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Variation of Thermal Time, Phyllochron and Plastochron in Passion Fruit Plants With Irrigation Depth and Hydrogel

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Abstract

The passion fruit demands water for its growth and production. Water management is relevant in regions characterized by low rainfall indices, such as semi-arid regions. In this direction, the use of hydrogel in the soil allows the water that is supplied through irrigation to be better utilized by the plants, reducing leach losses. The objective of this experiment was to evaluate the influence of hydrogel in soil cultivated with passion fruit and irrigated to various water depths on the thermal time of the phenological stages, phyllochron and plastochron of the plants. Treatments were distributed in randomized blocks in a 2 × 5 factorial arrangement, referring to the soil without and with hydrogel and raising the irrigation depth from 60% to 70%, 80%, 90% and 100% of crop evapotranspiration in four replications. The thermal requirements of the phenological phases and of the whole plant cycle, phyllochron of the main stem and the productive branches, and plastochron were evaluated. Increasing the irrigation depth from 60% to 100% reduced the total thermal time values from 3,811.8 to 2,401.3 °C day and from 3,707.8 to 2,628.7 °C day in the soil without and with hydrogel, respectively. The thermal time of the phenological phases and the phyllochron of the main stem and productive branches of the passion fruit were stimulated by an increase in irrigation depth.

Keywords: development, growth, polymer, water supplementation, *Passiflora edulis*

1. Introduction

Irrigated fruit cultivation has gained more and more space in Brazilian agriculture in the last decades, especially with respect to advances in the economy and efficiency of the use of water applied through irrigation, and in regions that present water scarcity such as the Brazilian Northeast where the cultivation of fruit trees is often restricted to the application of water to plants by irrigation (Araújo et al., 2012). In these regions, water deficiency is one of the most limiting factors to obtain economically viable productivity, and the production system depends on this supply of water to the plants for the production of fruits (Silva, Bezerra, Sousa, Pereira Filho, & Freitas, 2011).

The passion fruit (*Passiflora edulis* Sims) is a fruit tree that grows, develops and produces well in tropical regions; it is the most economical species among Passifloraceae, with approximately 95% of commercial orchards in Brazil cultivated with some genotype of this species (Meletti, 2011). Passion fruit is a very demanding plant for water, requiring during most of its vegetative and productive cycle at least 10 L per day to meet the needs of plants with a view to fruit production (Koetz, Carvalho, Sousa, & Souza, 2010).

Water management for this is of significant importance for increasing the production and quality of passion fruit fruits (Freire, Cavalcante, Rebequi, Dias, & Souto, 2011), mainly in areas characterized by high evapotranspirative demand, low rainfall indices and irregular rainfall, such as the arid and semi-arid regions of the Brazilian Northeast. The adoption of irrigation water management techniques that can attenuate losses due to evaporative effects in the soil, and that contribute to greater utilization by the plants is necessary to obtain greater crop yields in those regions where water is limited, particularly for fruit species (Souza et al., 2010).

In this context, the application of hydroabsorbent polymers appears as a management technique for reducing soil water losses, and greater use of this resource by plants. Carvalho, Cruz, and Martins (2013) explained that polymers maintain soil moisture for a longer period without compromising plant growth and production, allowing irrigation to be performed less frequently, and their use should be recommended for both rainy and irrigated conditions (Azevedo et al., 2014). Among the advantages of hydrogel in the soil, we highlight the optimization of water availability, reduction of percolation losses and nutrient leaching, improvement of aeration and soil drainage, and promotion of root and shoot growth (Fagundes, Cruz, Carvalho, Oliveira, & Soares, 2015).

In the last 5 years, studies related to water reduction by hydrogel application have indicated satisfactory results for seedling formation, initial growth and post-plant survival of forest, coffee, olive oil and fruit species (Carvalho et al., 2013; Azevedo et al., 2014). However, according to Monteiro Neto et al. (2017), little has been demonstrated for the effects of water-borne polymers on development, or on the phenological and productive aspects of crops after the transplantation of seedlings in the field until the harvest of fruits.

When considering hydrogel's positive action in the formation of seedlings of several crops, and the scarcity of information during the growth and production of fruit, including passion fruit, it is possible that the respective input provides a viable alternative to the reduction of water application in agriculture. The objective of this experiment was to evaluate the influence of hydrogel in soil cultivated with passion fruit and irrigated to varying water depths on the accumulation of thermal time in the different phenological stages and on the speed of emission of leaves and productive branches.

2. Material and Methods

The experiment was carried out from September 2016 to June 2017 at Macaquinhos site, Remígio City, Paraíba State, Brazil. The climate of the region, as classified by Köppen is As (hot and humid), with rainfall from March to July (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). Monthly average rainfall data, evaporation measured for a class 'A' tank, temperature and relative humidity of the air during the experiment are indicated in Table 1. Temperature and relative air humidity records were obtained using an HT-70 Datalogger, installed at a height of 2.5 m inside the orchard.

Table 1. Rainfall (R), evaporative values for a class 'A' tank (EAT), temperature (T) and relative humidity (RH) in the growing area during the experiment

Months	2016				2017			
	R	EAT	T	RH	R	EAT	T	RH
	mm	mm	°C	%	mm	mm	°C	%
January	129	4.3	-	-	10	6.7	20.8	70.2
February	33	5.4	-	-	9	6.8	21.4	66.4
March	102	5.7	-	-	58	6.5	21.5	80.8
April	124	4.3	-	-	54	4.7	27.0	81.2
May	158	4.8	-	-	77	4.6	24.7	76.1
June	33	4.2	-	-	75	4.5	22.6	75.3
July	14	5.4	-	-	-	-	-	-
August	8	6.2	-	-	-	-	-	-
September	19	6.2	25.3	75.6	-	-	-	-
October	10	8.2	26.2	76.2	-	-	-	-
November	0	8.3	27.1	75.2	-	-	-	-
December	103	7.3	20.7	77.3	-	-	-	-
Total/average	733	5.8	24.8	76.1	283.0	5.6	23.0	75.0

The soil of the experimental area was classified, according to the classification criteria of the Brazilian Soil Classification System—SiBCS (Embrapa, 2013), as Neolithic Regolithic Dystrophic. Before the start of the experiment, soil samples were collected for chemical characterization of soil fertility and texture, soil density and moisture (Embrapa, 2011), according to the results presented in Table 2.

Table 2. Chemical and fertility attributes and soil physical properties prior to experiment setup

Chemical attributes	Value	Physical attributes	Value
pH (H_2O)	7.3	Sand (mm)	830
P (mg dm^{-3})	352	Silt (mm)	113
K^+ (mg dm^{-3})	474	Clay (mm)	57
Na^+ ($cmol_c$ dm^{-3})	1.94	CDW (g kg^{-1})	25
H^++Al^{3+} ($cmol_c$ dm^{-3})	1.90	DF (%)	56.14
Al^{3+} ($cmol_c$ dm^{-3})	0.00	SD (g cm^{-3})	1.40
Ca^{2+} ($cmol_c$ dm^{-3})	6.55	Dp (g cm^{-3})	2.58
Mg^+ ($cmol_c$ dm^{-3})	3.98	TP (%)	45.74
EBS ($cmol_c$ dm^{-3})	13.69	H_{fc} – 0.010 MPa (g kg^{-1})	107
CEC ($cmol_c$ dm^{-3})	15.58	H_{pwp} – 1,500 MPa (g kg^{-1})	58
V (%)	87.87	Adi (g kg^{-1})	49
OMS (g kg^{-1})	24.15	Textural class	Free sand

Note. EBS = exchangeable base sum (Ca^{2+} + Mg^{2+} + K^+ + Na^+); CEC = cation exchange capacity [EBS + (H^+ + Al^{3+})]; V = saturation value by exchangeable bases (EBS/CEC) × 100; MOS = organic matter in substrate; CDW = clay dispersed in water; DF = degree of flocculation; Ds = soil density; Dp = Particles density; Pt = total porosity; H_{fc} = humidity at the water level of the field capacity; H_{pwp} = humidity at the water energy level at the permanent wilting point; MPa = mega Pascal; Wa = Water available (H_{fc} − H_{pwp}); P = phosphorus – Mehlich-1; K = Potassium – Mehlich-1; Na^+ = sodium – KCl 1 mol/L; Ca^{2+} = calcium – KCl 1 mol/L; Mg^{2+} = magnesium – KCl 1 mol/L; H^+ +Al^{3+} = potential acidity – calcium acetate 0.5 mol/L – pH 7.0; Al^{3+} = exchangeable aluminum – calcium acetate 0.5 mol/L – pH 7.0.

The treatments were distributed in randomized blocks with a 2 × 5 factorial arrangement, relative to the soil without and with hydrogel, and irrigation depths of 60%, 70%, 80%, 90% and 100% of crop evapotranspiration (CET) in four replications. Each experimental unit was represented by one plant, with 3 m of space between plants and 3 m between rows; the experiment was conducted in a pressure lysimeter 60 cm in diameter and 50 cm in height with an area of 0.28 m^2 and a volume of 120 dm^3, using 100 dm^3 of soil corresponding to 140 kg of substrate.

The hydroabsorbent polymer was purchased from Hydroplan EB/HyArogrogel and had the following physical properties: appearance – white granules, particle size – 0.5 to 3 mm; anionic, active ingredient (% solids content) – 100, water content (%) – 10, volume density (g cm^{-3}) – 0.8 and solubility – insoluble in water. The hydrogel was applied at a dose of 1 g kg^{-1} of soil to sandy textured soil, as recommended by the manufacturer, at four stations, one in each quadrant of the lysimeter, 10 cm from the wall, 20 cm from the stem of the plant and at a depth of 20 cm. Each station was opened with a diameter of 5 cm, and the respective volume of substrate was mixed with a quarter of the total of 140 g of the polymer (hydrogel + substrate) and then packed into the station. The seeds of passion fruit cv. Guinezinho were obtained from fruits of a commercial orchard of plants submitted to mass selection, of the local variety that is traditionally grown in the municipality of Nova Floresta city, Paraíba State, Brazil.

One day before transplantation, the soil moisture of all lysimeters was raised to the field capacity level. This practice consisted of applying a volume of water at the beginning of drainage and measuring the volume applied and drained after 24 h; humidity at the field capacity level was determined by the difference between the volume applied and the volume drained (Freire et al., 2011). The seedlings were transplanted 1 day after determination of the field capacity of the lysimeter, and the irrigations were carried out with a frequency of 2 days. The whole experiment with irrigation depths of 60%, 70%, 80%, 90% and 100% of CET, respectively, corresponded to application of 492.1, 574.1; 656.1; 738.1 and 820.1 L $plant^{-1}$ during the conduction of the experiment.

Irrigation of the plants was done manually, taking as reference the CET obtained from evaporation for a class 'A' tank. The following coefficients of cultivation (kc) were adopted as proposed by Freire et al. (2011): 0.40 from transplantation to pruning of the main stem; 0.64 from pruning of the stem up to 90 days after transplantation (DAT); 0.96 from 90 to 120 DAT; and 1.2 from 120 DAT until the end of the harvest. CET was obtained as the product of potential evapotranspiration (ET_0) and the crop coefficient (kc): CET = ET_0 × kc. Potential evapotranspiration was estimated via the product of evaporation from a class 'A' tank (ET_a) and the correction factor of 0.75 ($ET_0 = ET_a \times 0.75$), according to methodology described by Sousa Marouelli, Coelho, Pinto and Coelho Filho (2011).

Transplantation was done with standard seedlings with a height of 20 cm and three pairs of leaves. Plants were supported using a simple espalier made from no. 12 smooth wire, installed at a height of 2.7 m on the top of the piles. Plants grew on a single stem until reaching the supporting wire at the moment of pruning the apical bud 10 cm above the espalier, to stimulate the emission and growth of secondary branches, one in an easterly direction and the other in a westerly direction (Freire et al., 2011). Nitrogen (urea – 45% N) and potassium (potassium chloride – 60% K_2O) fertilization was carried out monthly from 30 DAT, at an N:K ratio of 1:1, applying 5, 10 and 15 g of N and K, at 60, 90 and 120 DAT. From 150 DAT until the end of the harvest, 20 g of N and 20 g of K was applied. Phosphate fertilization was carried out by applying 5 g plant^{-1} of a single superphosphate (18% P_2O_5, 20% Ca and 12% S) from 60 DAT, every 2 months until fruit harvesting.

In the experimental area, an HT-70 Datalogger was installed at a height of 2.5 m from the soil to record the daily air temperature, to estimate the daily and accumulated thermal time, both in degree days, for the whole cycle and for the phenological phases of the passion fruit culture. From transplantation of the seedlings to the field, the daily thermal time (TTd) was determined, according to the methodology proposed by Arnolds (1960), as presented in Equation 1. The base temperature used in this experiment for the whole passion fruit cycle was 8 °C, as reported by Souza et al. (2010) for passion fruit.

$$TTd = [(Tmax + Tmin/2) - Tb] \times Day \quad (1)$$

where, Tmax: maximum air temperature (°C); Tmin: minimum air temperature (°C); Tb = base temperature (°C).

The accumulated thermal time (TTa) of the entire crop cycle and of the phenological phases was obtained by summing the daily thermal time required to reach the phenological phase under evaluation, according to Equation 2:

$$TTa = \sum_{i=1}^{n} TTd \quad (2)$$

where, n is the number of days to complete all or part of the passion fruit phenological cycle.

The phenological phases were defined considering the appearance of specific organs distinguishable with the naked eye, which has the advantages of simplicity and easy identification in the field and defines the beginning and end of the phenological phase of a given culture (Streck, Bosco, Michelon, Walter, & Marcolin, 2006). Phenological phases or development subperiods were divided into: transplantation of seedlings to pruning of the main stem (TS-PMS), pruning of the main stem to pruning of secondary branches (PMS-PSB), pruning of secondary branches to the emission of flower buds (PSB-EFB), floral bud emission to fruit fertilization (EFB-FF), and fruit fertilization to fruit maturity (FF-FM).

From transplantation, the number of leaves on the main stem was counted every fortnight until pruning of the apical meristem and the beginning of emission of lateral branches at the beginning of fruiting, respectively, to calculate the phyllochron of the main stem and the secondary branches (°C day leaf^{-1}). From pruning of the lateral branches until the beginning of fruiting, and for the same evaluation period for the phyllochron of the secondary branches, the number of branches emitted by the secondary branches of the plants was recorded, to determine the plastochron (°C day branch^{-1}). From these data, linear regressions were established between the number of leaves (NL) and number of branches (NB), respectively, with TTa, for each evaluation. The values of phyllochron and plastochron consisted of the value of the inverse relationship of the coefficient of linear regression generated between NL and TTa (phyllochron) and NB and TT (plastochron), as also used by Martins, Reis, and Pinheiro (2012), and Martins, Radons, Streck, Knies, and Carlesso (2011), respectively.

The data were submitted to analysis of variance by F-test at 5% probability; the means referring to the absence and presence of the hydrogel were compared by F-test, which in this case is conclusive for two values of the same factor, and the mean values for regression irrigation depths ($p < 0.05$). For the statistical analysis and processing of the data, SAS/STAT statistical software was used.

3. Results and Discussion

From analysis of variance (Table 3), it was verified that the interaction hydrogel × irrigation depth exerts a significant influence on the thermal time of the subperiod corresponding to fertilization of the flower to the point of maturation of the fruit, on the whole crop cycle, and on the speed of leaf issue on the main stem and secondary branches (phyllochron). The isolated sources of variation (hydrogel and irrigation depth) interfered in the thermal time of the subperiods of pruning of the main stem to pruning of secondary branches and of emission of floral buds to fertilization of the flowers. The accumulated thermal time for the subperiods related to transplantation of the seedlings to pruning of the main branch and to pruning of the secondary branches to flower bud emission was not influenced by application of the treatments, presenting average values of 699.50 and 945.75 °C day TTa, respectively. A similar trend was observed for the plastochron variable, which did not respond to application of the sources of variation or to the interaction between them, requiring an average thermal accumulation of 30.12 °C day for the emission of a productive branch.

Table 3. Summary of analysis of variance, by the mean table, related to the variables of thermal time from transplantation to pruning of the main stem (TS-PMS), from pruning of the main stem to pruning of secondary branches (PMS-PSB), from pruning of secondary branches to the emission of flower buds (PSB-EFB), from floral bud emission to fruit fertilization (EFB-FF) and from fruit fertilization to fruit maturity (FF-FM), and related to total thermal time (TTT), phyllochron of the fruit (FPS), phyllochron of the secondary branches (FSB) and plastochron (PTC) of irrigated plants with varying irrigation depth (D) in soil without and with hydrogel (H)

SV	DF	Mean square				
		TS-PMS	PMS-PSB	PSB-EFB	EFB-FF	FF-FM
Blocks	3	6095.00^{ns}	3428.89^{ns}	1881.96^{ns}	681.82^{ns}	1703.69^{ns}
HYD (H)	1	6760.00^{ns}	31192.22**	739.60^{ns}	42055.22*	416.02^{ns}
DEP (D)	4	1724.62^{ns}	41717.31**	1777.81^{ns}	49460.90**	435015.53**
H × D	4	1654.62^{ns}	4402.28^{ns}	3764.91^{ns}	3857.60^{ns}	98450.83**
Residue	27	4001.85	4198.81	1629.81	5507.38	3177.82
Total	39					
Mean		699.50	327.37	945.75	477.72	806.57
CV (%)		9.4	19.79	4.27	15.53	6.99

SV	DF	Mean square			
		TTT	FPS	FSB	PTC
Blocks	3	9071.66^{ns}	6.22^{ns}	0.95^{ns}	23.15^{ns}
HYD (H)	1	121220.10**	50.62^{ns}	0.22^{ns}	46.22^{ns}
DEP (D)	4	1037376.16**	69.72**	3.68**	59.37^{ns}
H × D	4	179591.03**	51.87*	3.41*	71.60^{ns}
Residue	27	8700.90	16.85	0.84	43.13
Total	39				
Mean		3256.70	31.32	4.12	30.12
CV (%)		2.86	13.11	22.31	21.80

Note. SV = source of variation; DF = degrees of freedom; CV = coefficient of variation; ** and * = significant at 1% and 5% probability, respectively; ^{ns} = not significant at 1% and 5% probability.

The accumulated thermal time required to complete the subperiod corresponding to pruning of the main stem to pruning of the secondary branches was linearly reduced to the level of 4.2 °C per unit increment of irrigation depth (Figure 1A). An increase in water application from 60% to 100% of the evapotranspiration requirement of the crop reduced the thermal time of the subperiod or phenological phase from 420.03 to 250.83 °C day; that is, water supply adequate for the requirements of passion fruit plants decreased by 40% the time required to complete the phenological phase of PMS-PSB. Similarly, it was observed that the need for thermal units was reduced by 4.2 °C per unit increment of irrigation (Figure 1C). When comparing the lowest and highest water depths, the TTa of EFB-FF was reduced from 580.54 to 410.66 °C day, verifying that adequate water supply promotes greater growth stimulus of floral buds and, consequently, anthesis and fertilization of passion fruit flowers.

The stimulus in growth evidences the reduction in time or precocity of the plants to complete the development subperiods (Figures 1A and 1C). It is the main external factor stimulating the photosynthetic processes that allow plants to not suffer inhibition in growth and development, contributing to greater elongation, cell division and maintenance of leaf turgescence (Taiz, Zeiger, Møller, & Murphy, 2017). Under these conditions, plants use the nutrients and reserves vital for the synthesis and translocation of photoassimilates to new growth areas more efficiently (Yang, Qu, & Zhang 2012).

On the other hand, under water deficit, as shown in the 60% CET slide, carbon assimilation in the plant is inhibited due to limitation in the diffusion of CO_2 by a reduction of the stomatal opening that compromises the photosynthetic activity and growth of the plant (Zlatev & Lidon; 2012). In response, plants fail to invest in growth processes (cell division and elongation) and allocate non-photosynthetic organisms to the formation of defense molecules or biochemical changes in leaves, to reduce photosynthesis and prevent damage (Muller et al., 2011).

The thermal time of the phenological phases related to pruning of the main stem to pruning of the secondary branches (Figure 1B) and to emission of floral buds to flower fertilization (Figure 1D) was reduced with application of hydrogel, indicating that the soil was more moist for longer, as verified also by Mendonça, Urbano, Peres, and Souza (2013). The polymer stimulated the growth and development of passion fruit, revealing a need for thermal units of 7.9 and 12.7% lower for the phenological phases related to the periods of PMS-PSB and EFB-FF, respectively, compared to plants that were not treated with hydrogel.

This growth stimulus, in a shorter period, could be a response to the improvement of physical properties, such as soil structure and aeration and hydric properties such as moisture and storage of hydroabsorbent polymer water in the plants, resulting in better plant development (Azevedo et al., 2014; Fagundes et al., 2015), as observed in the initial growth of passion fruit seedlings (Carvalho et al., 2013). Hydroabsorbent polymers are preferentially indicated for regions with low water availability or long periods of drought, as has been occurring in recent years in the semi-arid regions of the Brazilian Northeast where the soil is low in moisture and reflects negatively on the growth and development of plants (Monteiro Neto et al., 2017).

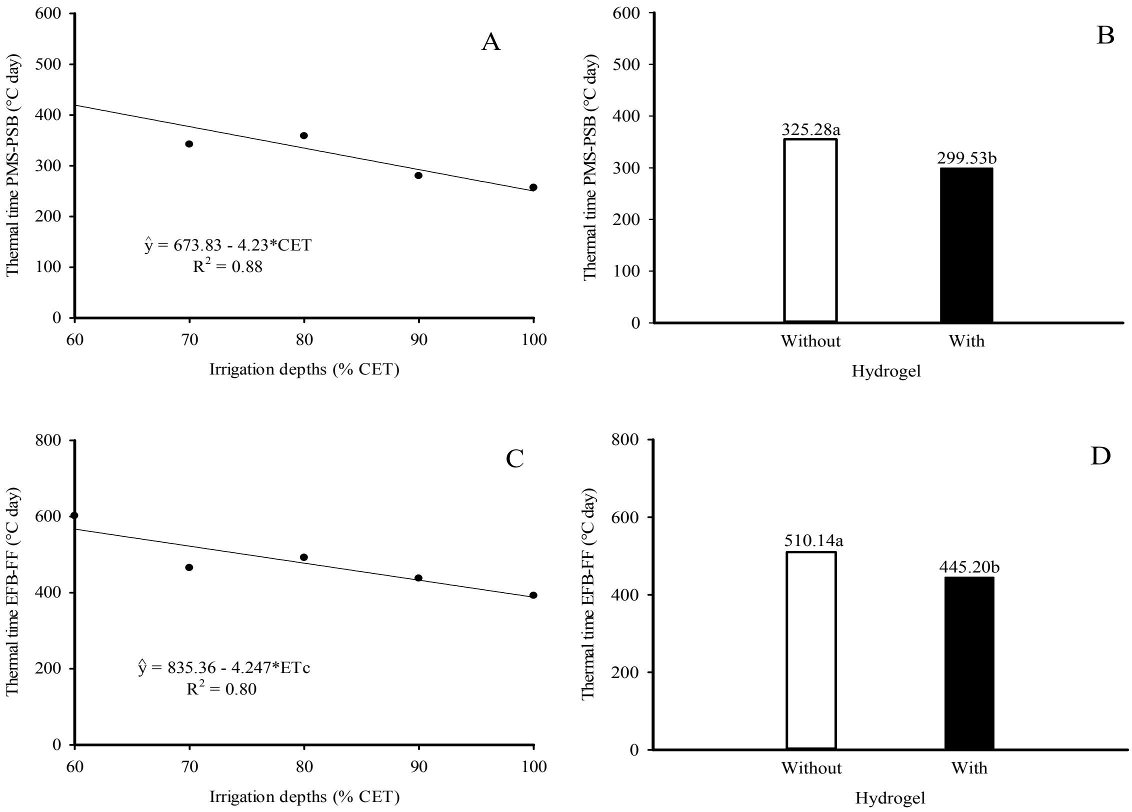

Figure 1. Thermal time accumulation of passion fruit plants in relation to the subperiods of pruning the main stem to pruning of secondary branches (PMS-PSB) and of issuance of floral buds to flower fertilization (EFB-FF) as a function of irrigation depth (A) and (C), for the substrate without and with hydrogel (B) and (D). Means followed by the same letter do not differ from each other by F-test at 5% probability

The thermal time to complete the phenological phase related to fertilization of the flowers to the point of maturation of the fruit was initially reduced with an increase in the irrigation water depth (Figure 2A). TTa decline with increasing irrigation depth occurred from 60% to 85.6% and 83.5% f CET, reaching the lowest values of 499.5 and 602.2 °C day in the soil without and with hydrogel, respectively; on the other hand, irrigation at depths above the minimum estimates elevated the thermal time of the phenological phase and inhibited growth of the fruit, consequently delaying the harvest.

When evaluating the thermal time relative to fruit fertilization to maturation of the passion fruit in Londrina, Paraná, Neves, Carvalho, and Neves (1999) found that for the complete phenological phase (FF-FM), the plants require thermal accumulation of 861.7 to 867.6 °C day. In other fruit trees, variability in the thermal requirement for the phenological interval FF-FM has been observed, as verified in cashew nuts (*Anacardium occidentale* cv. FAGA 1) cultured in Mato Grosso, Brazil, that require, on average, 437.3 °C day (Matos et al., 2014); Rodrigues, Souza, and Lima (2013), evaluating the period from opening of flowers to the point of harvest for mango fruits (*Mangifera indica* cv. Tommy Atkins), registered a thermal requirement of 862.21 °C day which is, therefore, superior to that for passion fruit.

The thermal time of the whole plant development cycle was linearly reduced from 29.58 to 19.58 °C day, in the soil without and with hydrogel, respectively, for each increment of irrigation depth (Figure 2B). When comparing the results of irrigation depth from 60% to 100% CET, total thermal time values decreased from 3,811.8 to 2,401.3 °C day and from 3,707.8 to 2,628.7 °C day, respectively, in the soil without and with hydrogel. This higher requirement of thermal units and longer duration for the plant to complete part or all of the development cycle, especially at 60% CET depth, is a result of the water deficit that causes an imbalance between the water available in the soil and the evapotranspirative rate of the plant. This situation naturally occurs in the field, impairing cell division and assimilation and accumulation of carbon, and reducing plant tissue expansion (Tardieu, Granier, & Muller, 2011).

The results for treatment of the plants irrigated with 100% CET are consistent with those of Souza, Chig, Costa, Lenza, and Campelo Júnior (2010) for passion fruit (*P. edulis*) irrigated in Mato Grosso, Brazil, where the plants required close to 2,500 thermal units for the crop to complete the cycle. This information shows that the thermal time is inherent to each species and serves as a reliable measure of the plant's biological time (Schmidt et al., 2017).

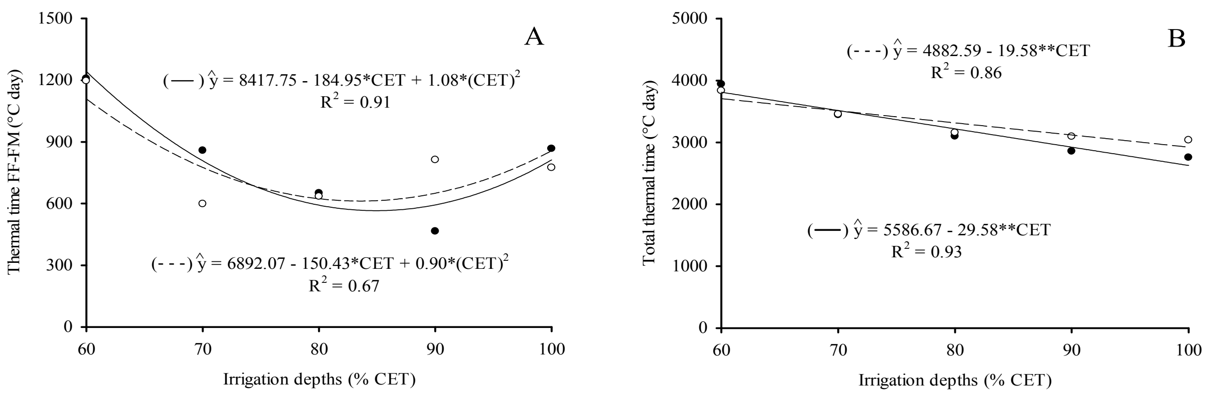

Figure 2. Thermal time accumulation of passion fruit plants from the development subperiod of the fruit to the fruit maturity point [FF-FM] (A), and total thermal time (B) as a function of soil irrigation layers without (—) and with (- - -) hydrogel

An increase in soil irrigation depth without hydrogel linearly retarded leaf emission (phyllochron) on the main stem of passion fruit plants at 0.185 °C $leaf^{-1}$ per unit increase of CET (Figure 3A). From the numerical relationship between the phyllochron values of 33.93 and 26.53 °C day $leaf^{-1}$, there was a reduction of 27.9% between the plants irrigated with water depths of 60% and 100% CET, but plants irrigated at 100% CET had a lower thermal time requirement and, therefore, faster leaf emission. In the hydrogel treatments, the phyllochron was elevated up to a maximum estimated irrigation depth of 82.1% CET, with a phyllochron value of 38.9 °C day $leaf^{-1}$, indicating that the input was delayed up to the maximum estimated emission of leaves by the plants.

Variation in the phyllochron of the secondary branches of plants in the non-hydrogel treatments with increased irrigation water depth did not fit any regression model, presenting a mean phyllochron value of 3.99 °C day $leaf^{-1}$ (Figure 3B). In the soil with hydrogel, an increase in irrigation depth from 60% to 100% of the evapotranspiratory requirement of the passion fruit reduced the need for thermal units from 6.86 to 4.06 °C day for emission of leaves on the secondary branches of the plants. The mechanisms of plant response to soil water deficit include stomatal closure, loss of photosynthetic activity, inhibition of leaf formation and acceleration of leaf senescence and abscission, as occurred with the phyllochron of passion fruit plants irrigated at 60% CET (Figure 3) (Taiz et al., 2017).

When comparing the phyllochron values of the main stem (Figure 3A) with those of the secondary branches (Figure 3B), it is observed that the leaf emission rate of the secondary branches is almost six times faster than that of the main stem; this behavior must be associated with the greater contribution of leaves and leaf area that promotes greater interception of sunlight, influx and assimilation of carbon, photosynthetic activity, growth and differentiation of tissues (Muller et al., 2011; Taiz et al., 2017) of the leaves of secondary branches. These results contradict those presented by Maldaner et al. (2009) who found that the phyllochron of the main stem of secondary branches in eggplant plants (*Solanum melongena* L.) showed no differences in thermal time during leaf emission.

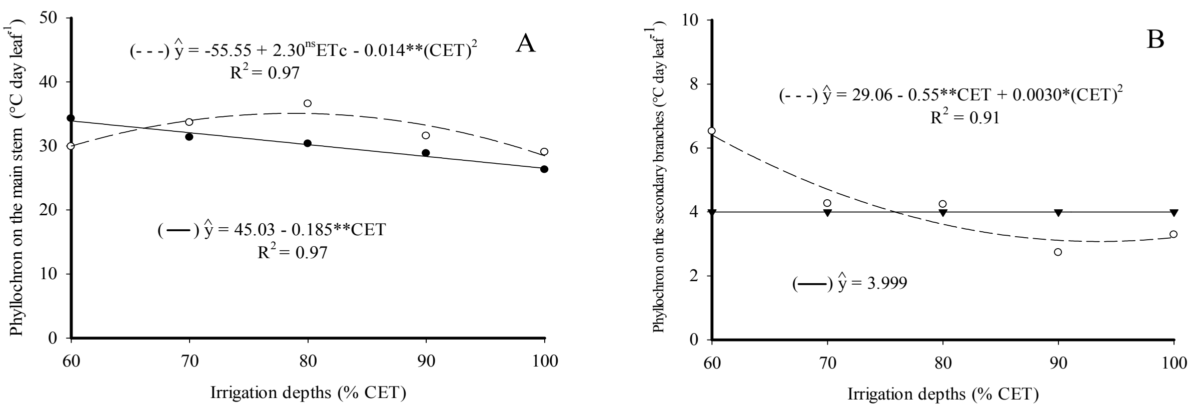

Figure 3. Phyllochron of the main stem (A) and secondary branches (B) of passion fruit plants irrigated to varying depths, in soil without (—) and with (- - -) hydrogel

From the mean values of the thermal time accumulated in each phenological phase evaluated (Table 3), a figure was created demonstrating the thermal time to complete each phenological phase of the passion fruit crop cycle (Figure 4). Among the phenological phases evaluated, the smallest and greatest need for thermal units corresponded respectively to the intervals between pruning of the main stem and pruning of secondary branches (PMS-PSB) and between secondary branch pruning and the emission of floral buds (PSB-EFB). In general, the thermal time of the phenological phases obeyed the order: from pruning of secondary branches to emission of floral buds (PBS-EFB) > from flower fertilization to fruit maturity (FF-FM) > from transplantation of seedlings to pruning of the main stem (TS-PMS) > from emission of floral buds to flower fertilization (EFB-FF) > from pruning of the main stem to pruning of secondary branches (PMS-PSB).

Monitoring of the heat requirement in fruit plants is widely used to estimate the time required to complete part or all of the development cycle of the crop, and represents the daily accumulation of energy required to stimulate plant growth. It is, therefore, an important parameter in decision-making and crop management factors such as planting, harvesting and cultural treatments, and in indicating the climatic potential of the species for commercial exploitation (Rodrigues et al., 2013; Matos et al., 2014).

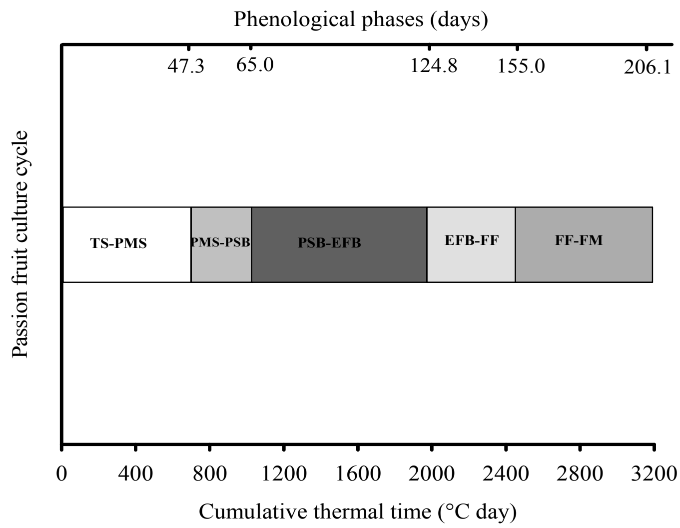

Figure 4. Thermal time and mean age in each phenological phase of passion fruit plants grown in the State of Paraíba

4. Conclusion

Increasing irrigation depth from 60% to 100% CET reduces the thermal time for phenological phases and stimulates leaf emission on the main stem and secondary branches of passion fruit.

The application of hydrogel as a form of water retention in the soil reduces the thermal time for the development subperiods of pruning of the main stem to pruning of secondary branches and of emission of floral buds to fertilization of the flowers.

The thermal need of each phenological phase of passion fruit follows the order: from pruning of the secondary branches to emission of floral buds (PBS-EFB) > from fruit fertilization to fruit maturity (FF-FM) > from transplantation of seedlings to pruning of the main stem (TS-PMS) > from emission of floral buds to flower fertilization (EFB-FF) > from pruning of the main stem to pruning of secondary branches (PMS-PSB).

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