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Evapotranspiration and crop coefficient of basil determined by weighing lysimeters

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ABSTRACT

The basil (*Ocimum basilicum*) crop is of great importance for trading as fresh or dried condiment for human consumption and essential oil for pharmaceutical and cosmetic industries. Water excesses and deficits can affect biomass production of plants, making it necessary to use the correct amount of water for each crop. Considering that determinations of water consumption and cultivation coefficients for medicinal plants are scarce, the aim of this study was determining evapotranspiration and crop coefficients of basil using lysimeters. The crop evapotranspiration was determined by weighing lysimeters for the replacements of 100, 75 and 50% of the maximum daily evapotranspiration. The reference crop evapotranspiration was estimated by the Penman-Monteith equation. Crop evapotranspiration for the 49 day cycle was 471, 352 and 236 mm, and daily rates ranged from 4.8 to 9.4; 4 to 8.1 and 3.7 to 7.4 mm/day, for the replacements of 100, 75 and 50% of the maximum daily evapotranspiration. Crop coefficients varied from 1.5 to 2.8 and were related to the days after transplanting, leaf area index, cover ratio and cumulative degrees-day.

Keywords: *Ocimum basilicum*, cover ratio, crop coefficient, medicinal plants, water consumption.

RESUMO

Evapotranspiração e coeficiente de cultivo de manjericão determinados por lisímetros de pesagem

A cultura do manjericão (*Ocimum basilicum*) é de grande importância para o comércio como condimento fresco ou seco, para consumo humano e óleo essencial para as indústrias farmacêutica e cosmética. Os excessos e déficits de água podem afetar a produção de biomassa das plantas, tornando necessário o uso da quantidade correta de água para cada cultura. Considerando que as determinações do consumo de água e dos coeficientes de cultivo para plantas medicinais são escassas, o objetivo deste estudo foi determinar a evapotranspiração e os coeficientes de cultivo de manjericão usando lisímetros. A evapotranspiração da cultura foi determinada por lisímetros de pesagem para as reposições de 100, 75 e 50% da evapotranspiração máxima diária. A evapotranspiração de referência da cultura foi estimada pela equação de Penman-Monteith. A evapotranspiração das culturas para o ciclo de 49 dias foi de 471, 352 e 236 mm, e as taxas diárias variaram de 4,8 a 9,4; 4 a 8,1 e 3,7 a 7,4 mm/dia, para as reposições de 100, 75 e 50% da evapotranspiração máxima diária. Os coeficientes de cultivo variaram de 1,5 a 2,8 e foram relacionados aos dias após o transplante, índice de área foliar, razão de cobertura e graus-dia acumulados.

Palavras-chave: *Ocimum basilicum*, razão de cobertura, coeficiente de colheita, plantas medicinais, consumo de água.

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Basil (*Ocimum basilicum*), is considered a sub-shrub, originating from Asia and Egypt, introduced in Brazil by the Italian colony. It is an aromatic plant, 30 to 100 cm height, cultivated as perennial or annual, adapting better in humid and warm or mild climate that can be cultivated in several regions of the world, where small producers deliver their production for condiments and medicinal purposes (Marques *et al*., 2015).

Excess or deficiency of nutrients and water are limiting for the plant production; however, in medicinal plants such as basil, those factors may also affect the content of phytol pharmaceuticals. Researchers report that a moderate water deficit, although reducing the biomass production, is beneficial for the accumulation of active principles in medicinal and aromatic plants. Thus, it is necessary to use the correct amount of water for each crop, according to the production system (José, 2014).

The crop coefficient (Kc) depends on the crop development stage and the climatic conditions of the growing environment. Kc values are calculated by the relation between maximum evapotranspiration of the crop (ETm), determined experimentally in cultivation without water deficit, and the reference crop evapotranspiration (ETo), calculated with meteorological variables during the experimental period by the Penmann-Monteith equation, parameterized according to the FAO-56 method (Allen *et al*., 1998). The amount of water required throughout the crop cycle can be determined by the product of Kc and ETo, that directly affects the development of the crop leaf area. In literature, Kc values are reported for many crops, but are scarce for medicinal and aromatic plants. (Allen *et al*.,1998; Marques *et al*., 2015).

The soil water balance accounting by means of moisture sensors, such as TDR, has been used worldwide as a promising technique due to the low cost and the possibility of automation; however they require calibration for each type of soil, not being very accurate and may have the values affected by soil chemistry. Lysimeter is a precise equipment used in research for determination of water requirement of crops. This equipment is a tank filled with soil in which the plants are grown to simulate the actual conditions of the growing environment, thus allowing the measurement of crop evapotranspiration and soil evaporation (Ruiz-Peñalver *et al*., 2015).

Among the lysimeter types, weighing lysimeter is considered the most accurate and reliable; however, its calibration is required under local conditions. Due to the complexity of installation and handling, and high costs involved in its construction and maintenance, this type of lysimeters is more indicated for research and not for daily field monitoring. Several authors performed calibrations and tests on weighing lysimeters and concluded that they are able to measure soil water balance components accurately, providing reliable readings at intervals shorter than 1 hour (Campeche *et al*., 2011; Mariano *et al*., 2015; Martins *et al*., 2017).

The aim of this study was to determine basil evapotranspiration and crop coefficients by means of weighing lysimeter.

MATERIAL AND METHODS

Basil crop evapotranspiration was determined during a period of 49 days (10/22/2016 to 12/09/2016) for treatments with water replacement of 100, 75 and 50% of the crop maximum evapotranspiration. Each treatment had three replications with one transplanted basil seedling for each pot and lysimeter for the cultivar Folha Larga.

The experiment was carried out in a non-climatized chapel-type greenhouse with brickwork surface in Jaboticabal, Brazil (21°15’22”S, 48°18’58”W, 595 m altitude). Climate according to the classification of Köppen is Aw, tropical with average precipitation of 1,340 mm concentrated in the summer, and average annual temperature of 21.7ºC with hot summer and mild winter (Alvares *et al*., 2013).

Twelve weighing lysimeters constructed in carbon steel, 30 cm in diameter and 30 cm deep were randomly placed in the greenhouse, surrounded by 78 polyethylene pots, 12 L, filled with a substrate composed of ravine land and 160 g filter cake. The used substrate was analyzed and classified as clay texture, with 58% clay, 29% silt and 13% sand. Each lysimeter was supported by a load cell, model GL 50 from Alfa Instruments Electronics S.A., 50 kilograms capacity and accuracy in irrigation depth of 0.57 mm. The load cells were connected to a data acquisition and storage system (data logger), and every three days the data were collected using as interface the PC200W software. The drainage system in the bottom of the lysimeter was constructed of gravel, sand and soil placed in sequential layers totaling 5 cm. Drainage was performed by a hose installed at the bottom of the lysimeters, from which the drained water was measured by a 500 mL beaker. Lysimeters were previously calibrated as described by Mariano *et al*. (2015).

The soil available soil water storage (AW), as given by the difference between storage at field capacity (FC) and permanent wilting point (PWP), was determined to evaluate the soil water conditions in each treatment throughout the crop cycle. PWP was estimated at the end of the crop cycle in the lysimeters of the 50% ETm treatment (Figure 1A), by assuming 0 mm of storage when plants started irreversible wilting. FC was determined in an uncropped lysimeter, by saturating the soil and then draining its gravitational water to determine the storage at field capacity (FC), which was 80 mm. Therefore, AW was taken as 80 mm.

Irrigation was applied twice a week by means of a drip irrigation system with self-compensated emitters (clickTif HD model, NaanDanJain Brand). The layout of the equipment consisted in two manifold, one to irrigate simultaneously the 100% ETm and 50% ETm treatments, and the second to supply the 75% ETm treatment. The irrigation depths applied during 49 days of the crop cycle were 471, 354 and 236 mm for the treatments 100%, 75% and 50%ETm, respectively.

The treatments were performed with 100, 75 and 50% ETm replacements to verify the capacity of the crop to keep and produce under the effect of water deficit, in order to contribute information for its cultivation in dry regions.

Determination of crop evapotranspiration and crop coefficient (Kc)

Crop evapotranspiration for the treatments with water replacement of 100, 75 and 50% of ETm was determined as following:

$$ETc = \frac{(\Delta A + P + I - D)1}{Fc},$$

in which ETc is crop evapotranspiration, ΔA is mean variation of soil water storage in four weighing lysimeters, P is precipitation, I is irrigation, D is drainage, all in mm, and Fc is a correction factor for *bouquet* effect, applied for Fc>1, as calculated by Equation 1. The environment was covered; thus, precipitation was zero.

The estimate of Kc throughout the growing cycle was obtained by the ratio of ETm, given by the lysimeters in treatment 100% ETm, and ETo: $Kc = Etm/Eto$.

Daily meteorological data were measured by a meteorological station installed in the greenhouse and stored in a data logger, which was programmed to calculate daily ETo by the Penman-Monteith method, parametrized according to FAO-56 (Allen *et al*., 1998). During the experimental period mean temperature and relative humidity were 25.4°C and 70.3%, respectively, with 37.9°C maximum and 12.8°C minimum temperature, with 737 degree-days cumulative thermal sum.

Leaf area index and degrees-day

Leaf area index (LAI) was obtained as: *LAI = LA/LisA*, in which LA is leaf area of the plant and LisA is lysimeter surface area, both in m^2. LA was calculated as the mean leaf area (LAmed) and leaf area form factor (FF), as following: *LAmed = FF(LW)* in which L is length and W is width (m) of five leaves randomly taken in each of the four plants of each treatment. The FF value was 0.6775, obtained by regression between the product values of L and W measured in 60 basil leaves randomly collected from plants at 47 DAT, and the measured values of leaf area of the same leaves by one integrator of leaf area meter (model LI-3100, brand LI-COR) (Figure 1).

The correction factor for *bouquet* effect (Fc) is equivalent to coverage ratio (Rc) when Rc is greater than 1, which is calculated by the ratio between canopy projection area on the ground (CanA) and lysimeter area (LisA), according to the relation:

$$Rc = CanA/LisA \quad (1)$$

in which CanA is calculated by: *CanA = Rc(E1 E2)*, in which Rc is the coverage ratio and E1 and E2 are the spacing between pots.

Rc was determined weekly with the aid of the Canopeo® mobile cellular app (Patrignani & Ochesner, 2015). The Rc values were interpolated over the weekly periods to calculate Fc and CanA.

The accumulated thermal sum (degrees-day), as proposed by Marques *et al*. (2015), was used to characterize the thermal requirements of the crop and to assist in the use of Kc, relating their development to the environment temperature.

$$DD = (Tm - Tb) + TM - \frac{Tm}{2}, if\ Tm > Tb;$$

$$DD = (TM - Tb)^2 + (TM - Tm), if\ Tm < Tb;$$

$$DD = 0, if\ Tb > TM$$

in which DD is degrees-day, TM is daily maximum temperature (ºC), Tm is daily minimum temperature (ºC) and Tb is basal temperature for basil of 10.9ºC (Marques *et al*., 2015).

RESULTS AND DISCUSSION

Soil water conditions and evapotranspiration

The experiment started with soil at field capacity for all treatments (Figure 2A). The irrigations carried out in the treatment 100% ETm replenished the evapotranspiration completely, keeping the soil with storage above 50% of the available water. In the treatments with deficit irrigation, the available water storage gradually decreased during

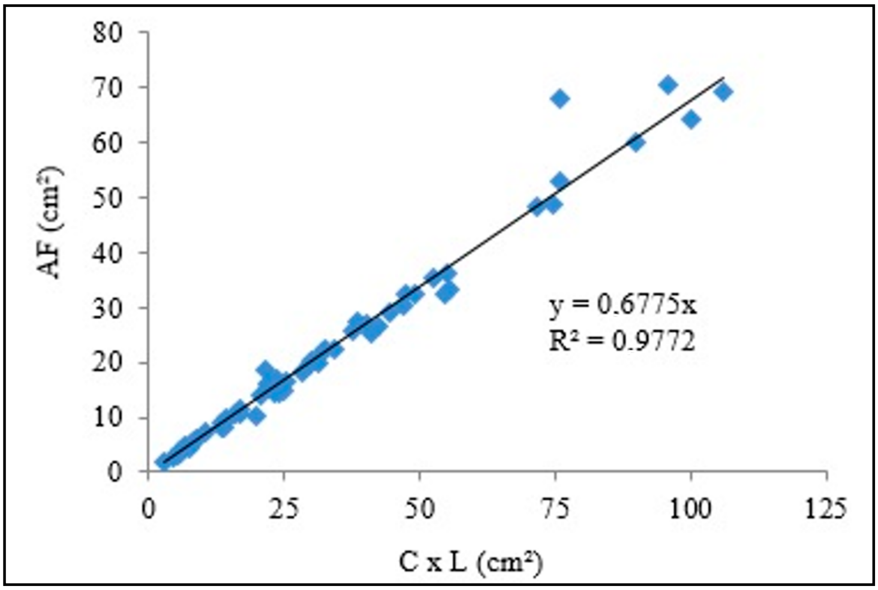

Figure 1. Regression of the form factor (FF). Jaboticabal, UNESP, 2016.

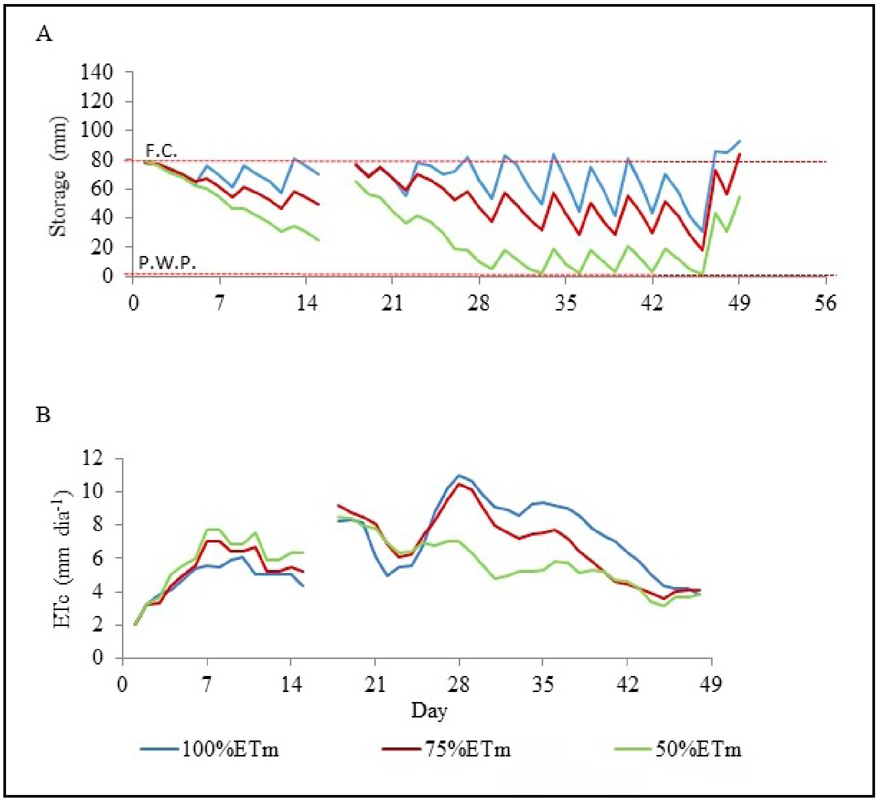

Figure 2. Water storage replacement (A) and crop evapotranspiration for 100, 75 and 50% maximum evapotranspiration of the crop (ETm) (B) during the experimental period. Jaboticabal, UNESP, 2016.

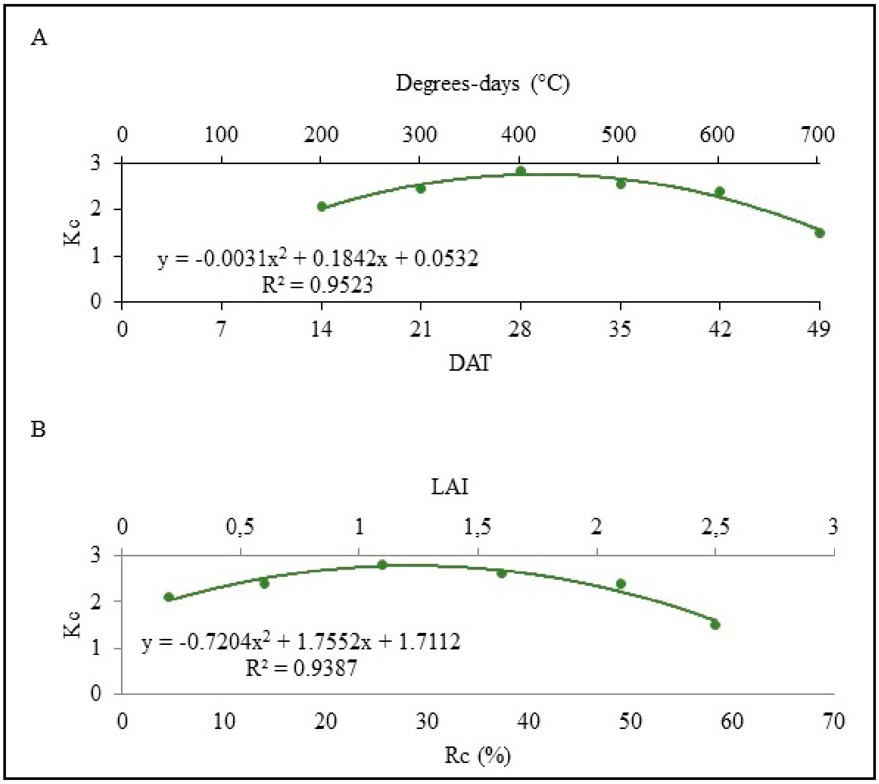

Figure 3. Coefficient of cultivation (Kc) as a function of days after transplant (A), leaf area index (B), during the experimental period. Jaboticabal, UNESP, 2016.

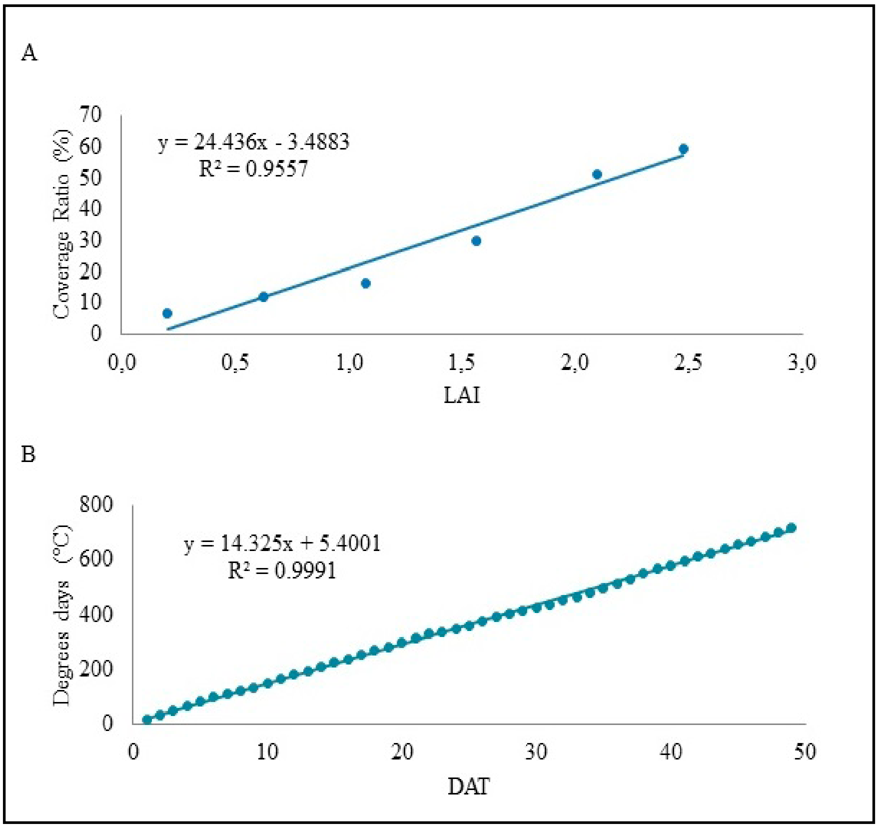

Figure 4. Coverage ratio according to the leaf area index (A) and degrees-day accumulated as a function of days after transplanting (B), during the experimental period. Jaboticabal, UNESP, 2016.

the crop cycle to remain between 30 and 60% of the available water in the treatment 75% ETm and between 0 and 30% in the treatment 50% ETm, 28 days after transplanting. The atmospheric demand, as given by the average ETo during the crop cycle, was 3.8 mm/day (Table 1) with maximum 4.2 mm/day at 20 days after transplanting (11/10/2016) and total of 152 mm. As a consequence of the water supply, ETc was reduced in the treatments with deficit irrigation as compared to full irrigation (Figure 2B, Table 1). The mean crop evapotranspiration during growing cycle was 6.9, 6.4 and 5.7 mm/day for treatments 100, 75 and 50% ETm, respectively. Marques *et al.* (2015) found crop evapotranspiration values varying from 1.27 to 4.82 mm/day for field-cultivated basil cycle which closed on October.

During the growing cycle, daily crop evapotranspiration rates ranged from 4.8 to 9.4; 4 to 8.1 and 3.7 to 7.4 mm/day for the treatments 100, 75 and 50% ETm (Table 1, Figure 2B). As the cycle progressed, daily crop evapotranspiration rates decreased depending on the water supply in each treatment, reflecting a possible adaptation of the crop to water stress. Vargas (2007), studying basil cultivars Maria Bonita, Mara and Genovese, at different irrigation levels, in the Northeast Brazil, observed partial closure of the stomata due to a decrease in the rate of photosynthesis and the rate of transpiration, indicating the existence of mechanisms for the adaptation of basil when subjected to water stress. We also observed that the cultivars showed accumulation of soluble carbohydrates due to the decrease of the water potential, characterizing an osmotic adjustment in the cultivars.

High crop evapotranspiration values, such as those found in this study, are explained by the occurrence of the *bouquet* effect and the "clothesline" effect. The clothesline effect occurs when height of the vegetation is larger than the surrounding vegetation, causing the crop to receive a greater amount of radiation, which leads to an overestimation of the crop evapotranspiration, a common occurrence for greenhouse crops. The

Table 1. Reference crop evapotranspiration (ETo) and crop evapotranspiration (ETc) during the experimental period. Jaboticabal, UNESP, 2016.

DAT	Stage*	ETo (mm/day)	ETc (mm/day)		
			100%	75%	50%
1-14	I	2.3	4.8	5.2	5.7
15-21	II	3.3	7.3	7.5	7.4
22-28	III	2.9	7.5	7.8	6.8
29-35	III	5.3	9.4	8.1	5,3
36-42	III	5.2	7.9	5.9	5,2
43-49	IV	3.7	4.6	4	3,7
Average		3.8	6.9	6.4	5,7

*I= Initial; II= Vegetative; III= Flowering and accelerated growth; IV= stabilization.

Table 2. Leaf area index (LAI), coverage ratio (Rc), correction factor (Fc) and crop coefficient (Kc), according to crop stage and days after transplanting. Jaboticabal, UNESP, 2016.

DAT	Stage*	LAI	Rc (%)	Fc	Kc
01-14	I	0.2	6.4	0.3	2.1
15-21	II	0.6	12.2	0.6	2.4
22-28	III	1.1	16.5	0.8	2.8
29-35	III	1.6	29.9	1.5	2.6
36-42	III	2.1	51.0	2.6	2.4
43-49	IV	2.5	59.5	3.0	1.5

*I= Initial; II= Vegetative; III= Flowering and accelerated growth; IV= stabilization.

bouquet effect occurs when leaf area of the crop exceeds the surface area of the soil, which is frequent in cultivation in pots. In condition of "clothesline" effect, the lower the lysimeter area, the more pronounced is the effect (Aboukhaled *et al*., 1982; Allen *et al*., 1991, 1998). In the case of *bouquet* effect, overestimation of crop evapotranspiration is due to the growth of the crop that exceeds the area of the lysimeter, which may cause an intercept of 40% more of the incident solar radiation when compared to grass outside the lysimeter area. Lysimeters wich area smaller than 2 m² may overestimate crop evapotranspiration as well as small lysimeters with short border areas have an effect of advection.

The *bouquet* effect occurred from 29 days after transplanting since the coverage factor (Fc) was higher than 1 (Table 2). Fc reached the value 3, which means that the plant canopy exceeded the lysimeter surface by 3 times.

Crop coefficient

Values of Kc were elevated throughout the cycle, ranging from 1.5 to 2.8 (Table 2). Values above the unit reflect the occurrence of "clothesline" effect, which had more significance due to the brickwork surface in the greenhouse. Mendonça *et al*. (2007) associated high values of Kc, obtained for a bean crop, to the *bouquet* effect caused by increased leaf area. In this study, excess of leaf area can be verified by the high values of Fc, showing that at 29 days after transplanting, the crop began to exceed the useful area of the lysimeters, reaching three times its area at the end of the cycle.

The linearity in the relationships between Rc and LAI, and degrees-day and days after transplanting, shows that Kc can be determined depending on leaf area index, coverage ratio and cumulative degree-days (Figure 3).

Quadratic regression curves were adjusted to describe the behavior of Kc during the cycle, depending on number of days after transplanting, coverage ratio and leaf area index (Figure 4). This quadratic behavior shows that the basil crop, in this study, reached the senescence period, with reduced plant biochemical activity. The reproductive phase of the crop began with flowering 21 days after transplanting and the end of flowering 42 days after transplanting. Since there was no harvest, the senescence of the crop began at that time. When crop is harvested several times throughout the year, Kc values always increase as a function to the crop cycle and coverage ratio, which means that accurate estimates of crop coefficient can be performed using Rc as an input (Marques *et al*., 2015).

Water consumptions of basil crop grown in pots under greenhouse were 9.6, 7.2 and 4.8 mm/day for the replacements of 100, 75 and 50% maximum evapotranspiration of the crop, respectively; The values of crop coefficient were high (1.5 to 2.8) due to the "clothesline" effect that occurs with plantations in greenhouse; crop coefficient can be related to degrees-day, leaf area index and coverage ratio, when the crop is cultivated during a single cycle; the crop shows senescence stage when cultivated to perform only one harvest.

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