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# Agrometeorological relations in banana cultivation under different levels of water stress

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**ABSTRACT:** Agrometeorological variables for the prediction of phenological phenomena and verification of thermal and photoperiodic needs were used in the planning of cultural data from several crops, including a banana tree. The objective of this study was to characterize the phenological phenomena and the exploitation of banana cultivars in function of the thermal sum and photothermal units under irrigated and non-irrigated system. The experiment was conducted at the School of Agronomy of the Federal University of Goiás, Goiânia-GO. The banana plants were planted on 10/30/2013 and evaluated until 12/15/2017, totaling four production cycles, in a spacing of 3.5 x 2.0 m, and stand of 1428 plants $ha^{-1}$. A randomized block design was used, with four replicates in a 2x4 factorial scheme (2 water regimes; 4 cultivars). The agrometeorological requirements were determined from the sum of degrees-day (DD) and the accumulation of photothermal units (PU). For the sum of DD and PU, cultivars developed differently, showing influence on the production cycle. It was possible to establish that BRS Conquista has the longest cycle with higher DD and PU, followed by SH3640 Graúda and BRS Japira with medium cycles, and BRS Platina with a short cycle and lower DD and PU.

**Key words:** degrees-day; hydric balance; *Musa* sp.; phenology; photothermal units

# Relações agrometeorológicas no cultivo da bananeira sob diferentes regimes hídricos

**RESUMO:** Variáveis agrometeorológicas para a previsão dos estádios fenológicos e verificação das necessidades térmicas e fotoperiódicas têm sido utilizadas no planejamento dos tratos culturais de diversas culturas, dentre essas, a bananeira. O objetivo desse trabalho foi caracterizar os estádios fenológicos e a produtividade de cultivares de bananeira em função da soma térmica e de unidades fototérmicas, sob sistema irrigado e não irrigado. O experimento foi conduzido na Escola de Agronomia da Universidade Federal de Goiás, Goiânia, GO. O bananal foi plantado em 30/10/2013 e as avaliações realizadas até 15/12/2017, totalizando quatro ciclos de produção, em espaçamento de 3,5 x 2,0 m, e estande de 1.428 plantas $ha^{-1}$. Utilizou-se delineamento de blocos casualizados, com quatro repetições, em esquema fatorial 2x4 (2 regimes hídricos; 4 cultivares). As exigências agrometeorológicas foram determinadas a partir do somatório de graus-dia (GD) e do acúmulo de unidades fototérmicas (UF). Para a somatória de GD e UF, as cultivares se desenvolveram diferentes, apresentando influência no ciclo de produção. Foi possível definir que a BRS Conquista apresenta ciclo mais longo com GD e UF maiores, SH3640 Graúda e BRS Japira com ciclos medianos e a BRS Platina com ciclo curto e também GD e UF menores.

**Palavras-chave:** graus-dia; balanço hídrico; *Musa* sp.; fenologia; unidades fototérmicas

## Introduction

Banana (*Musa* sp.) is one of the most cultivated fruit trees in tropical countries, which explains the large production of places such as China, India and Brazil, with them respectively occupying the first, second and third position in the world production (Kist et al., 2018). Brazilian banana plantations occupies an area of approximately 500,000 hectares, having a mean yield of 14,533 kg ha$^{-1}$ (IBGE, 2017) and with emphasis, regarding both production and cultivated area, on the States of São Paulo (1,089,820 t; 51,512 ha) and Bahia (1,084,548 t; 72,699 ha) (IBGE, 2016).

The state of Goiás stands out among the Midwest region producers, showing a significant expansion of the banana growing in recent years (Moraes, 2011), having about 15 thousand hectares, production of 199,000 t, mean yield of 14,740 kg ha$^{-1}$ (IBGE 2017), and also no records of Black Sigatoka occurrence, the crop main disease (Santos & Carneiro, 2012).

Generally speaking, the air temperature, solar radiation, photoperiod, wind speed and precipitation of the region are the limiting agrometeorological elements for cultivation (Fonseca et al., 2004; Coelho et al., 2009). From these variables, it is possible to verify the thermal and photoperiodic needs of the crop at each phenological stage. For this, the thermal sum method has been used, which is related to the sum of °C day that the plant needs in order to complete part or all of its cycle, thus characterizing the different phenological phases and the production margin (Souza et al., 2009).

For estimating the maturation time of a fruit by using the sum of °C days, the basal, lower (Tb) and higher (TB) temperatures must be known. Hence, it requires: basal temperatures lower than 14.6 °C, higher than 36 °C, and optimal temperature range between 28-30 °C; wind speed lower than 8,33 m s$^{-1}$; and rainfall between 1,200 and 1,800 mm year$^{-1}$ (Moreira, 1987; Fonseca et al., 2004; Figueiredo et al., 2006; Medeiros et al., 2013). Another method that has also been used to determine the maturation stage is named photothermal unit (PU), which in addition to the mean air temperature, incorporates the photoperiod (Villa Nova et al., 1999; Villa Nova et al., 2007).

Temperatures below 15 ºC cause a physiological disturbance known as "chilling"; causing damage mainly to the fruit peels (Borges & Souza, 2004). Temperatures above 35 °C, on the other hand, promote growth arrest due to dehydration of the leaves (Coelho et al., 2009).

The monthly water needs of the banana is around 100 to 150 mm (Coelho et al., 2013). In short, a banana plant can consume about 40 l of water per day (Costa et al., 2012; Oliveira et al., 2013; Silva et al., 2017). When cultivated under an irrigation system, the mean yield varies from around 25 to 30 t ha$^{-1}$ (Bezerra et al., 2017).

Therefore, the choice of varieties more adapted to the agrometeorological variations, more responsive to water (when cultivated with irrigation) and more tolerant to its deficit (when non-irrigated), allows a greater degree of success in the banana cultivation.

In this sense, this study aimed to characterize the phenological development and yield of banana cultivars as a function of the thermal sum and photothermal units under irrigated and non-irrigated systems, in the climatic conditions of central Goiás State.

## Materials and Methods

The experiment was conducted at the School of Agronomy, Federal University of Goiás, Goiânia, Goiás (16°35'12.98''S e 49º21'14.97''W; 730 m). The climate of the region is Aw (hot and humid tropical) with dry winter (Köppen & Geiger, 1928). Agrometeorological data were obtained from an automatic station located approximately 200 m away from the experimental area.

The soil of the experiment area was classified as dystrophic red oxisol ("Latossolo", according to the classification by Embrapa, 2013). The tillage for planting included a plowing, followed by heavy harrowing (conventional system). From the chemical analysis of the soil, the pH was corrected by applying 2,435 kg ha$^{-1}$ of limestone (base saturation: 70%) and the fertilization was performed according to the recommendations of Raij (1999). Manual weeding was employed to control weeds and the cultural treatments (thinning, defoliation, shoring, elimination of male inflorescence, and pseudostem cutting after harvest) were performed according to Borges & Matos (2006) recommendations.

Seedlings were manually planted on October 30, 2013. The experimental plots consisted of five plants, with row and plants spacing of 3.5 x 2.0 m, respectively, establishing a stand composed by 1,428 plants ha$^{-1}$.

Micro-sprinkling (50 L h$^{-1}$emitter$^{-1}$) was employed as the irrigation system, with a line of micro-sprinklers (4 m of wet diameter, and 2 m spaced emissions at the irrigation line) for every two rows of the plantation. This system was turned on three times per week, for two hours, supplementing rainfall and aiming to meet the water needs of bananas, as established in FAO-56 bulletin (Allen et al., 2006).

A randomized block design with four replicates in a 2x4 factorial scheme (2 water regimes: irrigated and non-irrigated; 4 cultivars: BRS Japira, SH3640 Graúda, BRS Platina and BRS Conquista) was employed. All cultivars had vegetable health certification and were propagated by the vegetative micropropagation method. Displayed on Table 1 are the cultivars descriptions regarding their genome, origin and resistances.

Soil water storage (mm) and actual evapotranspiration (AET, mm day$^{-1}$) were monitored based on the daily sequential water balance (WBds), according to the methodology described by Thornthwaite & Mather (1955) for the four productive cycles. The WBds calculation procedure considered a variable available water capacity (AWC, mm) as a function of the root growth, given through the daily rates, determined as a function of the maximum effective depth reached by the banana root system, equal to $Zr_{max}$ = 0.60 m (Sant'ana, 2012), reached at 365 days after planting (Bassoi et al., 2004). These data were applied in the following equation:

**Table 1.** Description of banana cultivars set up in the experimental banana plantations of the Federal University of Goiás. Goiânia-GO.

| Cultivars | Genome | Place of origin | Crossings | Resistances |
|---|---|---|---|---|
| BRS Japira | AAAB | Cruz das Almas, Bahia | Crossing of Pacovan with the M53 diploid | Resistances to MP, YS and BS |
| SH3640 Graúda | AAAB | La Lima, Honduras | Crossing of Prata-Anã with the SH 3393 hybrid diploid | Resistances to MP, and susceptible to YS e BS |
| BRS Platina | AAAB | Cruz das Almas, Bahia | Crossing of Prata-Anã with the M53 diploid | Resistance to MP and YS |
| BRS Conquista | AAB | Manaus, Amazonas | Obtained naturally by the Thap Maeo cultivar mutation | Resistance to MP, YS and BS |

YS: Yellow Sigatoka; BS: Black Sigatoka; MP: Mal-do-Panamá (*F. oxysporum*).

$$AWC = 1000 \times (\theta fc - \theta pwp) \times Zr \quad (1)$$

with $\theta fc$ being the volumetric humidity at field capacity ($m^3$ $m^{-3}$) and $\theta_{PWP}$ the volumetric humidity at permanent wilting point ($m^3$ $m^{-3}$). Moreover, a mathematical adjustment was performed in the WBds spreadsheet to adjust the proportionality of the AWC (mm) calculated on "i" day as a function of the "i-1" AWC from the previous day.

The crop coefficient (Kc) (dimensionless) varied its values as a function of crop development, divided into three cultivation phases: vegetative growth (Kc: 0.38 to 0.53); flowering (Kc: 0.74 to 0.85) and fruit growth (Kc: 0.98 to 1.13), according to Coelho et al. (2003) and Conceição et al. (2017).

Phenological stages of banana plants were identified by visual evaluations, following the described phenology by Conceição et al. (2017) for the four cycles. Thus detecting the dates between planting, inflorescence emission and harvest.

The thermal rhythm for banana growth and development was determined as a function of the thermal sum, given by obtaining the degrees-day (DD) (Ometto, 1981) (Eqs. 2-5). Lower and upper basal temperatures of Tb = 14.6 °C and TB = 36 °C, respectively, were used (Moreira, 1987; Figueiredo et al., 2006). Hence, the degrees-day (DD, °C day) were determined from the following criteria:

Case 1: TB > TM > Tm > Tb

$$DD = \frac{TM - tm}{2} + Tm - Tb \quad (2)$$

Case 2: TB > TM > Tm > Tb

$$DD = \frac{(TM - tb)^2}{2(TM - tm)} \quad (3)$$

Case 3: TB > Tb > TM > Tm

$$DD = 0 \quad (4)$$

Case 4: TM > TB > Tm > Tb

$$DD = \frac{2(TM_{tm})(tm - tb) + (TM - tm)^2 - (TM - TB)}{2(TM - Tm)} \quad (5)$$

with Tm as the minimum daily air temperature (°C), TM as the maximum daily air temperature (°C), Tb as the lower basal temperature (°C) and TB as the upper basal temperature (°C).

Photothermal units (PU) were obtained from the equation proposed by Villa Nova et al. (1999) (Eq. 6):

$$PU = \frac{\left(\frac{n}{2} DD\right)^{\frac{Nf}{Ni}+1}}{\frac{Nf}{Ni}+1} \quad (6)$$

in which *n* is the number of days in the period; Nf is the astronomical duration of the day at the end of the growing period; Ni is the astronomical duration of the day at the beginning of the growing period; DD is the degrees-day accumulated in the period (°C day).

Banana bunches were harvested at stage 2 of peel color (ripe-green), with the fruit displaying corners and wider sides. After harvesting, they were transported to the Horticulture Laboratory of the School of Agronomy. After that, their weight was obtained in the platform scale, with result expressed in kg. In each year of the study, the variable of bunch weight production was correlated with the thermal sum.

In order to identify differences between cultivars and irrigation use, the variables thermal sum and photothermal units were subjected to the analysis of variance (ANOVA), with means comparison tests between the treatments and graphical presentation with means standard deviation. For verifying the relations between the production and the thermal sum, Pearson linear correlation analysis was employed at the 5% probability level.

## Results and Discussion

The mean air temperature ranged from 17.2 to 29.9 °C. The lowest recorded minimum temperature was of 6.6 °C and the highest maximum temperature was of 39.8 °C. The highest thermal amplitude occurred in late winter and early spring (26.0 °C), and the lowest one in summer (2.8 °C) (Figure 1). The yield of banana plants is influenced by climatic conditions, especially in the first production cycle, but in subsequent cycles, in addition to the aforementioned, the cultivars genetic characteristics are also determinant (Lessa et al. 2012). These authors, when studying 13 different banana genotypes (Preciosa, Japira, Pacovan-Ken, Pacovan, BRS Platina, Prata-Anã, ST12-31, Nanicão, Grande Naine, Calipso, Ambrosia, Bucaneiro and FHIA-02), found that there is genetic variability among these genotypes, which influences different yields between cycles.

Photoperiod for the cultivation period ranged from 11 h, in the second half of June, to 13 h, for the second half of December (Figure 1b). Although the banana plant is not responsive to floral induction, photoperiods lower than 12 h can compromise the bunch formation, and even influence the flowering time (Turneri et al., 2007).

Daily sequential water balance extract of the banana plant indicated different water deficits from one cycle to another. These values correspond to 70, 126, 30 and 70 mm (first, second, third and fourth cycle, respectively) in the irrigated area (Figure 2a) and 693, 754, 620 and 603 mm (first, second, third and fourth cycle, respectively) for the non-irrigated area (Figure 2b). Therefore, the results showed that irrigation led to a 92% reduction in water deficit.

The mean precipitation of the experimental region does not fully meet the crop water need, which is between 1,200 and 1,800 mm.year$^{-1}$ and monthly water need of around 100 to 150 mm.month$^{-1}$ (Alves, 1991; Fonseca et al., 2004), varying the amount in accordance with its phenological phase, with the largest demand in the fruit growth phase (Coelho et al., 2012). Thus, the irrigation use in the region is important, as evidenced in a study by Braga-Filho et al. (2011), in which the use of 80% and 120% sprinkled water, expressed as a percentage of potential crop evapotranspiration (ETpc), showed the highest yields in different cultivars (Grande Naine, FHIA 18, Prata-Anã and Thap Maeo) in the Cerrado region, with an increase of up to 60% in final production.

The F test indicated significance for the thermal sum of the vegetative sub-period ($TS_V$) in relation to the cultivation cycles and for the cultivar vs. interaction cycles. Thermal sums of the reproductive sub-period ($TS_R$) and total thermal sum ($TS_T$) were significant for the relation of cultivars and cycles, and for the cultivar vs. interactions cycles. Even so, the $TS_T$ showed significance for the cultivar vs. management vs. cycles triple interaction.

Thermal sum for both vegetative ($TS_V$) and reproductive ($TS_R$) sub-periods were higher in the second and third cycles (Figure 3a, b), in which SH3640-Grauda cultivar attained the highest $TS_V$ (2,944 DD) and $TS_R$ (1,596 DD) in the second cycle, and the cultivars BRS Japira, BRS Platina and BRS Conquista had higher $TS_V$ (2,808, 2,805, 2,893 DD, respectively) and $TS_R$ (1,386, 1,319 and 1,450 DD, respectively) at the third cycle (Figure 3). Regarding the reproductive sub-period ($TS_R$) values, they were higher due to the 24.7 ºC mean temperature higher in the second and third cycles. While for the first and

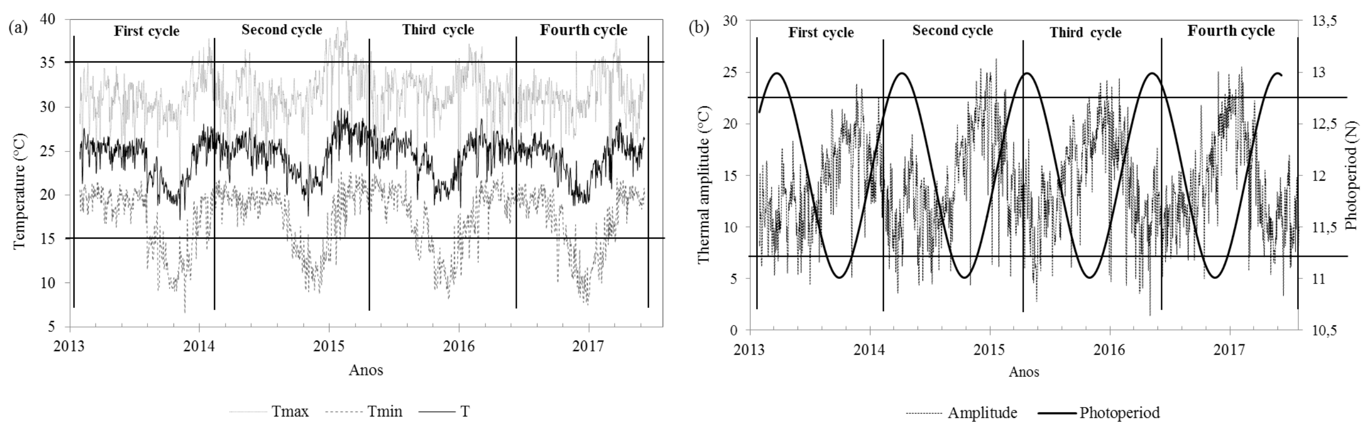


**Figure 1.** Maximum temperatures (Tmax), minimum (Tmin), daily (a) means (T), as well as the thermal amplitude and photoperiod (b) observed in the experimental area, corresponding to the period from October/2013 to December/2017. Goiânia-GO.

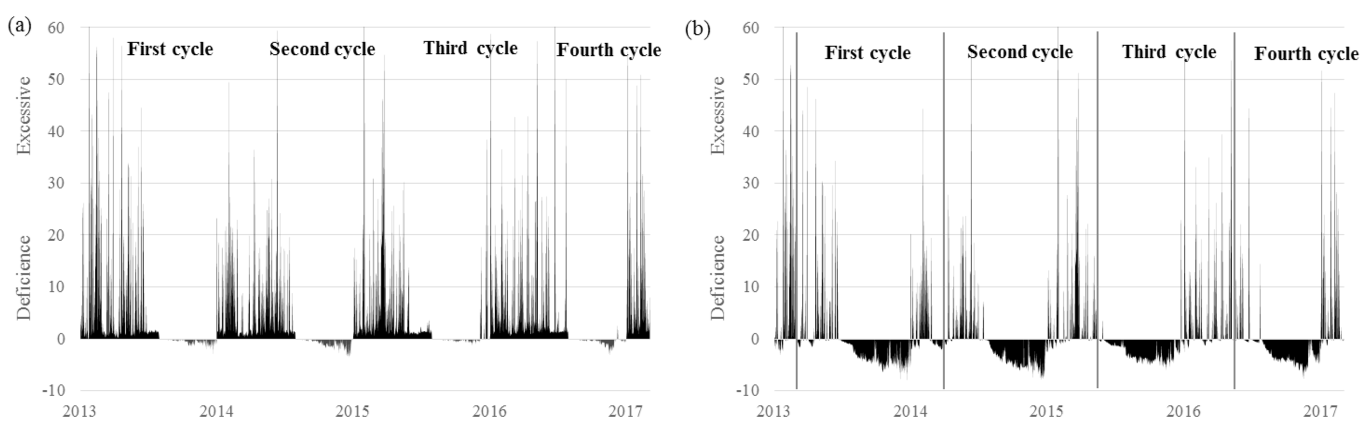


**Figure 2.** Slides of the water surplus (positive) and water deficit (negative) from daily sequential water balance for banana crop grown in irrigated (a) and non-irrigated (b) areas during four cultivation cycles in the period from October/2013 to December/2017. Goiânia-GO.

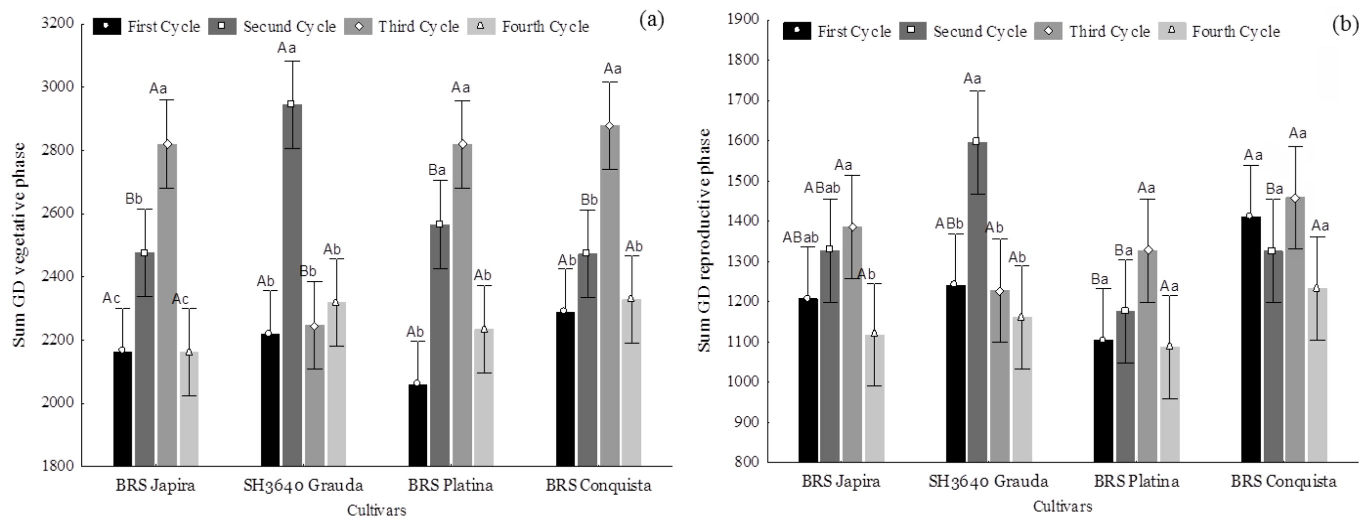


**Figure 3.** Sum of degrees-day (DD) in the vegetative (a) and reproductive (b) sub-period, in four cultivation cycles, for the four banana cultivars (BRS Japira, SH3640 Grauda, BRS Platina, BRS Conquista). Means followed by the same letter uppercase (Cycles) and lowercase (Cultivars) do not differ by Tukey test at 5% probability.

fourth cycles of $TS_R$, the mean temperatures were 23.9 °C, representing a reduction of 3%. The lower DD values found for the first cycle occurred due to the used seedlings hailing from micropropagation, which according to Salomão et al. (2016), influences the earliness and vigor in the first production cycle, explaining the vegetative period reduction of up to 54 days when compared to conventional propagation, this reduction is no longer seen in later cycles. The first cycle had the lowest accumulation of degree-days ($TS_V$, $TS_R$ and $TS_T$) for all cultivars, accounting for a number of days equal to 364.

There are few data available in Brazil regarding the thermal requirements of banana cultivars. The higher thermal sum required to complete the vegetative phase of SH3640 Graúda cultivar can be explained by it being an introduced cultivar from Honduras, located in the high temperatures area of Central America, consequently increasing its cycle when it is implanted in Brazil, a country of milder temperatures (Cerqueira et al., 2002).

In a study by Negreiros et al. (2014), Grande Naine cultivar showed a seasonal variation from 673 to 1001 DD in the reproductive sub-period. When compared to the cultivars of the present study, Grande Naine demonstrated a lower need for thermal sum in the reproductive sub-period. Coelho et al. (2006) can explain this, as the 'Grande Naine' banana plants are considered earlier than those of the Prata-Anã subgroup, showing a mean cycle reduction of up to 45 days in irrigated areas.

On average, cycles 2 ($TS_T$ = 3981 DD) and 3 ($TS_T$ = 4040 DD) were longer than cycles 1 ($TS_T$ = 3414 DD) and 4 ($TS_T$ = 3359 DD) (Figure 4). In the second cycle, the SH3640 Graúda cultivar had the highest mean, both in the irrigated and non-irrigated systems; however, in the third cycle this cultivar had the lowest means in both water regimes (Figure 4), where the other cultivars set the higher means values, not differing from each other, neither by the irrigated or non-irrigated system (Figure 4). In cycles 1 and 4, the BRS Conquista cultivar stood

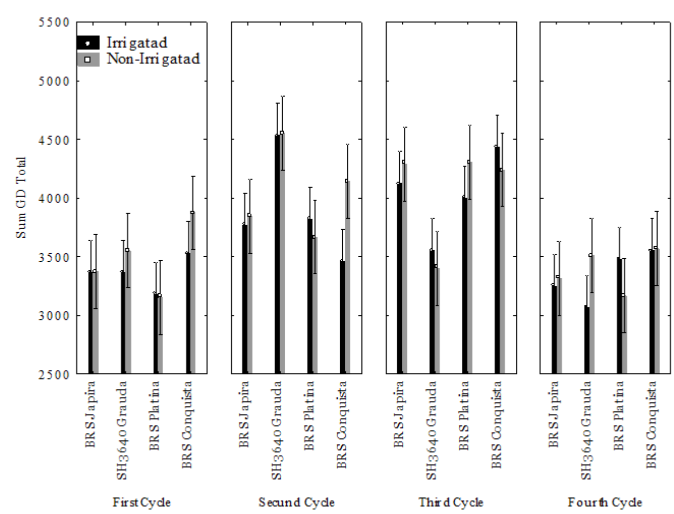


**Figure 4.** Mean values for the sum total of degrees-day (DD) in the total cycle in four cultivars, four cycles, two managements and their interactions and (A, B, C and D, respectively). Mean followed by the same letter uppercase (Cycles) and lowercase (Cultivars) do not differ by Tukey test at 5% probability.

out; nonetheless, this one presented statistical difference only in the first cycle (irrigated) when compared to the BRS Planaltina cultivar (Figure 4).

These results indicate that the cultivars show differences among themselves but respond in similar ways to the adopted management and the sum of degrees days for each cycle. They also show that the BRS Conquista cultivar has a cycle requiring greater accumulation of degrees-day, while cultivars SH3640 Graúda and BRS Japira have a medium cycle and the BRS Platina has an early cycle.

In a study by Santos et al. (2006) in Southwestern Goiás, it was observed a mean duration of the first three cycles of 393 days, from planting to harvest, for the earliest cultivars (FHIA 18 and Caipira). When compared with the cultivars from this study, it is clear that only BRS Conquista is similar, having an average of four cycles of 394 days. The other cultivars (BRS

Japira, SH3640 Graúda and BRS Platina) showed lower values (387, 389, 371 days, respectively). According to these authors, the crop cycle is important for the genetic improvement of banana because it represents the earliness, showing expectations of return of the initial investment.

Through the dispersion diagram graph, it was possible to determine the function between the dependent and independent variables, verifying the positive linear relationship of the variables. Regression analysis showed a thermal sum adjustment as a function of different cultivars and days after planting (DAP), with low dispersion $R^2 > 0.95$ (Figure 5). The linear equations showed similar angular coefficients (≈ 9.0), presenting similar growth rates between cultivars, whereas the intercept, or linear coefficients, were different for cultivars and managements.

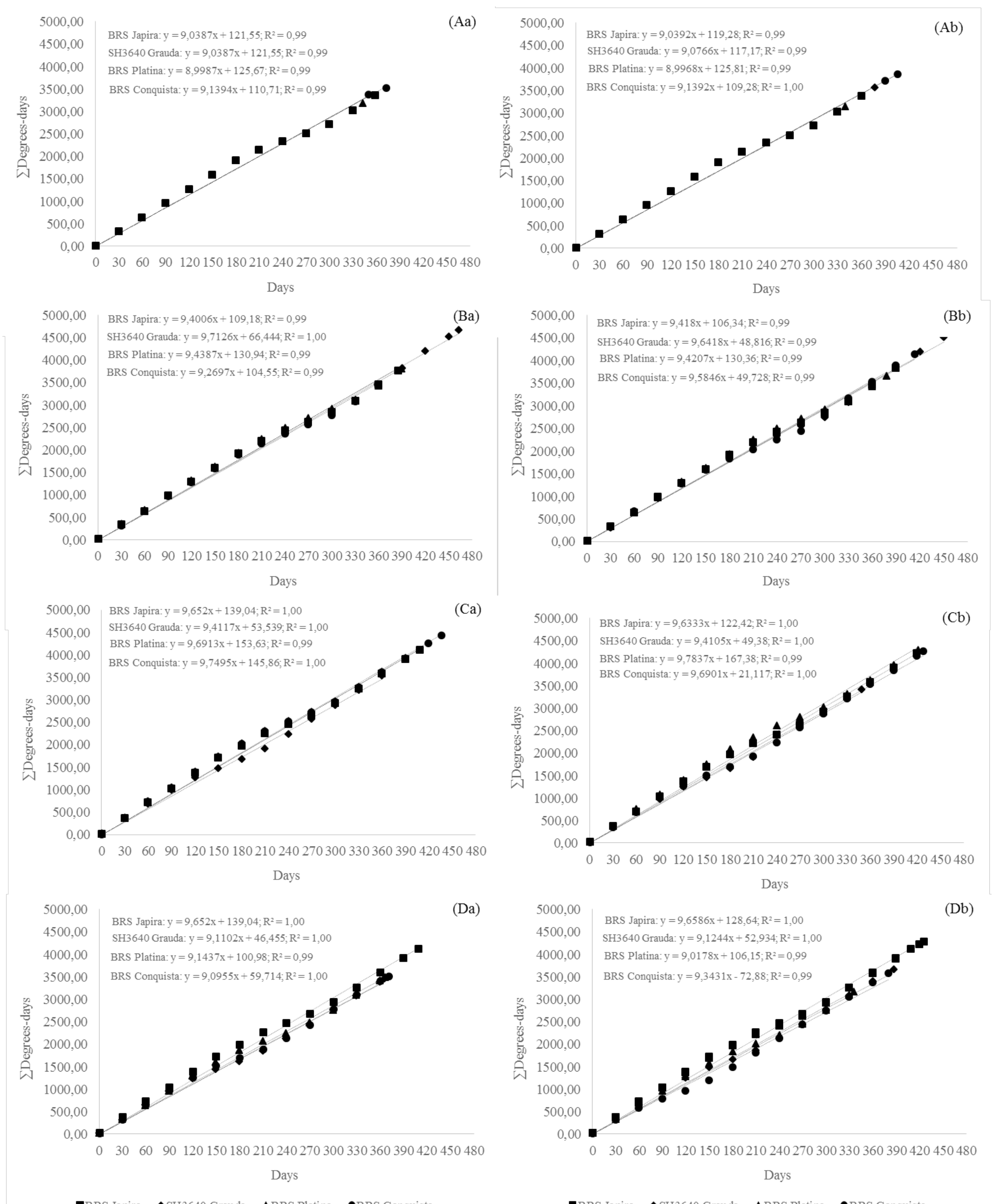


**Figure 5**. Mean values for the relation between ∑Degrees-Day and Cycle duration (Days) of four banana cultivars (BRS Japira, SH3640 Graúda, BRS Platina and BRS Conquista) during four production cycles (A, B, C and D, respectively) in an irrigated and non-irrigated system (a and b, respectively) at the Federal University of Goiás. Goiânia-GO.

Thus, it is possible to see a longer time to reach the maximum thermal sum in the second and third cycles after planting.

Linear regressions ($R^2 > 0.95$) also explained the pattern of bunch weight accumulation as a function of thermal sum (Figure 6), highlighting the cultivars SH3640 (first and third cycles), BRS Conquista (second and fourth cycles) as those that require the lowest thermal sum to reach the highest bunch weight (Figure 6). The exponential model showed a good fit, with low dispersion degree ($R^2 > 0.95$). It is possible to verify that at, the end of the period, the bunch weight displayed high amplitude among the cultivars (≈14 kg), having a general mean of (≈19 kg) (Figure 6).

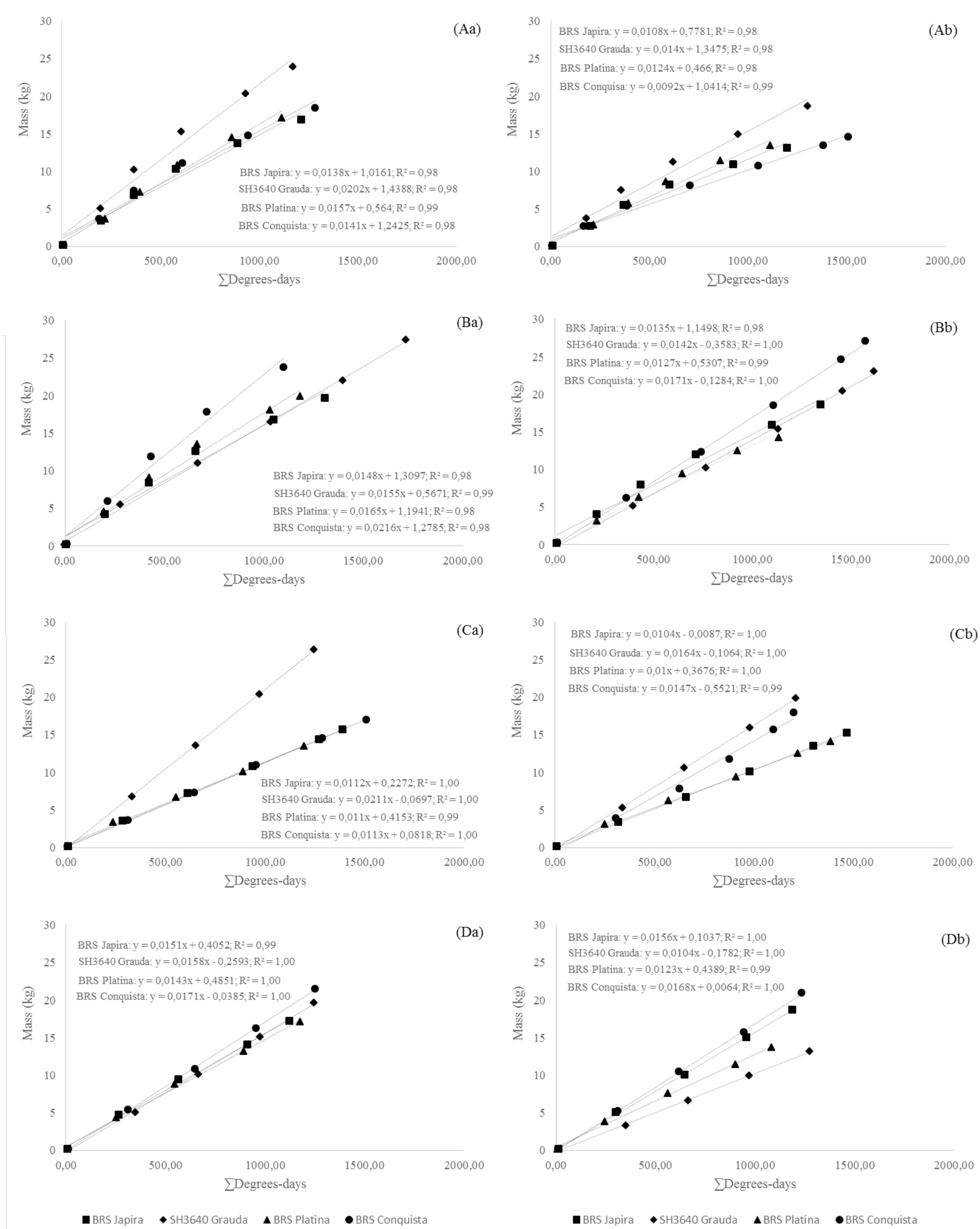


**Figure 6**. Mean values for the relation between yield and ∑Degrees-Day of four banana cultivars (BRS Japira, SH3640 Graúda, BRS Platina and BRS Conquista) during four production cycles (A, B, C and D, respectively) in irrigated and non-irrigated system (a and b, respectively) at the Federal University of Goiás. Goiânia-GO.

In the first cultivation cycle, the SH3640 Graúda cultivar stood out, which reached the highest bunch weight in both irrigated (≈24 kg) and non-irrigated (≈19 kg) areas, with approximately 1200 and 1300 DD, respectively (Figure 4a, b). In general, when irrigated, the banana crop displays taller plants with larger leaf area, accelerating its cycle and, consequently, increasing the productivity compared to non-irrigated plants (Coelho et al., 2012). In general, the amount of water needed and the increase in productivity varies depending on the cultivar physical characteristics and the weather conditions of the environment (Tuneri et al., 2007).

When comparing the general mean, the cultivars SH3640 Graúda and BRS Conquista stood out (22 and 20 kg, respectively), also having the highest amount of accumulated degrees-day at the end of the period (3,177 and 3,834 DD, respectively). The final weight of the fruit is influenced by the increase of the cell division rate, in a way that the increase of the air temperature during this phase, until the tolerable limits for the crop, increases this process (Jullien et al., 2001).

The degrees-day method contributes to determine the thermal sum required to complete the different phenological stages of different crops. These thermal sum values may vary between plant species. Cunha et al. (2016), when studying four fruit species from the Myrtaceae family (*Campomanesia aromatica* (Aubl) Griseb. (Guabiraba), *Eugenia punicifolia* (Kunth) DC. (Myrtle), *Eugenia tinctoria* Gagnep. (Mapirunga) and *Myrcia splendens* (Sw.) DC. (punchberry) observed that the thermal requirements were different between species, but increasing during the cycle. This variation also occurs between cultivars of the same species.

The F test result for photothermal units (PU) showed significant effect ($p < 0.05$) for cultivars, management, cycles and the interaction of factors during the vegetative sub-period ($PU_V$). For the reproductive ($PU_R$) and total ($PU_T$) sub-periods, a significant effect was observed only for the cycles and for the cultivar vs. interaction cycles.

The $UF_V$ in the first cycle were similar in relation to the cultivars, requiring smaller values (271342 $PU_V$) to complete the vegetative phase when compared to the other cycles (Figure 8), in which the cultivars SH3640 Graúda (second cycle = 728590 $PU_V$) and BRS Conquista (third cycle = 816374 $PU_V$) stood out, with BRS Platina (fourth cycle = 300987 $PU_V$) lower than the others. For banana cultivation, the formation of bunches with photoperiod above 12 h is favorable, since otherwise it may influence the reduction of bunch formation beginning, something that occurred in this current study during the winter period. Thus, even in environments with moderate temperatures (from 13 to 34 ºC) the photoperiod can influence variations in crop flowering (Turneri et al., 2007).

When comparing the management systems, it was found that the irrigated system showed lower accumulated $PU_V$ than the non-irrigated system, except for the BRS Conquista cultivar in which the non-irrigated system increased the accumulation of $PU_V$ by 51%. No differences were detected between irrigated and non-irrigated treatments for cultivars BRS Japira, SH3640 Graúda and BRS Platina (Figure 7).

The largest accumulations of UF for the reproductive sub-period ($PU_R$) occurred in the second and third production cycles. It can also be observed that only the BRS Conquista variety had a decrease for the mean values for $PU_R$ from the first to the fourth cycle (Figure 8). The other cultivars showed variations in the mean $PU_R$ values between cycles (Figure 8).

In the first and third cycles, significant differences were verified between the cultivars, with emphasis in the first cycle for the cultivar BRS Conquista (619473 $PU_R$) and in the third cycle for the cultivars BRS Platina (521409 $PU_R$), BRS Japira (360151 $PU_R$) and BRS Conquista (400133 $PU_R$). However, in the second and fourth cycles, there were no significant differences between cultivars (Figure 8).

The interaction between treatments, cultivars, management and cycles for the variable total photothermal unit ($PU_T$) showed significant differences only between the

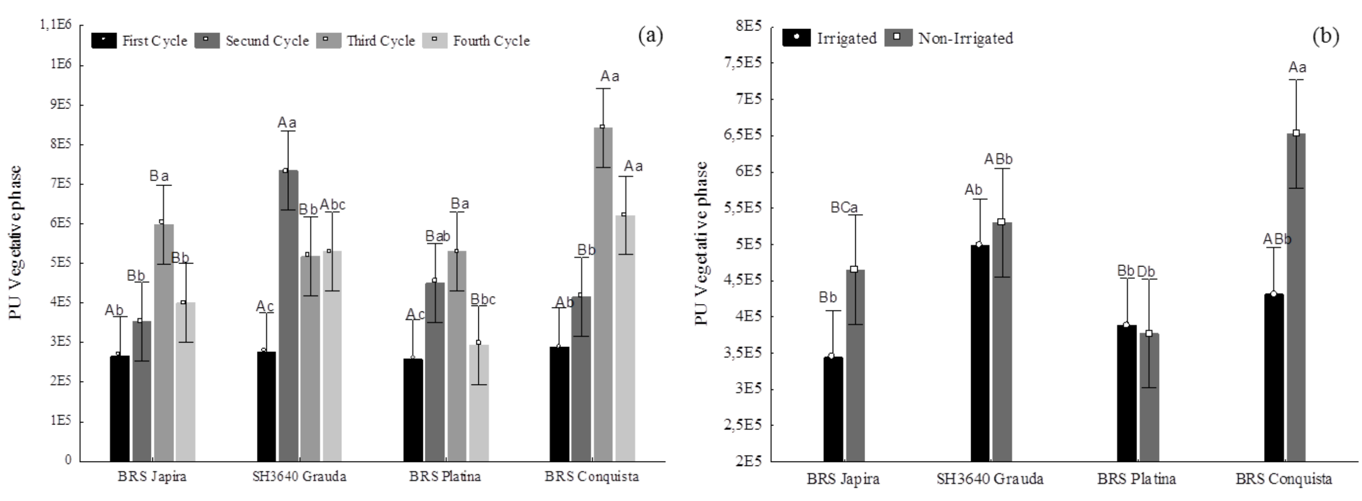


**Figure 7**. Photothermal units in the vegetative sub-period ($PU_V$) for four banana cultivars (BRS Japira, SH3640 Graúda, BRS Platina and BRS Conquista), and their interactions with cycles (a) [first, second, third and fourth cycle] and management (b) [irrigated and non-irrigated]. Means followed by the same letter uppercase (Cycles) and lowercase (Cultivars) do not differ by Tukey test at 5% probability.

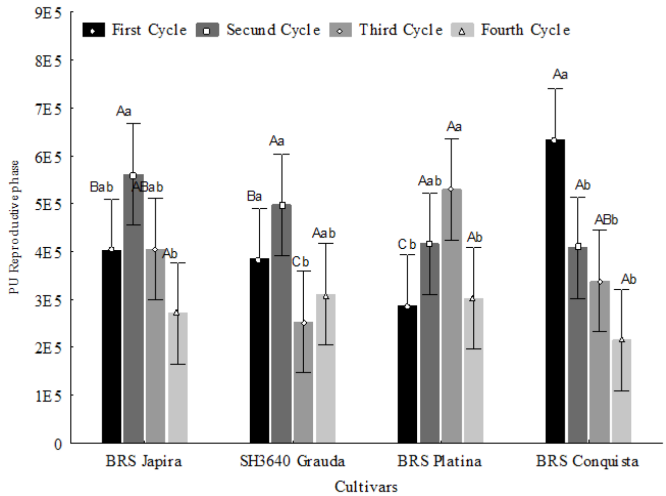


**Figure 8**. Photothermal units in the reproductive sub-period ($PU_R$) for four banana cultivars (BRS Japira, SH3640 Graúda, BRS Platina and BRS Conquista) and cultivation cycles [first, second, third and fourth cycle]. Means followed by the same letter uppercase (Cycles) and lowercase (Cultivars) do not differ by Tukey test at 5% probability.

BRS Platina (1022261 $PU_T$) and BRS Conquista (2254538 $PU_T$) varieties, non-irrigated, in the first cycle (Figure 9). Cultivars SH3640 Graúda (2725726 $PU_T$) and BRS Conquista (1442391 $PU_T$) had differences in the second cycle and in the irrigated system. BRS Conquista maintained the highest $PU_T$ means in the third cycle, irrigated (2683401 $PU_T$), while non-irrigated the BRS Platina had the highest accumulation (2787352 $PU_T$) (Figure 9). In the fourth cycle, the cultivars presented similar behavior in both managements, with a reduction of $PU_T$ accumulation (Figure 9). In general, the second and third cycles showed higher values (2127735 and 2195939 $PU_T$, respectively) of accumulation when compared to the first

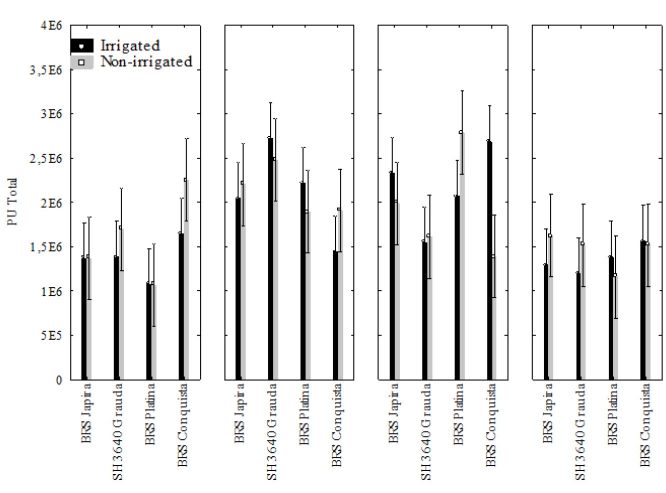


**Figure 9**. Total photothermal units ($PU_T$) for four banana cultivars (BRS Japira, SH3640 Graúda, BRS Platina and BRS Conquista), cultivation cycles (first, second, third and fourth cycle) and management (irrigated and non-irrigated). Means followed by the same letter uppercase (Cycles) and lowercase (Cultivars) do not differ by Tukey test at 5% probability.

and fourth cycles (1465047 and 1400329 $PU_T$, respectively), following the same trend of $TS_T$.

## Conclusions

BRS Conquista cultivar required a higher thermal accumulation to complete its cycle, while the BRS Platina cultivar required a lower thermal accumulation.

The largest thermal and photothermal accumulations were observed in the second and third cycles.

Thermal and photothermal accumulations were similar between the irrigated and non-irrigated systems.

Both thermal sums (DD) and photothermal units can be used to detect phenological stages in the banana crop.

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