

Determination of Basal Temperature and Its Relationship With *Jatropha* Crop in Irrigated and Non-irrigated System

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Abstract

Full plant growth and development require, among others, air temperatures and water availability at levels appropriate to each crop. The effect of temperature on plant development can be represented by the thermal sum, which requires the lower basal temperature for each plant species. However, plant responses may be different when associated with different soil water contents. This work determined the lower and upper basal temperature of *Jatropha curcas* L. and verified the relationship between thermal sum and crop development under different water regimes, in the climatic conditions of Goiânia, GO, Brazil. We evaluated twenty-four plants cultivated at the planting density of 2,222.2 plants ha⁻¹. Of these, twelve plants were irrigated from October 2010 to October 2012, whereas the other twelve remained unirrigated. Basal temperatures were estimated by four different methods described in the literature, in two phases of observation, maturity and total cycle. From the results, regression analysis was performed. The lower basal temperature was 4.9 and 7.2 °C, and upper basal temperature was 38.8 and 36.8 °C, respectively, for the maturity and total cycle stages. The accumulated thermal sum for the complete plant development of *jatropha* was 10,314.55 DD (± 1574.73) for the non-irrigated treatment, and 9,260.67 DD (± 735.06) for the irrigated treatment. The results of plant development showed good coefficient of determination in relation to the accumulated thermal sum.

Keywords: *Jatropha curcas* L., temperature, degree-days, growth and development

1. Introduction

Jatropha curcas L. is a perennial monoic species belonging to the family Euphorbiaceae, which also includes species of castor bean (*Ricinus* sp.), manioc (*Manihot* sp.) and rubber tree (*Hevea* spp.). Regarding production, its main characteristic is to supply raw material for Biodiesel generation. It is considered a rustic, sunlight-demanding crop with high resistance to drought. *Jatropha* presents great adaptability to diverse edaphoclimatic and low soil fertility conditions (Arruda, Beltrão, De Souza, Jamil Marur, & Severino, 2004; Freitas, Missio, Matos, Resende, & Dias, 2011).

Pena, Evangelista, Casaroli, and Alves Júnior (2016) determined the temperature range suitable for the development of *jatropha*: between 15 and 28 °C. Moreover, the authors observed that there are no regions unfit for crop development in the state of Goiás. The water demand of *jatropha*, for its full development, is 1,200 mm annual water. Tolerant to drought, *jatropha* also tolerates rainfall between 360 and 2,400 mm. However, so as not to affect production, ideal cultivation would be in regions where the deficit does not exceed 720 mm (Yamada & Sentelhas, 2014).

Temperature is one of the main environmental parameters delimiting environmental conditions for the development of a plant species. In plants, metabolic processes are highly dependent on the temperature of the site where they grow. Environmental temperature exerts a great impact on plant photosynthesis and respiration, since it influences several biochemical reactions related to these two physiological processes (Taiz & Zeiger, 1998; Beltrão & De Oliveira, 2008). Extreme air temperatures do not favor the development of certain enzymatic reactions in plants. For this reason, each plant species develops best within a certain air temperature threshold (Bonhomme, 2000).

One simple way to describe plant growth and its development as a function of air temperature is through degree-days (DD) ($^{\circ}\text{C day}$), which is the difference between the average daily temperature and the minimum temperature required by the species, called lower basal temperature (Müller et al., 2009; Pilau, Battisti, Somavilla, & Schwerz et al., 2011). Degree-days are used to include the effects of air temperature on biological processes as a function of time, on different developmental stages, allowing a rough estimate of the time at which a particular phenological stage will occur (Salazar-Gutierrez, Johnson, Chaves-Cordoba, & Hoogenboom, 2013).

Most studies on the subject neglect upper basal temperature in the assessment of degree-days since it shows a high value, rarely reached in the field during crop development (Müller et al., 2009). Notwithstanding, some models use this measure for determining degree-days, highlighting the importance of knowledge of both basal temperatures to optimize monitoring strategies, to improve yield and quality, to support selection and breeding programs, and to choose species that are more adapted to the climatic conditions of the growing site (Müller et al., 2009; Martins, Reis, & Pinheiro, 2012). With temperature values below or above the basal ones, development does not occur.

Several authors have proposed different classes of agroclimatic aptitude for jatropha. Due to the lack of bibliographic records evidencing the estimated value of basal temperatures for the development of jatropha, there is no consensus on the ideal temperature range. Jatropha is a crop valued due to its great importance in the biodiesel production system, which grows largely in the country. In view of this, and since temperature is an intrinsic development factor, this work determined the lower and upper basal temperature of *Jatropha curcas* L. Furthermore, we verified the relationship between thermal sum and plant development under different water regimes, in the climatic conditions of Goiânia, GO, Brazil.

2. Method

2.1 Experimental Site

The study was conducted in an experimental area of the Agronomy School of the Federal University of Goiás (EA-UFG), Goiânia, GO ($16^{\circ}35'44.22''$ S, $49^{\circ}16'44.40''$ W; 722 m). According to the climatic classification of Köppen, the climate of the region is type Aw (tropical wet, with dry winter), with annual average temperature, relative humidity and rainfall of 23°C , 70% and 1,498 mm, respectively (Silva, Heinemann, Paz, & Amorim 2014).

In the mentioned area, 768 *Jatropha curcas* L. plants, spaced 3.0 m apart and 1.5 m between rows, were cultivated. From this total, 24 plants were evaluated, twelve of which were irrigated from October 2010 to October 2012, and twelve unirrigated ones.

2.2 Biometric Measurements

The growth characteristics of the evaluated plants were: i) plant height—measured using graduated ruler; ii) crown area—determined from measuring the plant crown lengths in the direction of the planting row and perpendicular to it; iii) stem diameter—measured at a height of 10 cm from the soil surface; iv) number of branches in the main stem—by direct counting of the branches observed in the plant. Moreover, seed yield was evaluated in two harvests, one in the 2010/2011 crop season and another in the 2011/2012 crop season, both between February and March.

2.3 Weather Reports

The variables minimum air temperature (T_m , $^{\circ}\text{C}$), maximum air temperature (T_M , $^{\circ}\text{C}$), average air temperature (T_a , $^{\circ}\text{C}$), relative air humidity (RH%), rainfall (R, mm) and wind speed (W, m s^{-1}) were obtained at the automatic meteorological station of the Agronomy School of the Federal University of Goiás, located 287 m from the experimental area.

For the determination of lower basal temperature (T_b , $^{\circ}\text{C}$), degree-days were calculated (DD, $^{\circ}\text{C day}$) as described by Arnold (1959) (Equation 1):

$$DD = \frac{T_M + T_m}{2} - T_b \quad (1)$$

First, T_b values were established, which varied from 0°C to 20°C , in 0.5°C intervals. Thus, T_b was determined using different methodologies: i) standard deviation, in degree-days (SD_{DD}); ii) standard deviation, in day (SD_{day}); iii) coefficient of variation, in day (CV_{day}); iv) coefficient of variation, in degree-days (CV_{DD}) (Arnold, 1959; Yang, Logan, & Coffey, 1995).

In the SD_{DD} model, the plant's T_b is considered to be the resultant of the lowest standard deviation, thus T_b will be the one in which the sum of degree-days (DD) generates less dispersion (Equation 2):

$$SD_{DD} = \left[\frac{\sum_{i=1}^N (DD_i - DD_m)^2}{n-1} \right]^{1/2} \quad (2)$$

Where, DD_i is degree-days accumulated in the i th period using a T_b series, DD_m is the mean of the degree-days accumulated for all i th periods, and n is the number of periods.

The SD_{day} model is based on the basal temperatures previously selected in the preceding method, resulting from the lowest standard deviation between the different planting times (Equation 3):

$$SD_{day} = \frac{SD_{DD}}{T_m - T_{ag}} \quad (3)$$

Where, SD_{day} is the standard deviation (day), SD_{DD} is the standard deviation (DD) and T_{ag} is the global average air temperature from all observations ($^{\circ}C$).

CV_{DD} was determined by the relationship between SD_{DD} and the accumulated degree-days of all plantings (DD_m) (Equation 4). CV_{day} , in turn, was obtained according to SD_{day} and the number of days to reach a certain development stage (X_d) (Equation 5):

$$CV_{DD} = \frac{SD_{DD}}{DD_m} \times 100 \quad (4)$$

$$CV_{day} = \frac{SD_{day}}{X_d} \times 100 \quad (5)$$

Upper basal temperature (T_B) was determined following the same methodology applied for T_b . However, the T_B value was found when the standard deviation became constant. For this, temperatures between $20^{\circ}C$ and $40^{\circ}C$ were used, varying in $0.5^{\circ}C$.

After the determination of T_b and T_B , we performed the calculations of degree-days (DD, $^{\circ}C$ day), estimated by the methodology proposed by Ometto (1981), from the following set of equations:

Case 1, $T_B > T_M > T_m > T_b$:

$$DD = \frac{T_M - T_m}{2} + (T_m - T_b) \quad (6)$$

Case 2, $T_B > T_M > T_b > T_m$:

$$DD = \frac{(T_M - T_b)^2}{2(T_M - T_m)} \quad (7)$$

Case 3, $T_B > T_b > T_M > T_m$:

$$DD = \frac{2[(T_M - T_m)(T_m - T_b)] + (T_M - T_m)^2 - (T_M - T_B)^2}{2(T_M - T_m)} \quad (8)$$

Case 4, $T_M > T_B > T_m > T_b$:

$$DD = \frac{1}{2} \frac{(T_M - T_b)^2 - (T_M - T_B)^2}{T_M - T_m} \quad (9)$$

Degree-day values were added in each of the evaluated stages, vegetative growth and maturity, determining the thermal sum necessary to complete each one of them.

2.4 Statistical Analysis

The values of plant growth and development were correlated to the thermal sum by adjusting logistic and sigmoid equations.

3. Results and Discussions

The estimated values of lower basal temperature in the maturity and total cycle were equal to 4.9 and $7.2^{\circ}C$, respectively (Figure 1), regardless of the estimation method.

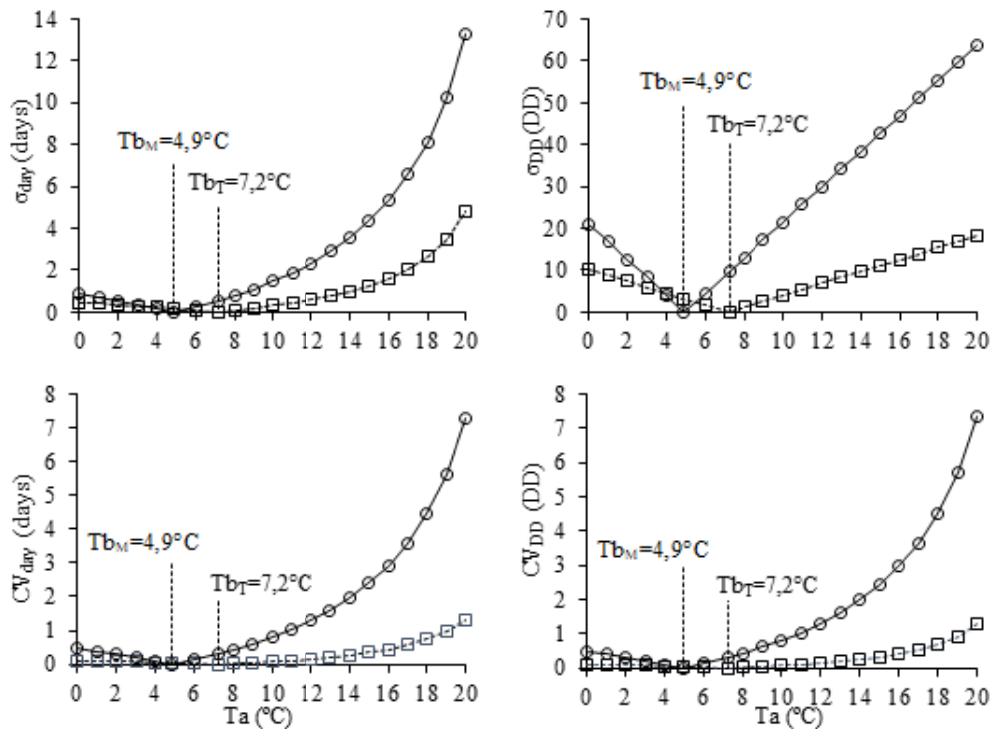


Figure 1. Method of the lowest standard deviation (σ) and coefficient of variation (CV%) for determination of lower basal temperature (T_b , °C) regarding maturity (M, \circ) and total cycle (T, \square)

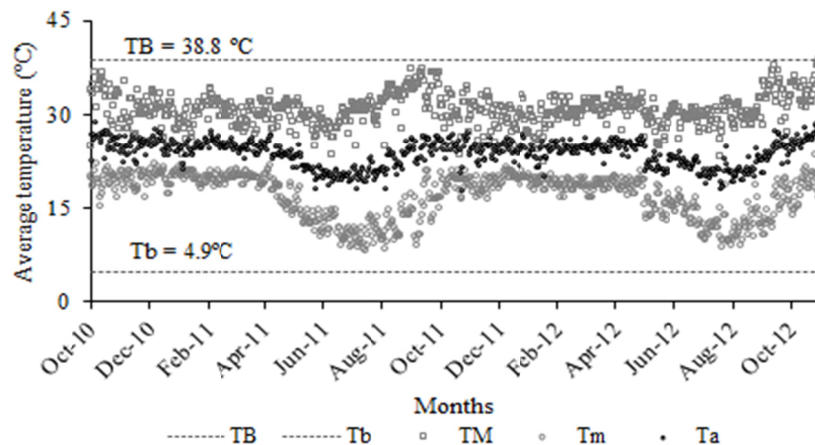


Figure 2. Maximum (TM, °C), minimum (Tm, °C) and average air temperature (Ta, °C); and upper (TB) and lower (Tb) basal temperatures for jatropha

Small differences were detected in the T_b values estimated by the four methods tested, SD_{DD} , SD_{day} , CV_{DD} and CV_{day} (Figure 1). This can be explained by the low variability and high stability of the maximum and minimum temperature data during the studied period, presenting a mean thermal amplitude of 13.85 °C (± 4.4 °C). The mean temperature of the period was 23.78 °C (± 2.1 °C), ranging from 20.12 to 26.43 °C (Figure 2).

Souza, Silva, Leonel, and Escobedo (2009) sought to establish basal temperatures for fig tree using the same methods and found small differences in deviation values. They explain this equality due to low temperature variability, with mean thermal amplitude of 9.79 °C (± 1.3 °C) and average temperature of 19.65 °C (± 2.4 °C) throughout the study, ranging from 15.09 to 24.49 °C.

Agroclimatic zoning for jatropha shows that average temperatures below 15 °C correspond to climatic risk, rendering the crop unsuitable for cultivation (Pena et al., 2016; Yamada and Sentelhas 2014). These authors considered thermal zones suitable for jatropha cultivation, or optimum air temperatures, when values were

between 15 and 28 °C. By concept, the crop presents the highest growth rates with such values. Nonetheless, jatropha plants do not show zero growth when air temperatures below 15 °C occur, initiating only a reduction of these rates, tending to zero. This makes the value of 7.2 °C for T_b (total cycle), found in this study, to be a coherent value.

Jatropha has a wide range of thermal adaptability; however, it has little tolerance to low air temperatures, and its lethal range is between -3 and 4 °C (Andrade, Caramori, De Souza, Jamil Marur, & De Arruda Ribeiro, 2008). Jatropha seeds remain vigorous (90% germination) when submitted to temperatures of 10 °C (Oliveira, Hilst, Da Silva, Sekita, & dos Santos Dias, 2015).

The values found for upper basal temperature (TB) were 36.8 and 38.8 °C, corresponding to maturity and total cycle, respectively, again with little difference in the methodologies used (Figure 3).

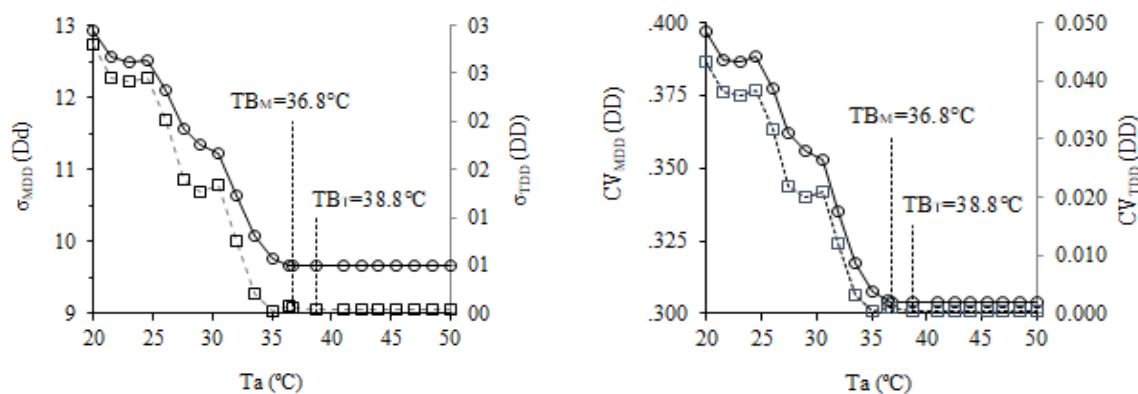
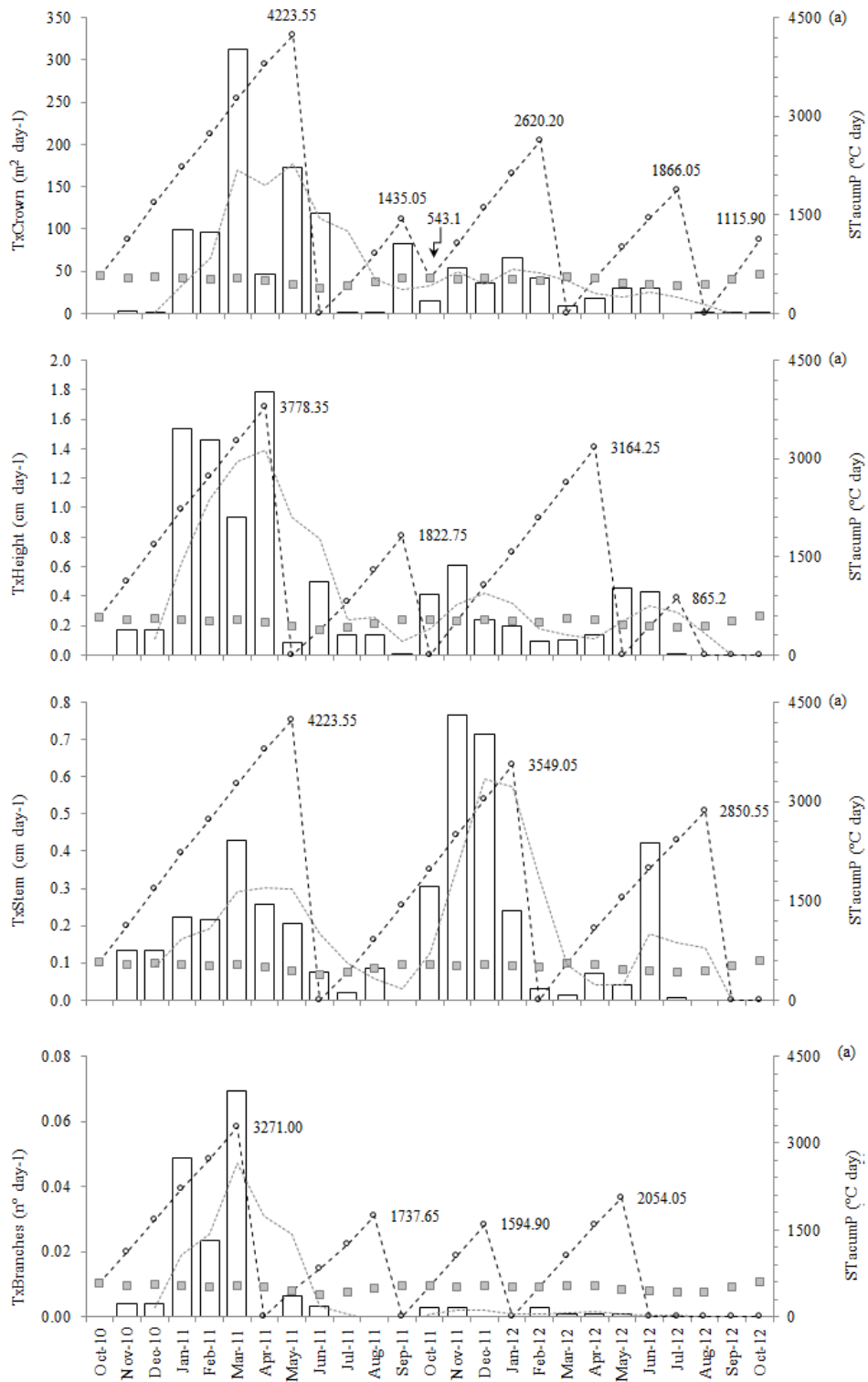


Figure 3. Method of the lowest standard deviation (σ) and coefficient of variation (CV%) for determination of upper basal temperature (TB, °C) regarding maturity (M, \circ) and total cycle (T, \square)

Information on the agrometeorological relations of jatropha is scarce in the literature, especially regarding basal temperatures. Pascuali, Schwanz da Silva, Gonçalves Porto, and Meneghello (2012) verified that the temperature of 40 °C decreases the percentage of normal seedlings by up to 82%. On the other hand, reports indicate that jatropha seeds exposed to the sun and under temperatures between 33 and 43 °C have satisfactory rates of germination and vigor (Zonta, E. Araujo, R. Araujo, & Dias, 2011). High temperature values are evidenced by Yamada and Sentelhas (2014), who found high thermal adaptability for the same crop when performing its agroclimatic zoning. Thus, these studies corroborate the TB values determined in the present study (Figure 3).

The thermal sum accumulated in the maturity stage of jatropha ($T_b = 4.9$ °C; $TB = 38.8$ °C), in the two production cycles evaluated, was 3,271.00 and 2,054.05 DD for non-irrigated system, taking on average 182 days to complete the development stage and conclude fruit ripening, and 2,726.60 and 1,593.35 DD for irrigated system, concluding the cycle with a mean of 151 days. The number of branches was considered as a reference to development (Figure 4).



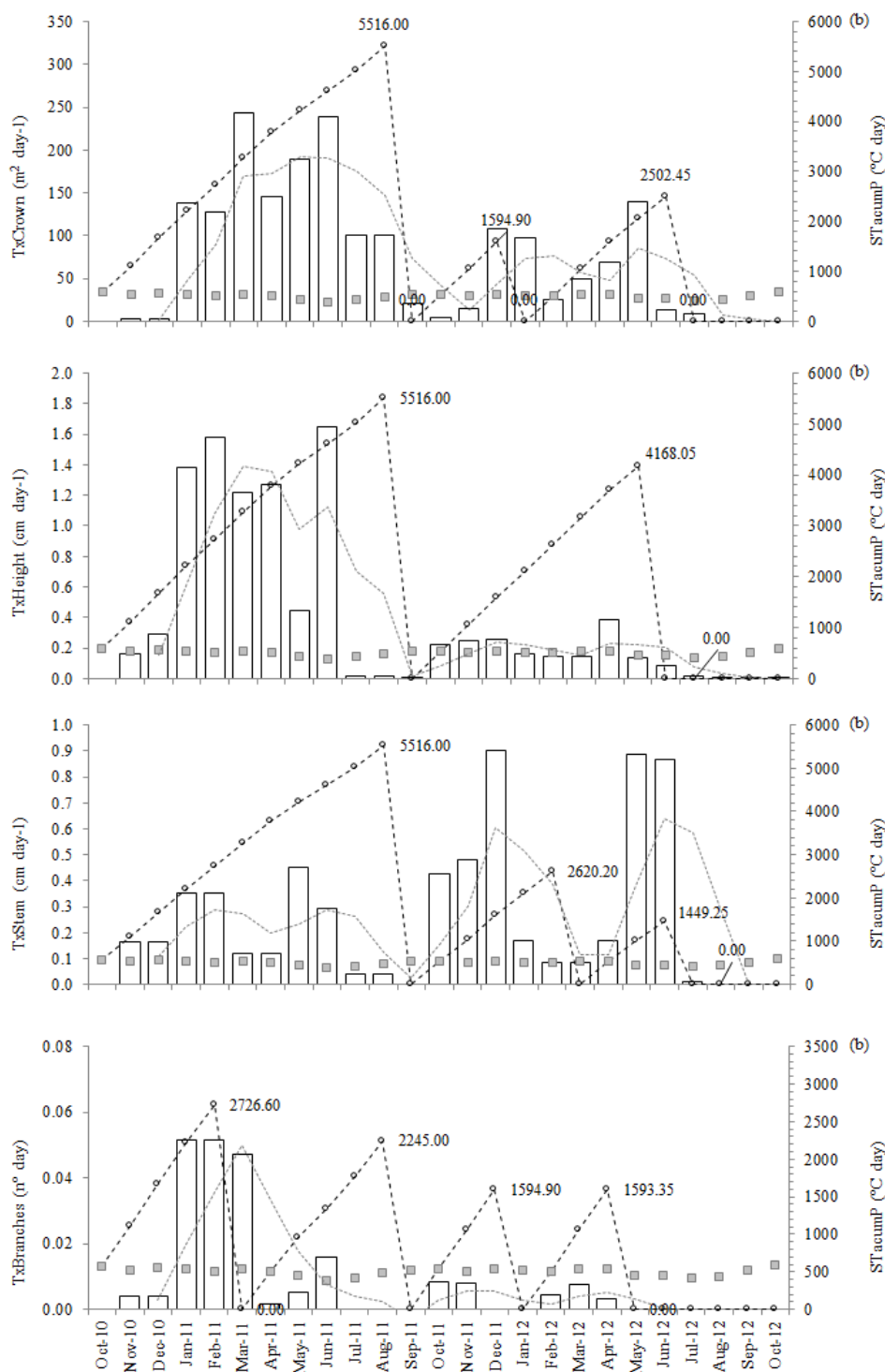


Figure 4. Growth rates: crown area, height, stem and branches (white columns), as a function of time (months-year) and accumulated thermal sum in periods of increasing or constant growth rates (black dashed lines and circles), as well as the monthly thermal sum (gray squares) and the moving average of the growth rates (gray dashed line), for non-irrigated (a) and irrigated (b) treatments

Similar values were found for avocado (*Persea americana* [Miller]), which is a perennial fruit of climatic adaptability similar to jatropha (Lucchesi, Montenegro, Nova, & Florencio, 1977). The authors determined a thermal sum for the fruiting/ripening cycle equal to 2,513 DD for the Pollock cultivar, and 3,278 DD for the hybrid cultivar (*Antilhana* × *Guatemalense*). The average temperature observed during the study period was

22.6 °C, close to that found in the present study ($T_a = 23.7$ °C), which may explain this similarity, along with its $T_b = 10$ °C.

Non-irrigated plants presented different cumulative degree-day cycles among plant growth factors (Figure 4a). Crown area, height, stem diameter and number of branches showed 12,346.95; 9,630.50; 10,623.15 and 8,657.60 total DD, respectively, for full development. In irrigated treatments, the cumulative cycles were similar to those recorded in non-irrigated treatments (Figure 4b). Crown area, height, stem diameter and number of branches showed 9,613.35; 9,684.05; 9,585.45 and 8,159.85 total DD for stabilizing development. The values highlighted in Figure 4 are observed in Figure 5 as the final mark of a growing and regular increase between the points and trend lines, strongly represented in the cumulative cycles.

The plant growth factor number of branches had four well-defined cumulative cycles for both treatments, irrigated or non-irrigated (Figure 4). These four cumulative cycles are related to the jatropha phenology proposed by Oliveira (2015), who observed a strong occurrence of sprouting, fruiting and maturity between October and April, and dormancy and senescence between April and September.

The plant growth characteristics evaluated presented a high correlation with the average accumulation of thermal sum. Correlations were positive with high coefficient of determination (R^2) for both factors evaluated (Table 1).

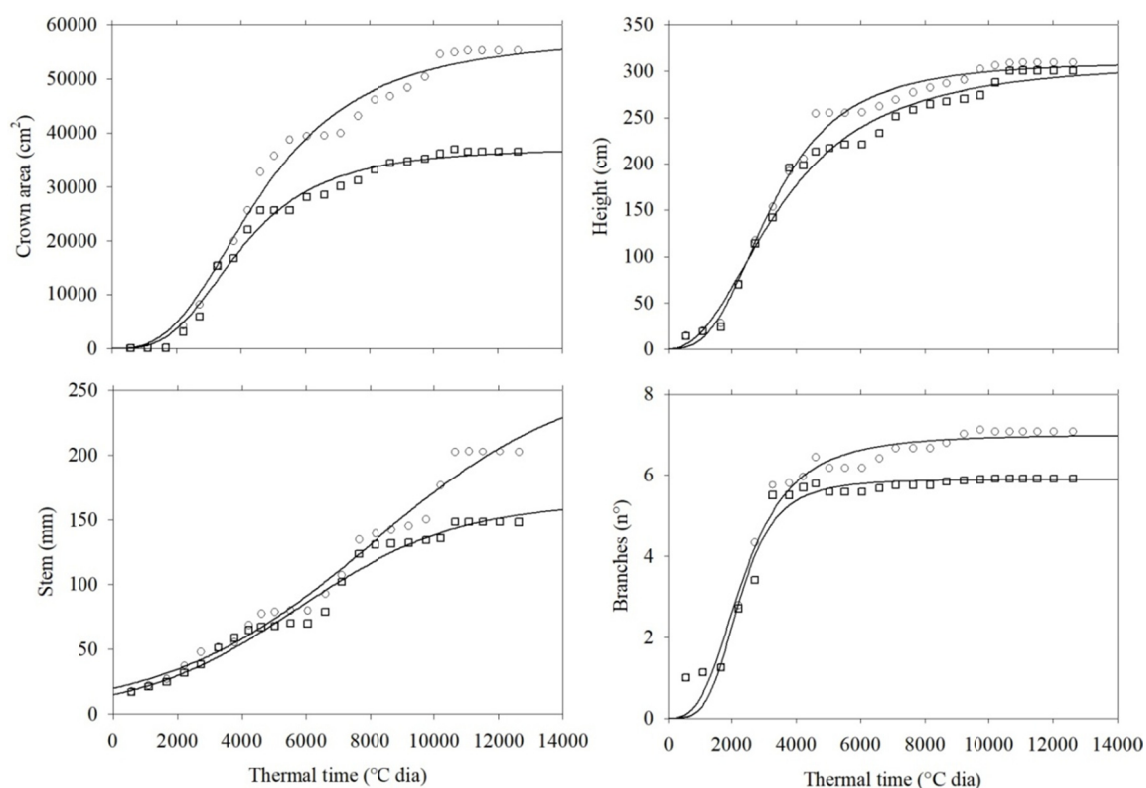


Figure 5. Growth variables of jatropha: crown area, plant height, stem diameter and number of branches for irrigated (○) and non-irrigated (□) system, as a function of accumulated thermal sum (TS, °C day), as well as the adjustment of logistic equations (full black line)

Table 1. Logistic and sigmoid equations, with three parameters, adjusted to the jatropha growth data, described by crown area, plant height, stem diameter and number of branches, for irrigated and non-irrigated system, as a function of the accumulated thermal sum (ST, °C day)

Equations	Parameters	R ²
Irrigated		
If b > 0, $\text{Crown Area} = \frac{a}{1 + \left \frac{x}{x_0}\right ^b}$	a = 57,953.2940 b = -2.8109 x ₀ = 4,665.7600	0.9860
If b < 0, $\text{Crown Area} = a \cdot \frac{\left \frac{x}{x_0}\right ^{ b }}{1 + \left \frac{x}{x_0}\right ^{ b }}$		

If b > 0, $\text{Plant Height} = \frac{a}{1 + \left \frac{x}{x_0}\right ^b}$	a = 310.7040 b = 2.9449 x ₀ = 3,264.4700	0.9906
If b < 0, $\text{Plant Height} = a \cdot \frac{\left \frac{x}{x_0}\right ^{ b }}{1 + \left \frac{x}{x_0}\right ^{ b }}$		

$\text{Stem Diameter} = \frac{a}{1 + \exp\left[-1\left(\frac{x-x_0}{b}\right)\right]}$	a = 265.7473 b = 3,216.0321 x ₀ = 8,092.0300	0.9814

If b > 0, $\text{Number of Branches} = \frac{a}{1 + \left \frac{x}{x_0}\right ^b}$	a = 7.0048 b = -3.0703 x ₀ = 2,378.5900	0.9713
If b < 0, $\text{Number of Branches} = \frac{\left \frac{x}{x_0}\right ^{ b }}{1 + \left \frac{x}{x_0}\right ^{ b }}$		
Non-irrigated		
If b > 0, $\text{Crown Area} = \frac{a}{1 + \left \frac{x}{x_0}\right ^b}$	a = 37,170.4475 b = -3.1564 x ₀ = 4,011.0600	0.9871
If b < 0, $\text{Crown Area} = a \cdot \frac{\left \frac{x}{x_0}\right ^{ b }}{1 + \left \frac{x}{x_0}\right ^{ b }}$		

If b > 0, $\text{Plant Height} = \frac{a}{1 + \left \frac{x}{x_0}\right ^b}$	a = 311.1390 b = -2.2818 x ₀ = 3,545.7100	0.9839
If b < 0, $\text{Plant Height} = a \cdot \frac{\left \frac{x}{x_0}\right ^{ b }}{1 + \left \frac{x}{x_0}\right ^{ b }}$		

$\text{Stem Diameter} = \frac{a}{1 + \exp\left[-1\left(\frac{x-x_0}{b}\right)\right]}$	a = 163.0896 b = 2,489.4524 x ₀ = 5,721.0780	0.9766

If b > 0, $\text{Number of Branches} = \frac{a}{1 + \left \frac{x}{x_0}\right ^b}$	a = 5.8899 b = -4.0498 x ₀ = 2,254.4000	0.9575
If b < 0, $\text{Number of Branches} = \frac{\left \frac{x}{x_0}\right ^{ b }}{1 + \left \frac{x}{x_0}\right ^{ b }}$		

The values of the coefficients “a” (Table 1) of the logistic equations adjusted to the data of the development characteristics of the evaluated plant indicate that there was effect of degree-day accumulation on these characteristics in the different treatments. It was also possible to observe a substantially higher development between irrigated and non-irrigated treatments (Figure 5), as can be seen in the coefficient “a” of the logistic equations. The crown area, stem diameter and number of branches of irrigated plants averaged 33.9%, 26.9% and 16.5% higher than those of non-irrigated plants. This increase can be explained by the water deficit that probably occurred. The climatic water balance (Figure 7) confirms that the treatment with irrigation presented a higher deficit of available water during the drought months in the study region, from April to October.

Regarding the months with water deficit, the deficit in the cumulative cycles of the number of branches affected growth rates (Figure 4). Irrigated treatments showed an accumulation of 2,245.00 DD, against the 1,737.65 DD accumulation of non-irrigated treatments. Other growth rates had a higher cumulative effect during these months, mainly in the 1st cycle, 5,516.00 DD for crown area, height and stem diameter. The response of treatments to the degree-days accumulated from October/2010 to September/2011 highlights the sensitivity of the crop to the degree-days, and the effect on its accumulation when exposed to extreme water deficit situations.

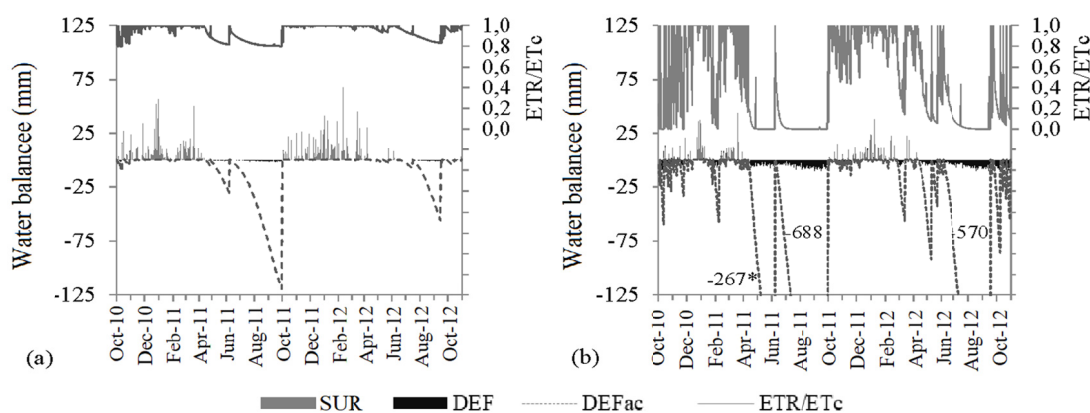


Figure 6. Daily sequential water balance for jatropa crop: daily water surplus (SUR, mm), daily water deficit (DEF, mm), accumulated deficit (DEFac, mm) and relative evapotranspiration (ETR/ETc); for the two years of cultivation in irrigated (a) and non-irrigated (b) system. *Maximum values of DEFac in the periods: 04/12/11 to 06/07/11; 06/09/11 to 09/30/11; 06/06/12 to 09/17/12

4. Conclusion

Lower basal temperatures for jatropa in the maturity and total cycle stages were 4.9 °C and 7.2 °C, respectively. Upper basal temperatures were 36.8 °C and 38.8 °C, respectively, for the maturity and total cycle stages.

About 10,314.55 DD (± 1574.73) must be available for the complete development of rainfed jatropa, and about 9260.67 DD (± 735.06) for jatropa cultivated in irrigated system.

For fruit development, the irrigated system requires between 3271.00 and 2054.05 °C, and the non-irrigated system requires between 2245.00 and 1539.35 °C.

Plant growth rates were satisfactorily adjusted to the accumulated degree-days, with determination coefficients higher than 95%. Therefore, these rates are highly sensitive to degree-day accumulation.

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