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Actual evapotranspiration and response factors of the cowpea in Amazonian edaphoclimatic conditions[1]

Evapotranspiração real e fatores de resposta do feijão-caupi nas condições edafoclimáticas Amazônica

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HIGHLIGHTS:

For the cowpea cultivar BR3-Tracuateua, the phenological stage with the greatest water demand was the flowering stage.
The flowering phenological stage showed the highest sensitivity to water deficit, with a response factor of dry biomass of 2.03.
Cowpea BR3-Tracuateua showed high sensitivity to water deficit, with a Ky of 1.48.

ABSTRACT: Due to the sensitivity of the cowpea to water deficit during the dry season in the Amazonian environment, there is a need for studies related to water management and the optimization of annual yield. Thus, the objective was to estimate the crop evapotranspiration (ETc) and the actual evapotranspiration (ETr), whilst also evaluating the effect of different irrigation depths on the yield response factor (Ky) and dry biomass (Kss) of the cowpea cultivar BR3-Tracuateua under edaphoclimatic conditions in the Amazon region. The experiment was carried out in randomized blocks, with six replicates and four treatments: T1 (100% ETc), T2 (50% ETc), T3 (25% ETc), and T4 (0% ETc), commencing in the reproductive phase with a drip irrigation system. The total evapotranspiration recorded for the cowpea cultivar BR3-Tracuateua across the four treatments was 337.5, 284.35, 258.62, and 219.82 mm with an average consumption of 4.6, 3.90, 3.54, and 3.01 mm d^{-1} for T1, T2, T3, and T4, respectively. The emergence phase showed evaporation rate of 5.19 mm d^{-1} and the reproductive, vegetative, and senescence ETc phases showed evaporation of 4.87, 4.84, and 3.32 mm d^{-1}, respectively. The flowering stage had the greatest water demand (5.88 mm d^{-1}). There was a significant difference in the crop yield among all treatments, with decreases of 18.91, 33.12 and 57.17% for T2, T3 and T4 in the grain yield, with a Ky of 1.48, and Kss of 2.03, 1.08, and 0.87 for the flowering, grain filling, and physiological maturation stages, respectively.

Key words: *Vigna unguiculata* (L.) Walp, sensitivity coefficient, water deficit, water balance, water demand

RESUMO: Devido à sensibilidade do feijão-caupi ao déficit hídrico no período de estiagem no ambiente amazônico, surge a necessidade de estudos relacionados com a gestão da água e otimização da produção anual por área. Assim, objetivou-se estimar a evapotranspiração da cultura (ETc) e a evapotranspiração real (ETr) e avaliar o efeito de distintas lâminas de irrigação sobre o fator de resposta da produção (Ky) e da biomassa seca (Kss) do feijão-caupi cultivar BR3-Tracuateua nas condições edafoclimáticas da região amazônica. O experimento foi realizado em blocos ao acaso, com seis repetições e quatro tratamentos: T1 (100% ETc), T2 (50% ETc), T3 (25% ETc) e T4 (0% ETc), iniciados na fase reprodutiva com sistema de irrigação por gotejamento. A evapotranspiração total do feijão-caupi cultivar BR3-Tracuateua foi de 337.5, 284.35, 258.62 e 219.82 mm com consumo médio de 4.6, 3.90, 3.54 e 3.01 mm d^{-1} para T1, T2, T3 e T4, respectivamente. A fase de emergência apresentou evaporação de 5.19 mm d^{-1} e as fases reprodutiva, vegetativa e senescência ETc média de 4.87, 4.84 e 3.32 mm d^{-1}, respectivamente. O estádio de floração obteve maior demanda hídrica (5.88 mm d^{-1}). Houve diferença significativa na produtividade entre todos os tratamentos com quedas no rendimento dos grãos de 18.91, 33.12 e 57.17% para T2, T3 e T4 com Ky de 1.48 e Kss de 2.03, 1.08 e 0.87 para os estádios de floração, enchimento de grãos e maturação fisiológica, respectivamente.

Palavras-chave: *Vigna unguiculata* (L.) Walp, coeficiente de sensibilidade, déficit hídrico, balanço hídrico, demanda hídrica

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INTRODUCTION

In the State of Pará, Brazil, cowpea (*Vigna unguiculata* (L.) Walp.) average yield was 821 kg ha^{-1} (14.4 sc ha^{-1}) with a drop in productivity due to rainfed cultivation, irrigation by non-traditional methods, difficulty in accessing information, and the lack of technical assistance in small properties (IBGE, 2017; Moreira et al., 2017; SEDAP, 2017).

Grain yield is affected by the duration and time of occurrence of the water deficit, with the knowledge of water demand in the phenological stages being a fundamental need for efficient irrigation (Azevedo et al., 2011).

It is therefore necessary to quantify the evapotranspiration and define the response factors of the crop to water deficit (Ky), which helps us to understand the phenological stage that is most sensitive to water stress (Doorenbos & Kassam, 1994; Keffer et al., 2019; Patanè & Saita, 2015). Ky is, therefore, an important parameter for the rational management of water in the production of cowpeas (Silva et al., 2014; Santos et al., 2017).

There are no estimates in the FAO 33 for the Ky/Kss for cowpea; estimates are only provided for common beans *(Phaseolus vulgaris*) that are highly sensitive to water deficit (Ky = 1.15) (Doorenbos & Kassam, 1994; Patanè et al., 2011). In Brazil, the sensitivity of cowpea was observed by Cordeiro et al. (1998), Carvalho et al. (2000), and Mousinho et al. (2008). Technical studies during periods of lower rainfall and on the effects of irrigation on crop productivity are necessary to increase productivity in the region.

Thus, the objective of this study was to estimate the crop evapotranspiration and the actual evapotranspiration (ETr) and to evaluate the effect of different irrigation depths on the yield response factor (Ky) and dry biomass (Kss) of the cowpea cultivar BR3-Tracuateua in Amazonian edaphoclimatic conditions.

MATERIAL AND METHODS

Our study was carried out from September 17, 2016 to November 28, 2016 (spring equinox) across an area of 3,168 m^2 at the School Farm of the Federal Rural University of the Amazon (UFRA), located in the municipality of Castanhal, PA, Brazil (1° 19’ 24.48” S, 47° 57’ 38.20” W), at an altitude of 41 m.

The climate of the region is “Am” of the hot and humid type according to the Koppen classification, with an average annual temperature of 26 °C and a maximum relative air humidity of 95% and a minimum of 79%. The region also has an average annual rainfall of 2,571.6 mm, with 35% of the rainfall concentrated in the months of January, February, and March and 16% across the months of July, August, and September (Souza et al., 2017).

The environmental conditions of the experiment showed an average air temperature, relative air humidity, and a wind speed of 27.2 °C, 77.8%, and 1 m s^{-1} respectively (Figure 1).

Samples of disturbed and undisturbed soil with four replications at each depth and type of sample were collected in the study area and analyzed in the Soil Laboratory of Embrapa Amazônia Oriental.

The soil samples showed the following chemical and physical characteristics: pH (H_2O) 3.7, P = 20 mg dm^{-3}, K^+ = 30 mg dm^{-3}, Ca^{2+} = 1 $cmol_c$ dm^{-3}, Mg = 0.2 $cmol_c$ dm^{-3}, Al^+ = 0.6 $cmol_c$ dm^{-3}, SB = 1.29 $cmol_c$ dm^{-3}; sandy loam texture, 83.5% sand, 12.5% silt, and 4% clay, and soil density of 1.56 kg dm^{-3}. The soil was classified as oxisol.

The soil water content in the field capacity (θfc) and permanent wilting point (θpwp) were measured using the Richard’s pressure chamber and adjusted with the values of the parameters of the soil water retention curve (Table 1) using Eq. 1 by van Genuchten (1980).

$$\theta = \theta pwp + \frac{\theta s - \theta pwp}{[1 + |\alpha \varphi m|^{n}]^{m}} \tag{1}$$

where:

θs - moisture at the soil saturation point, cm^3 cm^{-3};

θpwp - moisture at the permanent wilting point of the soil, cm^3 cm^{-3};

φm - matrix potential, hPa;

α, n, and m are empirical constants obtained from the soil water retention curve.

Table 1. Values of parameters of the water retention curve in the soil by the van Genuchten equation (1980), tension, and S index, for depths 0-0.20 and 0.20-0.40 m

Layer	θs	θcc	θpwp	Hi	α	S	n	m
(cm)		(cm^3 cm^{-3})		(hPa)				
0-20	0.26	0.21	0.12	17.4	0.0135	0.019	1.41	0.29
20-40	0.25	0.20	0.13	56	0.0031	0.021	1.63	0.38

θs - Soil water content at the saturation point; θfc - Soil water content at the field capacity point; θpwp - Soil water content at the permanent wilt point; Hi is the tension at the inflection point of the curve; S is the slope of the retention curve at the inflection point; α, n, and m are the empirical parameters of the model

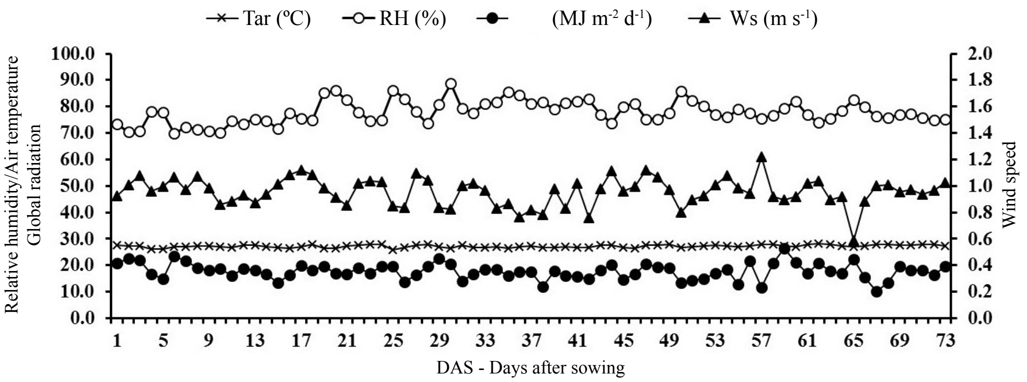


Figure 1. Mean daily values of relative air humidity (RH), air temperature (Tar), global radiation (Rg), and wind speed (Ws)

The limit of 0.17 $cm^3\ cm^{-3}$ for easily available water (EAW), which is the moisture between the field capacity and the permanent wilting point up to which plants absorb water without restrictions that compromise their growth and development, was obtained according to the methods described by Pereira et al. (2002).

The soil in the experimental area had conventional tillage (plowing and harrowing), application of 0.63 t by the base saturation method, and fertilization of the foundation with 195 kg ha^{-1} of NPK 6-18-15 (urea, simple superphosphate, potassium chloride). Thirty days after emergence, potassium chloride was also used to fertilize the foundation, according to the chemical analysis of the soil and the fertilization recommendation for the crop in the region, in 5 cm furrows along the planting line, as recommended by EMBRAPA (2005).

The cowpea cultivar BR3-Tracuateua of undetermined growth, prostrate size, and cycle of 60-70 days was planted manually with a spacing of 0.5 m between rows and at a rate of fifteen seeds per meter and then treated with Carbendazim fungicide (100 mL per 400 mL of water) for 100 kg of seeds. A density of ten plants per linear meter was maintained after thinning.

The cultural treatments carried out during the crop cycle were weeding with a hoe, weeding, and heaping. Pest and disease prevention was carried out by applying the insecticides Deltametrina (3 mL per 10 L of water) and Tiametoxam at a dose of 200 g ha^{-1}.

Daily monitoring of cowpea phenology was performed according to the methodology outlined by Farias et al. (2017) in 1 m lines with 10 plants. This method takes into consideration the vegetative and reproductive phenological phases and developmental stages of the plant: V0 (germination), V1 (cotyledon above ground), V2 (expanded cotyledon leaves), V3 (first leaf trifoliolate), V4 (third trifoliolate leaf), R5 (first floral bud), R6 (anthesis of the first flower), R7 (first knife-shaped pod), R8 (grain filling), and R9 (physiological maturation).

It was considered that the change in the phenological phase occurred when 50% + 1 of the plants in the line had a higher frequency of occurrence inherent to each phase and stage of cowpea (Giunta et al., 2009).

The experimental design was a randomized block with six replications, where each block had an area of 115 m^2 (11.5 x 10 m) and four treatments, spaced 1 m apart, totaling to 24 experimental units, 2.5 m in width and 10 m in length, spaced by 0.5 m. These were then subjected to 100% restoration of crop evapotranspiration (ETc) with irrigation + rain in the stadium (V4) for establishment and standardization of the crop from 17 September to 22 October, 2016 with soil maintained close to the field capacity.

The treatments started at the stage R5 and were performed as follows: T1 (100% ETc restoration), T2 (50% ETc restoration), T3 (25% ETc restoration), and T4 (0% restoration ETc). In T4, mobile covers of transparent polypropylene (100 μm) with a height of 1.5 m were built for each block in order to prevent water from entering. These were used only in the event of rain.

Watering was conducted through the drip irrigation system through in-line emitters, with 20 cm spacing (100 emitters per line) and drip tapes with polyethylene additives (16 mm) on the soil surface serving a 10 m planting line. The system was powered by a 2 cv submersible electric pump in a 40 m artesian well and operated at a service pressure of 5 mca.

The distribution uniformity coefficient (CUD), determined using Eq. 2 was of 88%, which is classified as 'good' according to Merriam & Keller (1978), and it was obtained using 2.000 mL collection vessels buried with the top leveled to the ground, distributed at the beginning, middle, and end of the tapes with a capture of three emitters for 20 min in the four treatments of all blocks with three repetitions.

An average flow of 1 L h^{-1} per dripper was obtained at a service pressure of 5 mca. The efficiency of the irrigation system (Ea) was determined using Eq. According to Bernardo et al. (2006), 3 of 80% was classified as 'acceptable'. The relevant calculations are as below:

$$\mathrm{CUD} = \left(\frac{q_{25}}{q}\right)100 \tag{2}$$

$$\mathrm{Ea} = 0.9\ \mathrm{CUD} \tag{3}$$

where:

q_{25} - average of 25% of the total drippers with the lowest flow rates, L h^{-1}; and

q - average drip flow, L h^{-1}.

A 3 m high micrometeorological tower was installed in the planting area with an automatic surface meteorological station for agrometeorological purposes. It was used for measuring temperature and relative air humidity, wind speed and direction, rain, global solar radiation, and soil moisture using sensors connected to the CR10X data logger (Campbell Scientific. Inc., Logan, Utah, USA-CSI) and an AM416 multiplexer (Campbell Scientific, Inc.). Readings were taken every 10 s, and averages were stored every 10 min.

The Penman-Monteith FAO 56 (Eq. 4) was the micrometeorological method used to estimate daily reference evapotranspiration values (ETo_{PM}) (Allen et al., 1998), with data taken from the automatic surface meteorological station of the National Institute of Meteorology (INMET) of Castanhal, located 3 km from the planting area. Calculation of the evapotranspiration values is as follows:

$$ETo_{PM} = \frac{0.408\Delta\left(R_a - G\right) + \gamma\left(\frac{900}{T+273}\right)Ws\left(es-ea\right)}{\Delta + \gamma\left(1+0.34Ws\right)} \tag{4}$$

where:

ETo_{PM} - reference evapotranspiration, mm d^{-1};

R_a - radiation at the top of the atmosphere, MJ $m^{-2}\ d^{-1}$;

G - heat flow in the soil, MJ $m^{-2}\ d^{-1}$;

T - air temperature at 2 m high, °C;

Ws - average daily wind speed at a height of 2 m, m s^{-1};

(es-ea) - vapor pressure deficit, kPa

Δ - slope of the saturation vapor pressure curve, kPa $°C^{-1}$; and,

γ - psychrometric constant, kPa $°C^{-1}$.

The crop coefficient (Kc) values of 0.8, 1.3, 1.4, and 0.6 obtained by Farias et al. (2017) for the cowpea cultivar BR3-Tracuateua in the initial, vegetative, reproductive, and final stages, respectively were used to determine ETc during the experiment (Eq. 5).

$$\mathrm{ETc} = \mathrm{ETo}_{\mathrm{PM}}\ \mathrm{K_c} \tag{5}$$

where:

ETc - crop evapotranspiration, mm d^{-1};
$\mathrm{ETo}_{\mathrm{PM}}$ - reference evapotranspiration, mm d^{-1}; and,
Kc - crop coefficient.

The irrigation events were carried out daily based on the ETc of the previous day, from which the net irrigation depth (LL) (Eq. 6) and the gross irrigation depth (LB) were calculated while considering the ratio between the net depth and the water application efficiency of the irrigation system (Eq. 7), with differentiation for each soil water replacement treatment. The measure of effective rain obtained with the rain gauge installed at the experimental site was discounted in the calculation of the irrigation depth.

$$\mathrm{LL} = \mathrm{ETc} - \mathrm{EF} \tag{6}$$

$$\mathrm{LB} = \frac{\mathrm{LL}}{\mathrm{Ea}} \tag{7}$$

where:

LL - net irrigation depth, mm;
ETc - crop evapotranspiration, mm d^{-1};
EF - effective rain, mm;
Ea - water application efficiency, decimal; and,
LB - gross irrigation depth, mm.

The ETr was estimated using the simplified water balance method (Eq. 8) with daily measurement of variables, assuming that the effective depth of the irrigated cowpea root system is 30 cm (Cardoso et al., 2017).

It was considered null owing to the negligible capillary rise in deep soils such as Oxisols (Pereira et al., 1997), runoff (flat and naturally well-drained terrain), and deep drainage due to the daily monitoring of precipitation and irrigation inputs via time domain reflectometry (TDR).

$$\mathrm{ETr} = \mathrm{P} + \mathrm{I} \pm \Delta\mathrm{h} \tag{8}$$

where:

ETr - actual evapotranspiration, mm;
P - precipitation, mm;
I - irrigation, mm; and,
Δh - storage variation (mm)

To monitor the variation in volumetric moisture in the soil, a 30 cm CS616 sensor (Campbell Scientific Inc., Utah, USA-CSI) was inserted vertically in each treatment.

The sensors were calibrated prior to the experiment using undisturbed soil samples from the experimental area, with the ratio of the volumetric moisture obtained by the gravimetric method and the daily readings of the apparent soil dielectric constant (Ka) and the volumetric moisture in the soil (θ) estimated by the sensor with a linear regression equation.

In each experimental unit made up of six 10 m long planting lines spaced 0.5 m apart, five plants were selected randomly in the two central lines, with a usable area of 15 m^2, to obtain a sample composed of leaves, stems (petiole, peduncle, and stem), and legume (pod and grain). These were then separated and dried in an oven at 70 °C for 72 hours to determine the dry biomass using a 0.01 g precision scale. The lateral lines of each experimental unit were used as the borders.

The grain harvest took place on November 28, 2016 (72 days after sowing (DAS)), when 90% of the plants had reached the R9 stage. Grain yield was evaluated using the 1 × 1 m quadrant method, with three replications performed at random for each treatment in two 2 m planting lines.

The grains after threshing were weighed before and after the greenhouse. Afterwards, the productivity calculation was performed by relating the dry weight of the grain in grams per square meter and converted to kilograms per hectare.

The response factors that quantify losses in grain yield (Ky) and losses of dry biomass (Kss) in different stages, due to the deficit in relative evapotranspiration, were calculated and classified using Eqs. 9 and 10 (Doorenbos & Kassam, 1979; Patanè et al., 2011).

$$\left(1 - \frac{\mathrm{Yr}}{\mathrm{Ym}}\right) = \mathrm{Ky}\left(1 - \frac{\mathrm{ETr}}{\mathrm{ETc}}\right) \tag{9}$$

$$\left(1 - \frac{\mathrm{SSr}}{\mathrm{SSm}}\right) = \mathrm{Kss}\left(1 - \frac{\mathrm{ETr}}{\mathrm{ETc}}\right) \tag{10}$$

where:

Ym - grain yield without water restriction, kg ha^{-1};
Yr - actual yield of the crop, kg ha^{-1};
Ssm - biomass yield without water restriction, kg ha^{-1};
SSr - biomass yield subjected to water restriction, kg ha^{-1};
Ky - grain yield response factor, dimensionless; and,
Kss - dry biomass response factor, dimensionless.

The data were subjected to normality (Shapiro-Wilk) and homogeneity (Bartlett) tests. Analysis of variance (ANOVA) was used to verify the difference in grain yield. Linear regressions were performed between grain yield and the evapotranspiration deficit in order to obtain the values of Ky and Kss and to evaluate water supply and grain yield (R Core Team, 2017).

RESULTS AND DISCUSSION

The various soil conditions, the germination time until the harvest lasting 68 days, and the days of irrigation depth used during the experiment are shown in Figure 2.

T1 during the experiment had a total ETc of 337.5 mm and an average consumption of 4.6 mm d^{-1}. With the reduction of irrigation depths at 36 DAS (Figure 2), treatments T2, T3, and T4 showed a total and average ETr of 284.35, 258.62, and

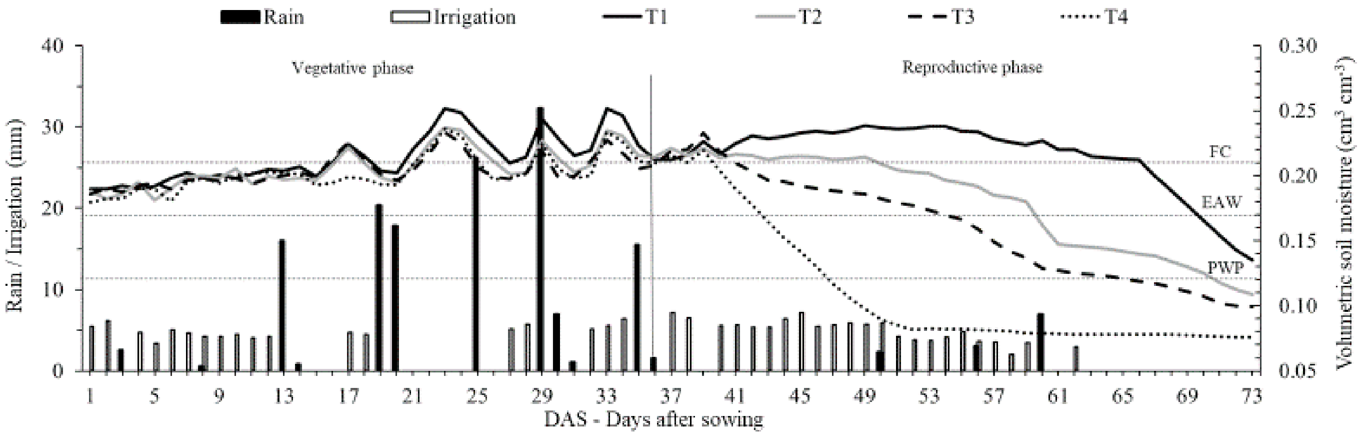


Figure 2. Daily averages of soil moisture, field capacity (FC), easily available water limit (EAW), permanent wilting point (PWP), and total daily values of rain and irrigation during the cultivation of cowpea cultivar BR3-Tracuateua

219.82 mm and 3.9, 3.5 and 3.0 mm d^{-1}, respectively, resulting in an accumulated deficit of 53.2, 78.9, and 117.7 mm, respectively.

T2, T3 and T4 received depths lower than T1 (Table 2) and reached the limit of easily available water at 60, 55, and 43 DAS, with the permanent wilting point at 71, 67, and 47 DAS, respectively (Figure 2). Under the conditions of water deficit, the plants did not present characteristics of physiological wilting in the field due to physiological rest, but they did show reduced cell multiplication (Giunta et al., 2009).

ANOVA showed a significant difference in cowpea grain yield ($p \leq 0.05$). Allied to the decrease in the water potential in the soil, the ETo_{PM} conditioning high atmospheric evaporative demand had a total, maximum, minimum, and average value of 368.84, 6.55, 3.53 and 5.05 mm d^{-1}. Influenced by the high air temperatures, the plant had greater control of transpiration, which corroborates the drop in the grain yield (Table 2).

During the phenological phases of cowpea (Table 3), the emergence phase showed the highest average evaporation due to direct solar radiation and little soil coverage, followed by the reproductive, vegetative, and senescence phases.

From the division of the crop cycle, the vegetative phase showed the highest total ETc values (149.93 mm) (Figure 3) due to the high water potential in the soil and the duration of the phase (Table 3). The reproductive phase had the second highest total ETc (121.84 mm), followed by the senescence (41.09 mm) and emergence (25.97 mm) phases.

At 61 DAS, the grain maturation stage commenced and irrigation was interrupted; however, the senescence phase showed high ETc values, which may be due to the decrease in the area coverage and the amount of water in the soil (Figure 2).

There was variation in soil moisture (Figure 2), ETc, and ETr (Figure 4) with rain; however, monitoring of soil moisture by TDR allowed for a real-time assessment of the need for irrigation.

Table 3. Period and duration of each phenological phase and crop evapotranspiration of cowpea cultivar BR3-Tracuateua

Phenological phase	Period	Duration (days)	ETc (mm d^{-1})
Emergence	18/09 to 21/09/16	4	5.19 ± 1.18
Vegetative	22/09 to 22/10/16	31	4.84 ± 0.88
Reproductive	23/10 to 16/11/16	25	4.87 ± 1.41
Senescence	17/11 to 28/11/16	12	3.32 ± 0.62

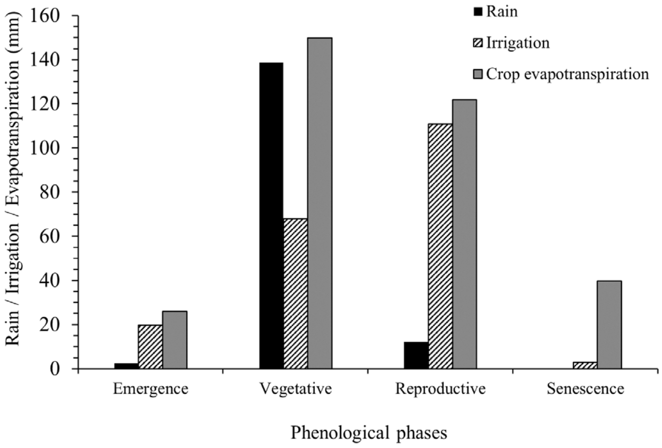


Figure 3. Rain, irrigation, and evapotranspiration of cowpea cultivar BR3-Tracuateua grown in 100% ETc during the different phases and phenological stages

When ETc was observed in cowpea growth stages (Figure 4), R5 presented the highest average water demand (5.9 mm d^{-1}), justifying the greater availability of water in the reproductive phase, followed by the vegetative phase, grain filling, and physiological maturation with 4.8, 3.6 and 3.2 mm d^{-1}, respectively. These results are further corroborated in a previous study by Farias et al. (2017).

Figure 4 also shows the behavior of global radiation with an average of 17.8 MJ m^{-2} d^{-1}, influencing the variability of

Table 2. Amount of water available through irrigation and rainfall and the grain yield (PG) of cultivar BR3-Tracuateua

Treatments	Vegetative phase		Reproductive phase		Total	Number of irrigations	PG
	Rain	Irrigation	Rain	Irrigation			
	(mm)						
T1 (100% ETc)	141.2	87.6	12.2	113.8	354.8	40	1.597 a
T2 (50% ETc)				56.2	297.1	40	1.295 b
T3 (25% ETc)				28.4	269.5	40	1.069 c
T4 (0% ETc)			0	0	228.8	17	684 d

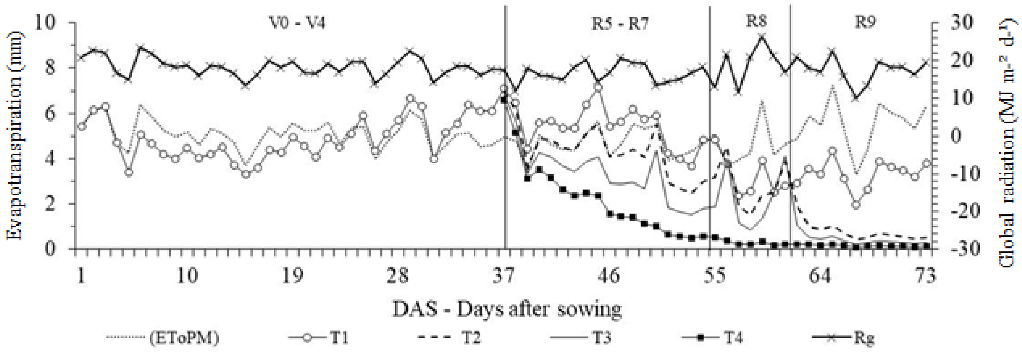


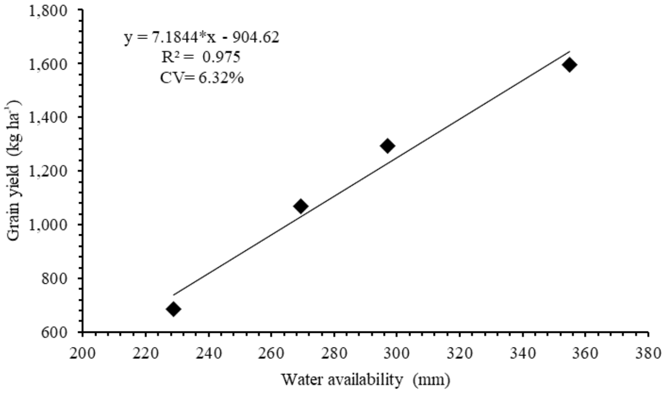
Figure 4. Reference evapotranspiration (ETo_{PM}), crop evapotranspiration (T1-100% ETc), and actual evapotranspiration (T2-50% ETc, T3-25% ETc, and T4-0% ETc) by cowpea cultivar BR3-Tracuateua during cultivation in the vegetative (V) and reproductive (R) phases and global radiation (Rg) in the months from September to November 2016

evapotranspiration such that during the vegetative phase until 23 DAS, ETo_{PM} was superior to ETc, with the soil maintained in field capacity to meet the atmospheric evaporative demand. It was observed that the most frequent ETc values during cultivation were 4.6, 3.9, 6.5, 5.2 and 5.9 mm d^{-1}.

After 24 DAS, cowpea ETc was higher than ETo_{PM} for up to 57 DAS, reaching the highest ETc values, with a maximum value of 7.15 mm d^{-1}. This variation observed between ETc and ETo was due to the increase in the leaf area index, transpiration, and soil cover (Farias et al., 2017).

The decrease in ETc at 55 DAS occurred at the beginning of the grain filling stage, extending to physiological maturation with senescence, with the ETr aggravated by the reduction of the irrigation depth, soil drying, and environmental conditions. This fact is corroborated by the significant difference in the grain yield of cowpea, where T1 (337.5 mm) differed from the other treatments (Figure 5).

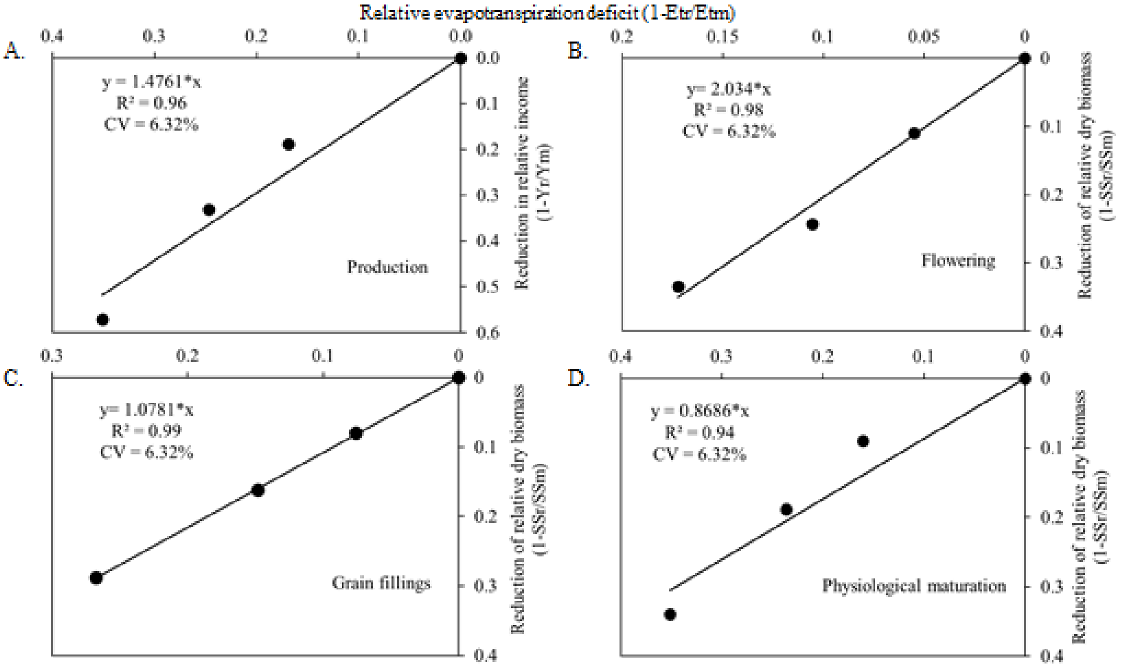
The angular coefficient of the linear regression equation indicated a Ky of 1.48 (Figure 6A) for the decrease in grain yield with the reduction of evapotranspiration in cowpea, which was accentuated as the water restriction increased in the soil (Figure 5).



* - Considered statistically significant at $p \leq 0.05$ by F test

Figure 5. Grain yield of cowpea cultivar BR3-Tracuateua as a function of available water

For T2, T3, and T4, a decrease of 21%, 31% and 42% in relative evapotranspiration was observed and the productivity



* - Considered statistically significant at $p \leq 0.05$ by F test

Figure 6. Decrease in the marketable relative yield of the grain (A) and the decrease in the relative dry biomass at the phenological stages of flowering (B), grain filling (C), and physiological maturation (D) as a function of the deficit of relative evapotranspiration of cowpea cultivar BR3-Tracuateua in the reproductive phase

was reduced by 18.91%, 33.12%, and 57.17% in the reproductive phase of the plant, respectively.

Losses of dry biomass ranged from approximately 10 to 30% (Figures 6B, C, D), where the flowering stage showed greater sensitivity to water deficit, followed by the grain filling and physiological maturation stages, which presented low to medium sensitivity, and this was corroborated by Doorenbos & Kassam (1994) and Santos et al. (2012), who have reported that water deficit at the flowering stage results in a significant reduction in grain yield.

Cordeiro et al. (1998) found that the Ky values for cowpea were below 1, indicating low crop sensitivity to water stress; the grain-filling stage showed greater sensitivity to water deficit, while the flowering stage showed less sensitivity. Carvalho et al. (2000) found that the vegetative stage was the most sensitive to water deficit (Ky = 1.28), followed by the flowering (Ky = 1.05) and fruiting (Ky = 0.98) stages.

Conclusions

1. The cowpea cultivar BR3-Tracuateua had a total evapotranspiration of 337.5, 284.3, 258.6, and 219.8 mm and an average consumption of 4.6, 3.9, 3.5 and 3.0 mm d^{-1} in T1 (100% crop evapotranspiration - ETc), T2 (50% ETc), T3 (25% ETc), and T4 (0% ETc), respectively.

2. The flowering stage of the cowpea cultivar BR3-Tracuateua showed the highest water demand and high sensitivity to water deficit, with a dry biomass response factor (Kss) of 2.03.

3. The cowpea cultivar BR3-Tracuateua showed a high sensitivity to water deficit (Ky = 1.48), with greater yield limitations in the non-irrigated conditions in the reproductive phase.

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