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ADJUSTMENT OF THE CROP COEFFICIENT CURVE OF SUNFLOWER CV. BRS 323 IN THE NORTHWEST OF MINAS GERAIS

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ABSTRACT

The sunflower develops in phases that reflect the development and maturation of the plant and the knowledge of its crop coefficient (Kc) can help to improve management and increase productivity. The objective of this study was to determine the Kc curve of the sunflower cultivar BRS 323 in the northwest of Minas Gerais. The experiment was carried out in a protected environment at the Federal Institute of Northern Minas Gerais – Arinos Campus, with cultivation in pots of 25 L volume. These pots had at the bottom a filter composed of gravel, shade screen and, on top of it, 24 L of a Dystroferric Red Latosol. Drains with low-density polyethylene tubes were installed at the bottom of the vessels, so that they served as drainage lysimeters. Irrigation management was based on soil water balance by determining the actual crop evapotranspiration (ETr) using lysimeters. The reference evapotranspiration (Eto) was determined using the EVAPO mobile software. The daily Kc were determined by the ratio between ETrc and Eto. The duration of the crop phases was determined visually, by the anatomy of the plant, especially the inflorescence. The leaf area index (L) was determined by the ratio between the total leaf area (m^2) and the soil surface area (useful area of the pot in m^2). The Kc and L were associated by multiple regression using the SISVAR statistical software, after finding a significant relationship by the F test. The initial stage of the sunflower lasted 6 days and the Kc1 was constant with a value equal to 0.6. The vegetative development stage lasted 25 days and Kc2 ranged linearly from 0.6 to 1.78. The flowering phase, represented by Kc3, lasted 34 days and the value found was 1.8. The physiological maturation phase lasted 9 days and Kc4 ranged linear and

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decreasing between 1.8 and 0.74. It was observed, in this study, that the culture coefficients differ from those found in the literature, as they vary according to the cultivar, the boundary conditions and the method of determination of Kc (single Kg). Further studies are needed to determine the Kc under field conditions and correlate it with the Kc obtained in a protected environment.

Keywords: Helianthus annuus L. Vegetative stage. Leaf area. Evapotranspiration.

INTRODUCTION

The sunflower (*Helianthus annuus* L.), of the Asteraceae family, is a herbaceous annual plant with yellow flowers that follow the sun (phototropism). Its typical dicotyledon morphology includes root, stem, and alternate leaves with serrated margin. The inflorescence has central tubular flowers and ligulates at the margin, while its anatomy reveals structures such as epidermis, parenchyma, xylem and phloem, essential for the transport of water and nutrients (Oliveira; DoVale; Guimarães, 2022). These factors make the sunflower an attractive and significant plant, both from a scientific and economic perspective (Santos et al. 2021).

It is a widely cultivated plant and is considered the fourth most important oilseed on the planet, ranking fifth in vegetable oil production. The cultivation of this plant has increased due to the demand for biodiesel, especially after the creation of the National Program for the Production and Use of Biodiesel (PNPB) in 2004 (Amaral et al. 2020). In the 2021 crop report, the planted area in Brazil was 42,251.0 ha and production was 68,871 tons. Due to the fact that the North and Northeast regions do not cultivate this oilseed, as they face some limitations such as the subtropical climate and higher temperature, the rainfall regime is irregular, the soil in some northern regions is more acidic and the lack of incentive influences these limitations, and with that, the Midwest region, The South and Southeast receive highlights of this amount. The southeastern region of the state of Minas Gerais has 3,620.0 hectares of cultivated area and 6,459.0 tons of production. This is much smaller than the Midwest region, which has 36,021.0 hectares of cultivated area and 58,381.0 tons of production (IBGE, 2021).

The sunflower develops in stages and are categorized into phases that reflect the development and maturation of the plant. These stages include germination, marked by the emergence of seedlings, the vegetative stage, which promotes the development of leaves and stems, and the bud stage (R1), which signals the beginning of flower bud production. During flowering (stages R2 to R5), renewal and pollination occur, highlighting the characteristic yellow flowers of the plant. Subsequently, seed formation (R6 to R8) ensures grain growth, culminating in maturation (R9), when the seeds are ready for harvest (Olive; DoVale; Guimarães, 2022).

Determining the phases of greatest water demand of the crop is becoming increasingly relevant, as it can help improve cultural management and increase productivity. For this, knowledge of crop evapotranspiration is essential and this depends on the crop coefficient. Although it is considered drought-resistant, research indicates that the sunflower may be vulnerable to water stress, especially in several of its developmental stages.

Crop evapotranspiration (ETc) is the combination of plant transpiration and evaporation of water from the soil. The relationship between crop evapotranspiration (ETc) and reference evapotranspiration (ETo) is the crop coefficient (Kc). The crop should be free of stress factors such as pests, diseases, and competition with invasive plants, and the soil should have sufficient moisture and fertility to maximize its potential. Kc is used to calculate the amount of water needed for a crop, which is expressed in millimeters per day (mm) (Bernardo et al. 2019).

The four stages of the phenological cycle of annual crops represent the division of the crop coefficient being the initial stage (Kc1): This phase occurs when the crop cover of the soil is less than 10% and marks the beginning of crop growth. At this point, the frequency of rainfall or safety and the type of soil preparation have a significant impact on the Kc. Vegetative development stage (Kc2): Soil cover ranges from 10% to 80% at this stage. As the crop develops, the leaf area index increases and the Kc increases. Kc3 is the flowering stage and in this phase it occurs between the beginning of full soil cover (beginning of flowering) and the beginning of maturation, which can be assisted by discoloration or fall of leaves. The Kc3 values are the highest and usually coincide with the highest water demand of the crop. The maturation stage (Kc4) is the period from the beginning of leaf discoloration or fall to the point of harvest or full maturation. These steps are essential for control management and estimation of crop water demand (Albuquerque and Coelho, 2021).

The Kc curve helps researchers and rural producers to establish the amount of water needed at each stage of plant development, enabling more effective and sustainable irrigation. Farmers need to know the specific Kc for the crop they are growing, which can be obtained through agronomic research or technical literature (Santos et al. 2021).

The main objectives of sunflower breeding programs in Minas Gerais are: to develop genotypes more adapted to local edaphoclimatic conditions in order to increase productivity and oil quality; Select cultivars that are more resistant to water stress and heat, critical characteristics for plant sustainability in varied climates. In addition to increasing sunflower production, these objectives aim to ensure that the crop becomes a viable option for crop succession in grain-producing areas (Resende et al. 2022).

In view of the above, it is necessary that the sunflower cv. BRS 323 has its Kc curve defined and adjusted for each region, in order to contribute to a better management of water resources. In this context, the objective of this study was to generate the crop coefficient curve of sunflower cv. BRS 323 adjusted for the northwest of Minas Gerais and elucidate the relationship between this coefficient and the leaf area index.

METHODOLOGY

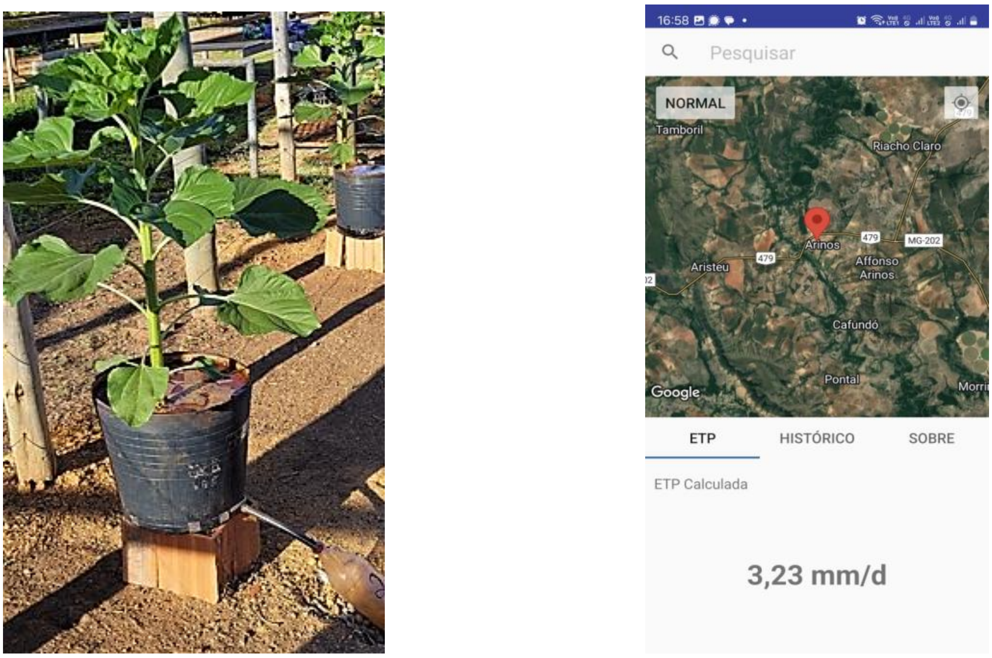
The experiment was conducted in a protected environment at the Federal Institute of Northern Minas Gerais. The climate of the place is characterized as tropical C2wA'a', that is, the climate for the city is characterized as subhumid megathermal with moderate water deficit in winter (Oliveira; Oliveira, 2018). As plant material, sunflower cv. BRS 323 (*Helianthus annuus* L.) cultivated in 25 L pots, whose management was carried out by the water balance of the soil in drainage lysimetry. The pots with a volume of 25 L were used with a filtering layer formed by 1.0 cm of gravel n° 1, shade® screen and, on top of it, 24.0 L of a medium-textured Dystroferric Red Latosol from an experimental area of the campus. The removal and deposition of the soil in the pots was done in order to maintain the physical properties of the soil under field conditions as much as possible.

Soil correction consisted of liming to increase base saturation to 80% (Aguiar et al. 2014) and application of dolomitic limestone to correct acidity. The amended soil was kept at rest for a period of 40 days with moisture close to field capacity. Fertilization was also carried out according to instructions from Aguiar et al. (2014) adapted for experimentation in pots (Novais et al. 1991). The sources of NPK were, respectively, simple superphosphate, potassium chloride and urea.

Planting was carried out manually, with the distribution of 10 seeds per pot in the useful area of the soil surface. Subsequently, thinning was carried out, when the stand formation reached 80% plant emergence (12 days after sowing), resulting in the permanence of only one plant per pot for analysis (experimental unit). The cultural treatments followed those recommended for the crop and include manual weed control, surface chiseling of the soil before irrigation and the implementation of phytosanitary measures with the application of chemical and biological products. The micronutrient supply was administered via foliar fertilization whenever characteristics of nutritional deficiency were visually observed.

Irrigation management was based on soil water balance by determining the actual crop evapotranspiration (ETr), using four drainage lysimeters (Figure 1a), following the methodology used by Gusmão et al. (2018) and Almeida et al. (2020) in previous studies.

Figure 1 - Drainage lysimeter (a) and EVAPO software layout (b).



Source: Authors (2025).

The water replacements represented the actual crop evapotranspiration (Etrc) obtained through the water balance of water in the soil in drainage lysimeters. To determine the reference evapotranspiration (Eto), the EVAPO software (Figure 1b) was used, which calculates, for the site, the potential evapotranspiration using the standard Penman-Monteith method (FAO-56) (Allen et al. 1998). The software uses online databases, the current location, and satellite imagery to determine key parameters of the equation, such as maximum and minimum temperature, relative humidity, and solar radiation (Maldonado et al. 2019). ETrc and Eto information was obtained daily.

To calculate the daily Kc in order to construct the Kc curve, the ratio between ETrc and Eto was used according to Equation 1 (Doorenbos; Pruitt, 1977). The values were converted to mm of water in the soil, by the ratio of the evaporation-free area (area of the pot in m²).

$$Kc = \frac{Etrc}{Eto} \qquad (1)$$

Where:

Kc = culture coefficient, (dimensionless);

Etrc = crop evapotranspiration, in $^{mm\text{-}day\text{-}1}$;

Eto = reference evapotranspiration, in mm $^{day\text{-}1}$.

As evapotranspiration depends on the transpiration area of the plant, the leaf area was determined indirectly through Equation 2 proposed by Maldaner et al. (2009), after accounting for the length of all leaves in the period between 20 and 90 days after emergence (DAE).

$$AF = 1{,}7582\ L^{1{,}7067} \qquad (2)$$

Where:

AF = leaf area, in cm²;

L = longitudinal length of the sheet, in cm.

The Leaf Area Index (L) was also determined, which describes the size of the assimilatory apparatus of the plant stand, being the primary factor that determines both the growth of the crop and the net assimilatory rate (Equation 3) suggested by Lopes and Lima (2005).

$$L = \frac{A_f}{S_t} \qquad (3)$$

Where:

L= Leaf area index, in decimal;

Af = Leaf area at 90 days, in m²;

St = Soil surface area in m² (considered the useful area of the soil in the pot of 0.0974 m²).

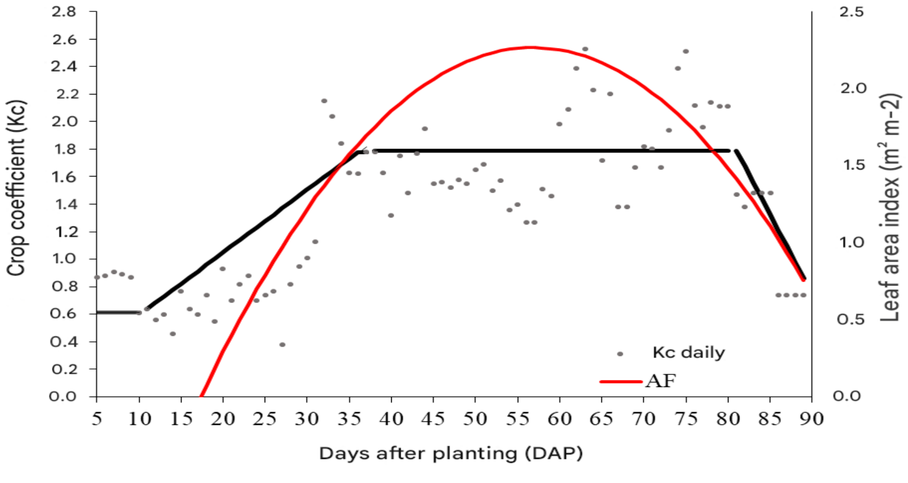
The Kc adjustment methodology was the one proposed by Carvalho and Oliveira (2012). The Kc1 value was determined by the mean of the Kc values of the 15 days after emergence (DAP). Kc2 is variable and was determined by the daily increments obtained by the values of Kc1 and Kc3 at 36 DAP. To do this, we proceeded with the ratio between the difference between Kc3 and Kc1 and the interval of days. Kc3, similar to Kc1, was determined by the average Kc obtained between 36 and 83 days. Kc4, on the other hand, was determined by the daily decreases obtained by the ratio of the difference between Kc3 and Kc4 and the interval of days.

The phases of the sunflower were determined visually, following information from Castiglione et al. (1997). The relationship between Kc values and leaf area index was determined by multiple regression, since similarity was observed between the stages of the Kc curve and leaf area.

RESULTS AND DISCUSSION

Figure 2 shows the Kc curve and the leaf area index throughout the crop cycle (days after planting). The following topics describe the intervals in days and the Kc values obtained.

Figure 2 - Crop coefficient and leaf area index of sunflower as a function of days after planting.



Source: Authors (2025).

Kc BETWEEN 4 AND 10 DAYS AFTER PLANTING (Kc1 - INITIAL)

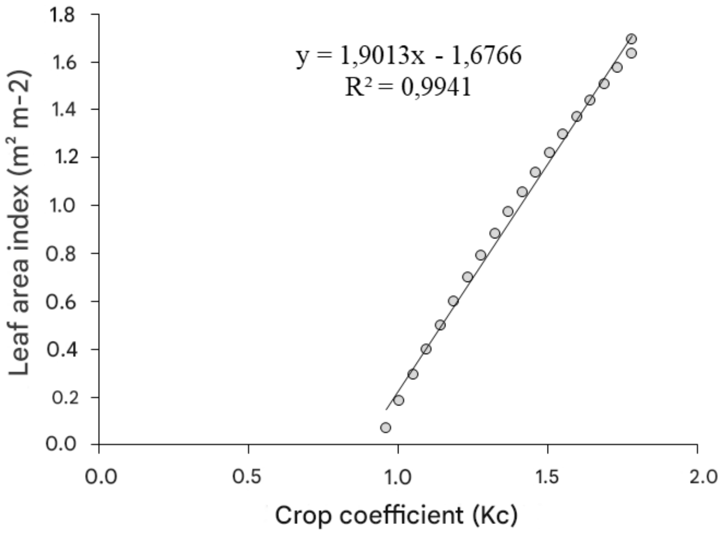
The initial stage of the sunflower lasted 6 days. In this period, the Kc was constant with a value equal to 0.6. In this phase, the Kc varies, mainly, due to the evaporation of the soil, and should consider the frequency of wetting. This Kc value is equal to that found by Júnior et al. (2013) in cv. Catisol I in the chapada do Apodi-RN.

Kc BETWEEN 10 AND 35 DAYS AFTER PLANTING (Kc2 - VEGETATIVE DEVELOPMENT)

In this interval, the Kc value ranged from 0.6 to 1.78. In this phase, also called vegetative development, the crop develops in height, stem diameter, root and leaf area. As a result of this growth, the crop demands greater water supply, driven by transpiration. Castiglioni et al (1997) report that the initial growth of the sunflower is slow, however, between 25 and 30 days it becomes accelerated, intensifying the absorption of water and nutrients, with 7 to 10 days before flowering being the most critical period. In the vegetative development of cv. BRS 323, it was observed that the L has a linear relationship with the Kc (Figure 3).

The L in this period varied between 0.07 and 1.69 m2 m-2, indicating that the plant is still developing leaf cover, preceding the period of differentiation (flowering). Sunflower is a crop that develops a low number of leaves, but a high leaf area, which gives this crop high transpiration and photosynthetic rates. It should be noted that the linear relationship obtained in figure 3 occurs, primarily, with adequate levels of water in the soil (field capacity).

Figure 3 - Relationship between the cultivation coefficient and the leaf area index of sunflower in the period from 11 to 37 days after planting.



Source: Authors (2025).

Kc BETWEEN 36 AND 80 DAYS AFTER PLANTING (Kc3 – FLOWERING)

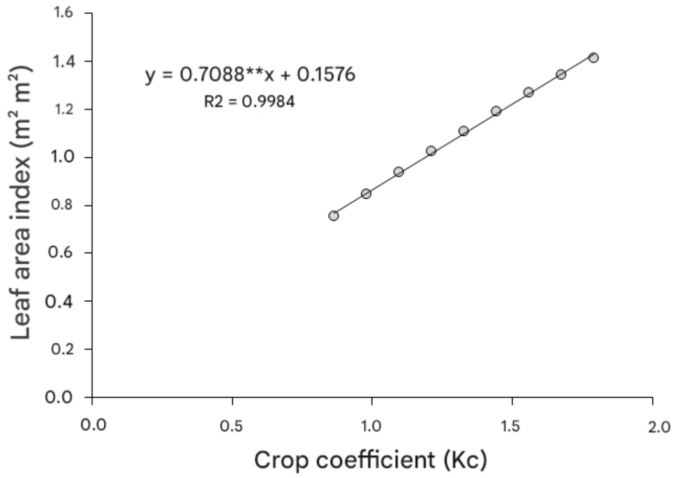
The Kc 3 of the BRS 323 cv was, throughout the flowering phase, equal to 1.8. This is the average value of Kc's for the period. This value is above that recommended by FAO (FAO, 2025) and this value is attributed to the method of determining evapotranspiration by the EVAPO software that determines ETo for the region and not in situ, as in lysimeters. Another possibility is that the Kc adjustment made in this study does not take into account dual Kc, however, for Santos et al. (2021), the calculation of ETc by the simple Kc method is still the most used form in irrigation management programs, as it includes in a single coefficient, both crop transpiration and soil water evaporation.

In addition, it was observed that the L increased up to 56 DAP (2.26 m2 $^{m-2}$), which confers greater water demand of the cultivar. In this phase, plants commonly produce photoassimilates to maintain the vegetative structure and translocation to the inflorescence, due to the source-drain relationship (Lopes; Lima, 2015). For Ferrazza et al. (2025), when the water content in the soil is maintained between 80 and 70%, soil moisture is readily available to the sunflower, allowing the crop to increase the L and thus contribute to plant growth.

Kc BETWEEN 81 AND 90 DAYS AFTER PLANTING (Kc4 – PHYSIOLOGICAL MATURATION)

In the physiological maturation phase, which lasted 9 days, the Kc4 ranged from 1.8 to 0.74. This reduction in the cultivation coefficient was accompanied by a reduction in the leaf area index, which can be seen by the linear relationship in Figure 4.

Figure 4 - Relationship between the cultivation coefficient and the leaf area index of sunflower in the period from 81 to 90 days after planting.



Source: Authors (2025).

The Kc value is close to that found by Júnior et al. (2013). The translocation of nutrients and carbohydrates from the leaves, stems and receptacles to the achenes intensifies in this phase, which leads to a gradual reduction of the leaf area (Castiglioni et al. 1997).

For Albuquerque and Coelho (2021), the climatic variations that occur in each location and on each day of the crop cycle interfere with Kc values, consequently, with water demand. In this sense, the daily adjustment of the Kc values becomes necessary for adequate management. Thus, it is evident that the need to establish the crop coefficient is important, because they are used to determine water demand, helping to establish the time and amount of water needed for the crop (Tavares, 2023).

FINAL CONSIDERATIONS

The initial stage of the sunflower lasted 6 days and the Kc was constant with a value equal to 0.6.

The vegetative development stage lasted 25 days and the Kc ranged linearly from 0.6 to 1.78. At this stage, the leaf area index has a high relationship with the Kc values (0.99).

The flowering phase, represented by Kc2, lasted 34 days and the value found was 1.8 and, despite this constant value, the leaf area index increased until 56 days after planting, making a value equal to 2.26 m2 m-2.

The physiological maturation phase lasted 9 days and the Kc ranged linear and decreasing from 1.8 to 0.74. These decreasing values are also related to the leaf area index.

In this study, it was observed that the crop coefficients differ from those found in the literature, as they vary according to the cultivar and the boundary conditions.

Further studies are needed to determine the Kc under field conditions and correlate it with the Kc obtained in a protected environment.

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