditions.

K_{cb} determinations for coriander have not yet been defined. However, closer approximations have been obtained by Mejía *et al.* (2014) with the determination of K_c under controlled conditions in mesh houses. K_c values of 0.83 for germination, 1.12 for linear growth and 1.40 for fresh harvest (from 27 to 35 DAS) have been obtained.

On the other hand, remote sensing is currently seen as a science of great importance because of its application in different fields, especially agriculture. The possibility of obtaining information from vegetation without coming into direct contact with the crop makes its application conspicuous since it is a non-destructive and low-cost method. The effectiveness of remote sensing is related to the physiological capacity of plants, specifically chlorophylls, xanthophyll and carotene, which interact with radiation from the sun and generate reflectivity spectral responses associated with phenotypic states seen in the field. The measurement of vegetation reflectivity can be done by using a radiometer or multispectral images adjusted to the spectral resolution (Chuvieco, 2008).

With the first satellite observations with multispectral images of the Earth's surface, Rouse *et al.* (1974) showed certain correlations of vegetation biophysical parameters with specific regions of the electromagnetic spectrum, more precisely, the regions included in the spectrum of Red (R) and near infrared (NIR). Since then, the combinations of different bands of the spectrum to identify agronomic variables have been diversified according to the phenomena of interest; these combinations have been called vegetation indices (VI).

Worldwide, the VI with greater impact and expansion in remote sensing is the Normalized Difference Vegetation index (NDVI) (González, 2006). This index is characterized by results between -1 and 1; when photosynthetically active vegetation densities are high, the NDVI is close to 1. However, for bare soil surfaces, this index is close to zero and takes on negative values for water bodies or cloud cover. One of the advantages and reasons for the great acceptance of NDVI is the simplicity and ease of applying it to intermediate canopy covers (Gilabert *et al.*, 2010). Its high correlations with biophysical variables, such as K_{cb} (Tab. 1) and the plant cover fraction (f_c) (González, 2006; Er-Raki *et al.*, 2007; López *et al.*, 2009; Johnson *et al.*, 2012; Zhang *et al.*, 2015), have allowed for its implementation in studies on water balances in large land surfaces.

Although changes in soil surface roughness and humidity affect the spectral response of a soil (Baret *et al.*, 1993), it is important to note that there are no studies that show a clear relationship between K_e and NDVI because K_e depends on the soil moisture content in the first 10 or 15 cm and not just at the surface. Therefore, K_e cannot be deduced from spectral information of the surface and must be calculated with a water balance.

The quantification of K_e is intrinsic to the fraction of coverage (f_c). As vegetation develops through phenological stages, it increases in the ability to intercept incident light and reduces the exposed soil fraction. Quantifications of f_c have been performed at various scales (local, regional

and national), yielding good results in schedules and water management. The research conducted by White *et al.* (2000) concluded that the use of images captured with cameras is the easiest and most reliable mechanism for measuring f_c.

On the other hand, the use of satellite images has seen an exponential increase worldwide since the 1970s, with the development of the first LANDSAT missions. These developments have allowed a wide range of Earth-orbiting satellites to provide information at different spectral and temporal resolutions (González, 2006).

Based on multispectral satellite images, Bausch (1995), Er-Raki *et al.* (2007), and Toureiro *et al.* (2017) were able to quantify water requirements and apply irrigation more accurately in maize and wheat crops. However, the biggest constraint for the use of this technology in Colombia is associated with cloudiness, geographical location and topographical conditions of the country (Martínez, 2017). For this reason, research at lower scales with unmanned aerial vehicles or local measurements is considered viable alternatives (García *et al.*, 2015).

The aim of this study was to quantify the water demand of two varieties of coriander (CL and CP), determined with a water balance, integrating biophysical variables (f_c and K_{cb}), and estimated from remote sensors.

Materials and methods

This study was carried out between the months of April and August, 2017 at the CEUNP experiment center of the Universidad Nacional de Colombia, Palmira (3°25'33"N, 76°25'52"W, 930 m a.s.l.). The nearest meteorological station to CEUNP (14 km) is the Alfonso Bonilla Airport (IDEAM station: 26075040), which has a record period of 1972 to 2016. The data show an average annual precipitation of 893.5 mm, distributed over 144 d, reaching a maximum of 89.6 mm in 24 h. The average temperature is 24°C, and the relative humidity is 73.2%, registering 1810 h of total annual solar brightness and an average wind speed of 1.2 m s^{-1}.

The mechanized land preparation was carried out on the upper 40 cm of the surface, making two passes per implement (disc harrow and rotavator). A soil sample was taken to determine the texture (clay loam) and moisture retention curve (field capacity (FC) = 37.86% and wilting point (WP) = 20.84%).

The sowing was carried out on April 22 (day 0 after sowing, DAS) by distributing the seeds manually at a 25 cm distance between furrows. Weeds were manually controlled during the first six weeks. The nutritional management of the crop was carried out following the recommendations of the experiment center, which consisted of foliar applications of potassium nitrate, Cosmocel® and Triple 18, at different concentrations throughout the stages of growth, development and fruit filling. In addition, at the mid-development (27 DAS), granulated urea was broadcast. For the second week of flowering, on June 28 (61 DAS), "boxing" tutoring was installed on double furrows.

A complete block design was implemented with two treatments (CP and CL varieties) and three replicates, working an area of 34 m^2 distributed in six experiment units (EU) of 5 m^2 (2.5 m x 2 m), as shown in Figure 1. Because of the lack of germination uniformity in the third replicate of CP, this EU was ruled out in the follow-up and analysis.
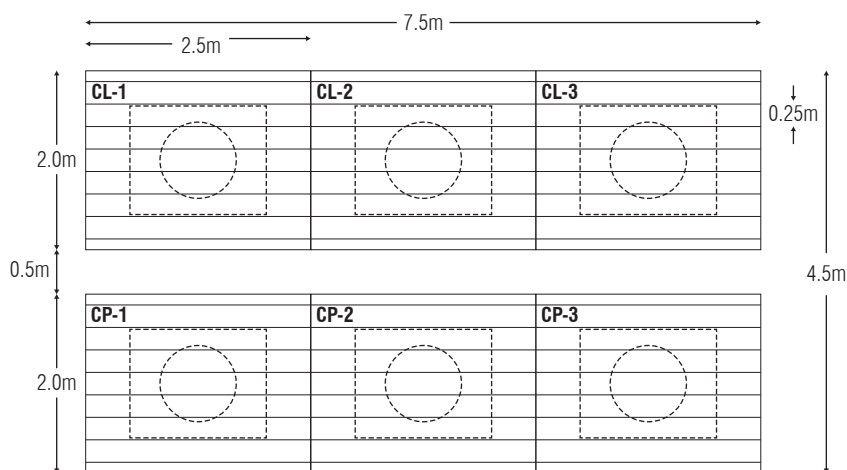

FIGURE 1. Distribution of experiment units (EU) in the field of the two studied varieties. The horizontal lines indicate the rows of the crop. The boxes and circles (dashed line) indicate the area covered by photography and radiometry, respectively.

Calculation of the water demand was based on Equation 2, following the methodology described by Allen *et al.* (2006) in FAO 56, using climatic variables of temperature, relative humidity, solar radiation, wind velocity, precipitation, crop height, f_c and K_{cb}, adapted to local conditions. Drip irrigation system was installed to meet the water requirements of the crop, which was programmed to function according to the level of depletion accumulated in the soil, with the exception of the first week between sowing and germination when the surface was watered following the recommendations of Estrada *et al.* (2004). In general, the irrigation applications ensured that the crop was kept free of water stress.

Climatic information was obtained with the use of a Campbell scientific automatic meteorological station installed on a reference surface of grass or festuca, which recorded data of relative humidity, wind velocity, solar radiation, precipitation and temperature every 10 min. For the days without information from July 2 to 6 (41 and 45 DAS), the information from a near station, belonging to the CENI-CAÑA automated meteorological network, was used.

Based on the only method recommended to determine ET_o, the FAO Penman-Monteith equation adapted to a festuca reference surface (and daily scale) was used (Allen *et al.*, 2006):

$$ET_o = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \frac{900}{T + 273} \times u_2 \times (e_s - e_a)}{\Delta + \gamma \times (1 + 0.34 \times u_2)} \quad (3)$$

where ET_o is the reference evapotranspiration (mm d^{-1}), R_n is the net radiation on the crop surface (MJ M^{-2} d^{-1}), G is the soil heat flux (MJ M^{-2} d^{-1}), T is the average air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (m s^{-1}), e_s is saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), $e_s–e_a$ is the vapor pressure deficit (kPa),

Δ is the slope of the vapor pressure curve (kPa °C^{-1}), the psychrometric constant (kPa °C^{-1}).

The height of the plant was measured weekly; additionally, radiometry and photography were taken to determine the NDVI and f_c, respectively. With these parameters, the evolution of the crop was traced, and linear tendencies were plotted with the objective of determining the water demand and scheduling irrigation on the following week (Bausch, 1995; Gonzalez *et al.*, 2004).

The estimation of the f_c was carried out with a Pentax digital camera, model Optio E85, 12 mega pixels, with spectral resolution in the optical range and a field of vision of 53°8' (determined in a laboratory). Three photographs were taken per EU, fixing the camera to a rigid T-shaped structure adjusted to a 1.50 m height. Subsequently, the images were subjected to classifications supervised by algorithms of maximum similarity with the ArcGIS 10.3 software. Six trainings were developed according to the evolution of the crop: (1) germination, (2) mid-exponential growth, (3) maximum coverage, (4) flowering, (5) fruiting and (6) senescence.

For the NDVI (Eq. 4), an Apogee PS100 spectroradiometer with a spectral range between 350-1100 nm was used, with an instantaneous field of view of 23°. For the photographs, three measurements were taken per EU at a 2.1 m height above the ground surface. Two spectral ranges, red (R) and infrared (NIR), based on Landsat 8 bands, were used.

$$NDVI = \frac{NIR - R}{NIR + R} \quad (4)$$

where NDVI is the vegetation index with the standard difference (dimensionless), R is the average reflectivity between 636-673 nm and NIR is the average reflectivity between 851-879 nm.

TABLE 1. Mathematical relationships between the NDVI and the crop basal coefficient (K_{cb}) reported in the literature.

Equation K_{cb}	R^2	Crop	Author
1.181 * NDVI - 0.026	–	Maize[*]	(Bausch *et al.*, 1987)
1.092 * NDVI - 0.053	0.96	Maize[*]	(Neale *et al.*, 1989)
1.49 * NDVI - 0.12	0.92	Cotton	(Hunsaker *et al.*, 2003)
1.50 * NDVI - 0.10	0.94	Maize	(González *et al.*, 2004)
1.56 * NDVI - 0.10	–	Various crops	(Calera *et al.*, 2005)
1.46 * NDVI - 0.19	0.93	Maize and wheat	(González, 2006)
1.64 * NDVI - 0.14	0.79	Wheat	(Duchemin *et al.*, 2006)
1.34 * NDVI - 0.14	0.86	Wheat	(López *et al.*, 2009)
1.44 * NDVI - 0.10	0.96	Grape	(Campos *et al.*, 2010)
1.464 * NDVI - 0.253	0.85	Maize	(Toureiro *et al.*, 2017)

[*] Relationship referred to alfalfa as reference surface.

With the NDVI value, and taking into account the NDVI-K_{cb} relationship for various crops (Tab. 1), all the equations were averaged and the K_{cb} of each measurement was determined. Taking into account the response of the NDVI and the f_c, the lengths corresponding to each stage were defined.

The harvest was carried out at 104 DAS, which is equivalent to 98 d after germination (DAG), when the achenes changed from brown to dark brown. The yield was assessed by taking samples of 1 m^2 per EU, collecting the aerial parts of the crop between 8 and 9 a.m. (local time), carefully using pruning shears to avoid making dry achenes fall. At the end of the study, seed samples were randomly taken to determine the moisture content of the seeds at harvest and after drying in the open air.

The samples were left to dry in a covered cellar for 3 d. Afterwards, the seeds were collected manually and, using a sieve, the seeds were separated from the crop residues. For each sample, 5 g of seeds were taken and dried in an oven for 1 h at 130±2°C to determine the moisture content (ISTA, 2016).

After the harvest, the soil was taken to saturation to assess the depth and extent of the roots. Five roots per EU were manually extracted, and the depth and maximum width were measured.

Results and discussion

From the climatic variables measured in the field with the Campbell station, the daily ET_o was calculated along the crop using Equation 3. On average, the ET_o was 3.7 mm d^{-1}. However, as expected, the evapotranspiration of the reference surface had abrupt changes from one day to another because of the variation of weather conditions in the area (Fig. 2).
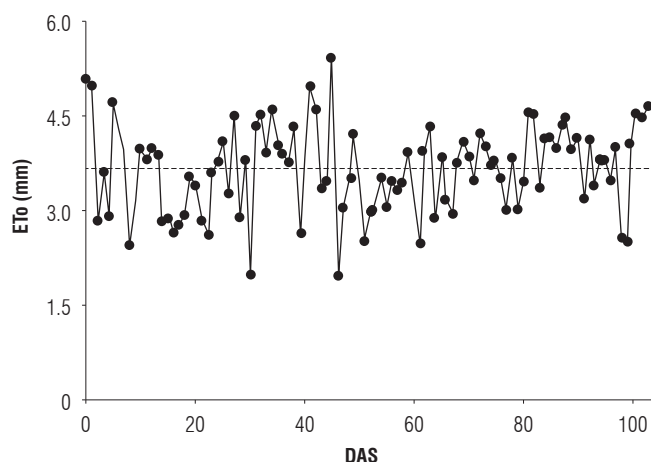

FIGURE 2. Evolution of ET_o during the test. The horizontal line indicates the average ET_o (3.7 mm).

The average plant density in the final stage was 164 and 108 m^{-2} for the CL and CP varieties, respectively. Differences in plant density are considered a statistically non-significant factor in the response of CP seed yield (Puga *et al.*, 2008) and were not evident in the results presented here. However, future studies should focus on evaluating foliage production for green harvest and the influence of stocking density, especially for the CL variety.

Figure 3 shows the evolution of f_c and NDVI for each variety as well as the development stages established under the following criteria: The initial stage (L_{ini}), starts from sowing and ends when f_c is around 0.10, when the crop is in the middle of exponential growth, and its presence begins to exert changes in the response of NDVI. The middle stage (L_{mdc}) is maintained while the f_c is above 0.90; after this point, the NDVI reduces sensitivity to the point of saturation (Odi *et al.*, 2013). As for the final stage (L_{end}), it starts with values of f_c lower than 0.90; the NDVI generates a response to photosynthetically inactive tissues, maintaining distant values for f_c.

The measurements of f_c and NDVI responded adequately to changes throughout the cycle, especially at 59 DAS, where winds stronger than 2 m s^{-1} managed to overturn much of the CP variety and the installation of tutoring considerably reduced f_c in the mid-stage (Fig. 3). However, the NDVI comparisons in CL, before and after tutoring, gave the same response, so the presence of white flowers (about 6%) on the surface of the crop achieved the same effect.

The f_c presented values of 0.02 during the emission of the first true leaves and gradually increased up to 0.99, where it reached the maximum vegetative development shortly before flowering (Fig. 3). The largest standard deviations of f_c were seen in the middle of the development stage and mid-stage, which coincided with the expansion of the crop in search of new spaces of light, until reaching the maximum development where standard deviations were lower. In the mid-stage, there was an increase in the standard deviation because of the tutoring that left fractions of bare soil exposed, increasing the heterogeneity of the crop cover.

The response of the NDVI varied between 0.14 and 0.30 (bare soil) at the initial stage, with 0.14 seen when a low moisture content was present in the soil and 0.3 in the presence of moist soil. In the mid-stage, the response of the NDVI varied between 0.92 and 0.93 when the foliage reached its maximum expression, as shown in Figure 3.

On the other hand, the correlations between NDVI and f_c, before the tutoring, were 0.99 for CL and 0.96 for CP (Fig. 2), according to what was reported by Calera *et al.* (2005),
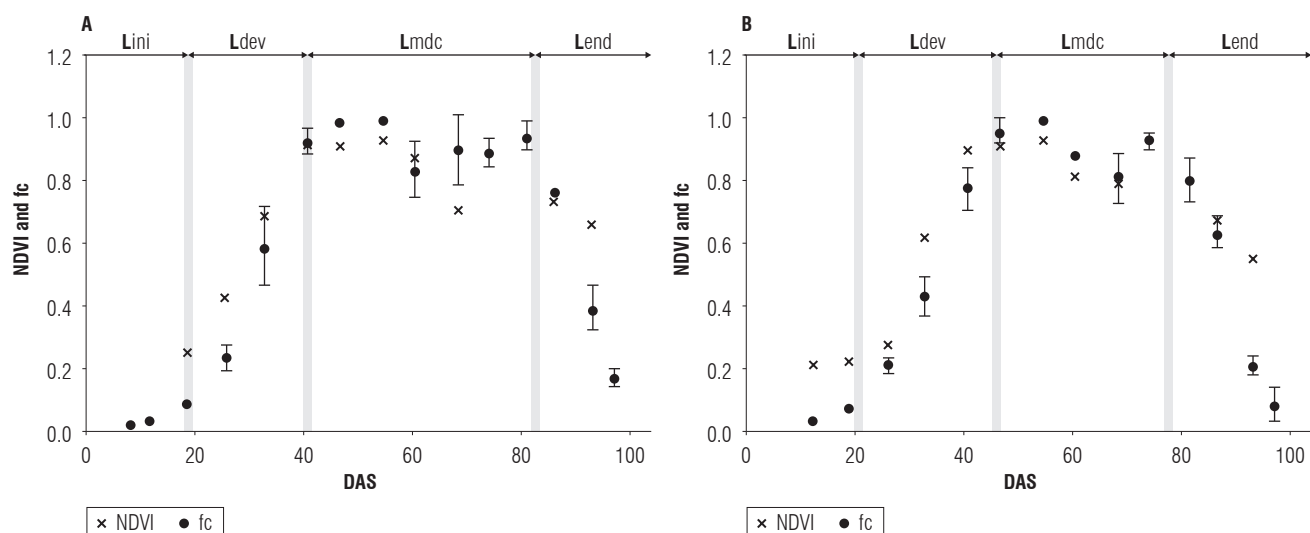
FIGURE 3. Evolution of the f_c and NDVI with demarcation of the stages of development, during the life cycle: A) Laurena and B) Precoso varieties.
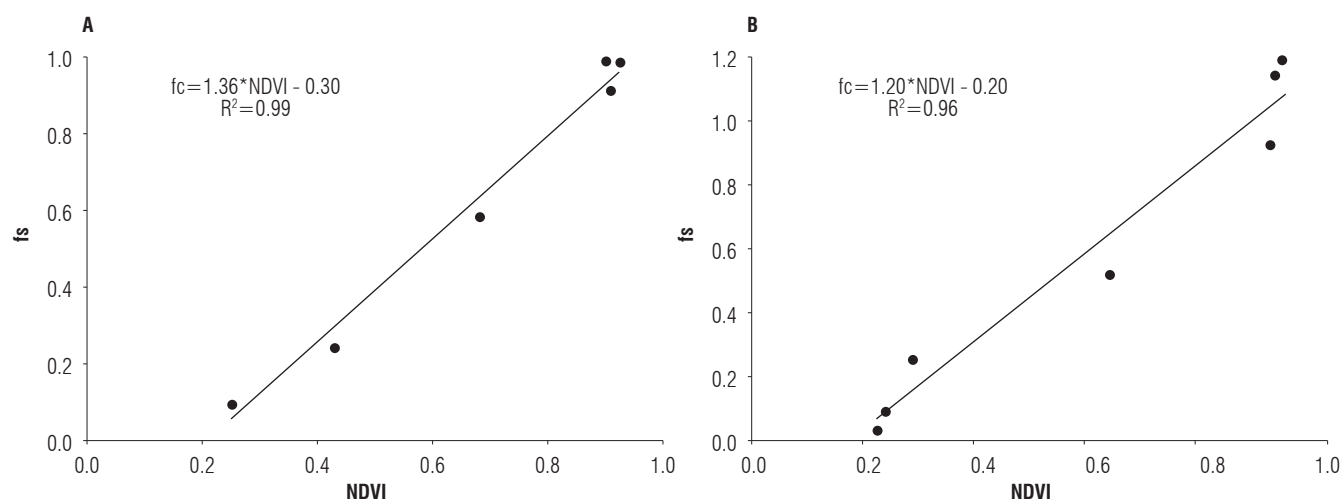

FIGURE 4. Linear relationship found between NDVI and f_c. A) Laurena and B) Precoso varieties.

González (2006), Er-Raki *et al.* (2007), López *et al.* (2009) and Johnson *et al.* (2012).

The duration of the stages of development, without taking the days until germination into account, is presented in Tab. 2. The CP variety showed a 5-day shorter period in the vegetative stages (start, development and mid). This can be an advantage for farmers because it reduces the time until

foliage harvest. The final stage may change because the decision to harvest seeds is based on the farmer's experience and the climatic conditions, resulting in a variable final stage.

The values obtained for K_{cb} are shown in Figure 5, with the different NDVI-K_{cb} approximations reported in the literature and presented in the Table 1, using the values

TABLE 2. Length of crop development stages according to the FAO 56 methodology.

Variety	Start	Development	Mid	Final*	Sowing date	Region
	(L_{ini})	(L_{dev})	(L_{mdc})	(L_{end})		
Laurena CL	19	22	42	15	April rainy season	Tropical region
Precoso CP	21	25	32	20		

Values are expressed in days. Lengths corresponds as follow: L_{ini} = From germination until 0.10 f_c, L_{dev} = f_c>0.10 to f_c 0.90, L_{mdc} = fc>0.90 up to beginning of senescence and L_{end} = fc<0.90 up to crop. * Variable stage.

of NDVI obtained in the present study. In this figure, it is observed that the standard deviation of the estimated K_{cb} was small despite the physiological and morphological differences of the various crops of agricultural importance, with values of 0.05 for NDVI near bare soil and 0.11 close to total plant cover.

Based on the K_{cb} average equation, water vapor liberation was maintained through the estomatic aperture in relation to the increase of the exposed plant superficial area and the aerodynamic resistance. For this reason, higher transpiration levels appeared in the mid-stage (Tab. 3).

According to the height measurements, the maximum height for coriander was recorded in the flowering season, with 1.40 m for CL and 1.38 m for CP. Compared to the height achieved with the height reported in the literature,

TABLE 3. Basal crop coefficients (K_{cb}) and maximum height adapted from the FAO 56 methodology.

| Variety | K_{cb} | | | Max. height |
	Initial	Medium	Final	(m)
Laurena (CL)	0.14	1.17	0.79	1.40
Precoso (CP)	0.14	1.15	0.64	1.38

the CP variety significantly exceeded the 0.90 m that was reported by Vallejo *et al.* (2004).

On the other hand, and as seen in Equations 1 and 2, the behavior of the K_c was the result of the summation of K_e and K_{cb}, where the greatest contributions of K_e were seen in the initial stage or phase of establishment of the crop, and the lowest contributions were seen when the K_{cb} was at the maximum (Fig. 6). However, the strong changes in
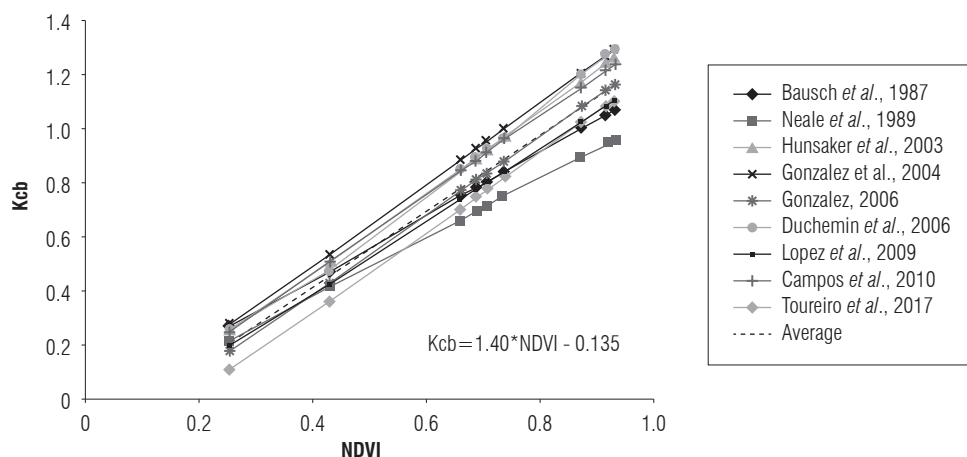

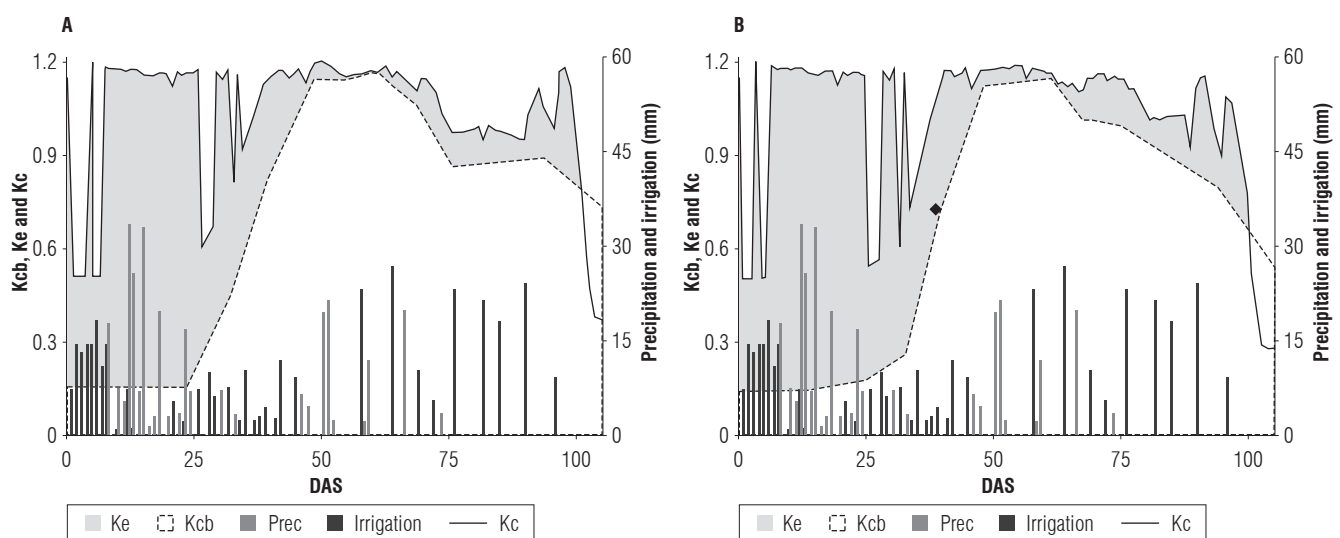**FIGURE 5.** K_{cb} approximations calculated with NDVI values.

$Kcb = 1.40 * NDVI - 0.135$

FIGURE 6. K_{cb}, K_e and K_c behavior over time with precipitation and irrigation, A) Laurena and B) Precoso varieties. For the latter variety, the rhombus indicates the appropriate time for foliage harvesting.
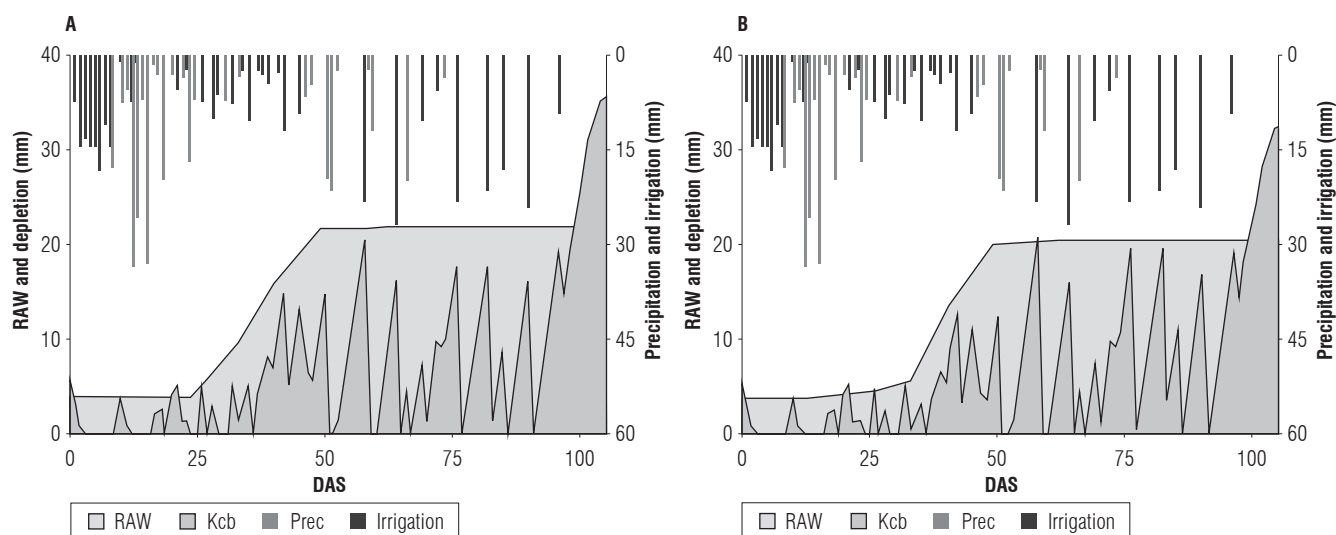
FIGURE 7. Readily available water (RAW) behavior for the crop and water depletion in the soil, in terms of rainfall and irrigation inflows. A) Laurena and B) Precoso varieties.

the behavior of K_e were associated with the capacity of the soil to retain water in the first centimeters and transfer it easily to the atmosphere when it was not covered. For this reason, after a precipitation event, when the total exposed surface was moistened, the K_c presented the maximum values, whereas localized irrigation applications decreased the contribution of evaporation to the K_c by up to 66%. At the end of the cycle, when the availability of water in the soil was considerably reduced, the contribution of K_e was eliminated, and the contribution of K_{cb} decreased with the crop senescence.

According to the water balance, until the middle of the development stage when the fresh foliage was harvested (up to 41 DAS), the crop demand (ET$_c$) was 156 mm for CL and 151 for CP, indicating that with this methodology, the water requirements were under those reported by Estrada *et al.* (2004) and Mejia *et al.* (2014). Additionally, for both varieties (CP and CL), the water input by precipitation and irrigation was between 208 mm to 187 mm, respectively, whereas losses through drainage (percolation) were 242 mm for CL and 245 mm for CP.

High losses resulting from drainage are a reflection of three factors: the first, the uneven distribution of precipitation throughout the vegetative cycle; the second, the concentration of precipitation in the first days of planting, and third, the application of frequent supplementary irrigation in order to ensure the development of the seed. This is done because, during the initial stage, the pivoting root has not yet been emitted or absorbent hairs have little scope making it impossible to absorb water stored between the porous spaces of the ground surface.

The irrigation schedules, made with estimates of effective depth of 30 cm, yielded positive results, allowing the level of soil depletion to exceed the capacity of readily available water (RAW) by the plant at the end of senescence, which could occur under stress conditions and favor the drying of the fruit (Fig. 7). However, the root analysis at the end of harvest showed that the roots did not exceed a 20 cm depth or a 25 cm width. This suggests that the root-extraction process may underestimate the horizontal and vertical reach of secondary roots.

Under the conditions of this research, the average seed yield was 181 g m^{-2} (±49) for CP and 175 g m^{-2} (±31) for CL, with a seed moisture content of 11% and 12%, respectively. This performance is suitable for both varieties as compared to the yields obtained by Usman *et al.* (2003) and Banda *et al.* (2011) with different methodologies.

Future studies should address the behavior of coriander until foliage harvest as well as the influence of sowing density and a follow-up on evaporation with lysimeters on water requirements, given that, in this study, the behavior of the whole vegetative cycle was assessed.

Conclusions

In the present study, it was observed that water demand management of this crop, based on remote sensors, is viable because of the sensitivity of the images and the radiometry used to determine biophysical variables (f$_c$ and K$_{cb}$) of the coriander, responding adequately to the natural and human variations that occurred throughout the vegetative cycle.

The transpiration behavior (K_{cb}) in the variety UNAPAL Laurena (CL) and the UNAPAL Precoso (CP) varieties were very similar, differing slightly in the mid-stage (CL = 1.17 and CP = 1.15), with a more accentuated difference in the final stage of senescence (CL = 0.79 and CP = 0.64).

On the other hand, the most contrasting difference between the two varieties was the length of the stages, where CL reached maximum development 5 days before the CP variety. However, CL took 10 d to complete the mid-stage before initiating the stage of senescence, a factor to be taken into account for the drying of seeds in the field.

The calculated ET_c from sowing to harvesting foliage (41 DAS), under field conditions, was 156 mm and 151 mm for CL and CP, respectively. Both varieties demand short and frequent irrigation during the initial stage and at the beginning of the development stage.

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