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Accumulation of degree-days and chilling hours for 'Eva' apple tree production in temperate climate

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Abstract

The cultivation of apple tree is highly dependent on meteorological variables, especially temperature. The link between accumulation of degree-days (DD) and accumulation of chilling hours (CH) are determinant to field success, in the context of climate change. The objective of this study was to quantify the accumulation of DD necessary during the reproductive phenological stages for cultivar IAPAR 75 Eva, considering the accumulation of CH during the period of dormancy. The study was carried out at the Experimental Station from the Rural Development Institute of Paraná IAPAR-EMATER, in the municipality of Palmas, Paraná State, Brazil. The evaluations were from 2013 to 2019, showing for each three days, the phenological phases and the value of DD and CH. The results were submitted the simple and multiple correlation by the R® software. We verified the influence of the increase in temperature on the cycle acceleration, in addition, it was verified a tendency of less requirement for DD to advance the cultivar cycle. Were verified the value of chilling hours as 281, 156, 84, 326, 96, 76 and 11 hours of chill, respectively, and the consequent accumulation of DD to breaking dormancy was appointed as 1093, 1156, 1574, 1157, 1834, 1096 and 1838 DD, respectively. We concluded that CH causes impact in DD accumulation to development of apple tree. Higher temperatures accelerate the apple tree development. With the information of CH accumulation in dormancy, it is possible estimate the quantity of DD to develop the phenological phases. This information contributes to agricultural planning for cultivar Eva farmers.

Keywords: *Malus domestica Borkh*., Apple tree phenology, Agricultural planning, , Air temperature, Global Climate change.

Introduction

Despite the recent technological advances, the weather conditions still influence the agricultural production, as the apple tree (Malus domestica Borkh.) which has its production higher dependent on the weather conditions (Morais and Carbonieri, 2015). The apple tree has a significant socio-economic relevance across the world. In Brazil, around 98% of national production is located in Southern States (Oliveira et al., 2017).

This specie has two key phenological phases during its cycle: The dormancy and the reproductive phases. These two periods have specific requirements for the dormancy phase, as a need to accumulate chilling hours (CH) (Lopes et al., 2013), and in the reproductive phase, there is a need to accumulate heat, as degree-days (DD), to fruit development and complete the cycle. If the apple tree accumulated less chilling hours required to broken the dormancy, it will be required higher accumulation of heat, to complete its cycle. In the case of insufficient chilling hours, the consequences are reduction in productivity and delay in fruit development, harming the fruit quality and commercialization (Lopes et al., 2013; Harrington et al., 2010; Oliveira et al., 2013a). The accumulation of DD influences the speed of development after dormancy (Lopes et al., 2012). According to the Francescatto et al. (2015), the flowering and sprouting process have a direct link with the increase in temperature, by the rapid accumulation of DD and standard flowering in orchard. In addition, there is a correlation between temperature increase and phenological development speed, in the reproductive phases (Oliveira et al., 2013b).

Observing the importance of air temperature for apple tree cultivation, there is concern about the climatic projections, according to the report from IPPC - Intergovernmental Panel on Climate Change (2019), that shows the increasing of average air temperature, and as a key harm consequence, a decrease to accumulation of CH. For this context, Asghar et al. (2012) studied the impact between apple tree and the weather conditions, during several years. In addition, the increase of the consumer demand contributes for scientific research to develop better and adapted cultivars, as the IAPAR 75 Eva apple, exhibiting less CH requirements. According to the Fioravanço and dos Santos (2013), this cultivar needs 100 to 450 CH to broken the dormancy phase, that means, a better adaptation to areas traditionally explored by other crops. In addition, these researches programs, as plant genetic breeding, aim to carry out a better tolerance for cultivars, increasing average temperature, one the key meteorological variable affected by climate change (Chagas et al, 2012; Pandolfo et al., 2014; IPCC, 2019). However, it is should be noted that there is a lack of information on the cultivar IAPAR 75 Eva and the influence of variability on the environment along time.

The objective of this study was to quantify the accumulation of DD in the reproductive stages for the production of the cultivar Eva and the accumulation of CH during dormancy, in the municipality of Palmas, Paraná State, Brazil, aiming to assist the farmer, with relevant information to aid the agricultural practices, as a better establishing of agricultural planning.

Results and discussion

Characterization of DD, CH and cycle (in days)

According to the Table 1, the years studied exhibited variation between the accumulated values of degree-day (DD), days (d), phenological phases of the cultivar IAPAR 75 Eva and in the total cycle. Considering that during all experiment the plants received the same agricultural treatments, we admitted that the verified differences come from the meteorological variables, corroborating to study of Francescatto et al. (2015), who also reported variations on the phenological development of apple tree, due the weather conditions. During seven years this study, the dates of emergence of dormancy buds were variable (Table 2), however, near the harvests periods, around December 11 to December 26, characterizing the early quality of the cultivar, harvesting before the traditionally cultivars in Paraná State and in the Southern of Brazil, as Fuji and Gala (Francescatto et al., 2015).

Analysis of meteorological variables

We used the Climatological Water Balance (CLIMWB) To analyze the influences of meteorological variables on the physiological development of cultivar, according to the Figure 02.

The results exhibited absence of water deficiency for apple tree, during the years evalutaed, due the great supply of water in the soil and chiller temperatures in the municipality of Palmas, not reaching surplus values in just two months of the years 2017 and 2018, but without disabilities, showing only insignificant extraction of water from the soil that was stored. These favourable conditions were verified by Petri et al. (2011), who carried out the CLIMWB in Santa Catarina State, Brazil, exhibiting that both in the dormancy and reproductive phases of the apple tree, is highly dependent on precipitation. As we do not verify water deficiency in this study, we analysed the variable of air temperature, comparing it with each phenological phase of the cultivar, in total of degree-days and total in days. For adopting that procedure, it is able to obtain a better comprehension of the temperature effects during the cycle of IAPAR 75 Eva.

Statistics analysis of DD, average air temperature and accumulated days

The results from the Figure 3 exhibited the positive correlation between the duration of phenological phases (degree-days and days) with the meteorological variable of air temperature. In addition, we compared, using a simple correlation, the effects of air temperature with degree-days and with days and, in both results, we verified a positive correlation with phenological phases (Figure 4).

We can verify the speed increasing of sprouting and flowering process, during the years that phenological phases were under higher temperatures (Table 1 and Figure 4), for example, verifying peaks of temperature (Table 3) in the initial phenological phases (Phase B to Phase E) in 2015, with the days of duration in days of the phenological stages, it is noted that in only 21 days of the bud sprouting, the cultivar IAPAR 75 Eva was already in developed flourishing, and the average air temperature, during this phase, was 15.66°C.

Years with lower temperatures in these same initial phases, caused the delay of physiological development, and the year 2017 can be cited as the most delayed, from Phase A to Phase E 46 days, with the average air temperature in these phases as 13.25ºC.

Similarly, in more advanced phenological phases, such as from green fruits to ripe fruits (Phase J), we verified the effects of air temperature on the duration of the cycle. In 2014, with an average air temperature of 20.15°C, the phase lasted for 75 days, while in 2015 with an average air temperature of 19.19°C, the same phenological phase occurred in 112 days. In a similar condition, Lopes et al. (2012) concluded that the air temperature had an effect on the development stages of the apple tree, with all sub-periods accelerating in development, from when the average temperatures increases. Oliveira et al. (2013b), also observed a positive correlation of changes in the duration of phenological stages, with temperature variation.

In addition, the results are corroborating to the Francescatto et al. (2015), who appointed that initial processes, as sprouting and flowering are highly influenced by temperature, due when the temperature is higher, the physiological processes occur faster when compared with less temperatures, and the reverse occurs when the average temperatures are lower. However, it is possible to verify, in few cases, the opposite effects of the temperature correlation with the duration in days of the phenological phases, for example, the year 2013, which had the duration of Phase B until Phase E of 21 days (the same duration of those phenological phases of the year 2015), however with the lowest average temperature of the years under analysis for this period of 13.10°C, compared to 15.66°C in 2015. Also in more advanced phenological phases, such as Phase J in 2018, even with the average temperature of 18.59°C it was required 98 days to complete the phase phenological, not delaying as much as expected, as the year previously mentioned in 2015 with an average temperature of 19.19°C, with 112 days to complete the phenological phase J.

Statistical and descriptive analysis of the effect of CH on DD and cycle in days

These opposite effects in few cases of the number in days of the phenological phases in relation to the average air temperature, it was verified in the present study that they are related to the accumulation of CH during dormancy, influencing the accumulation of DD necessary for the apple tree to advance its phenological stages (Table 1 and Table 2). Despite several apple cultivars exhibits higher requirements of chilling hours for breaking dormancy, the cultivar Eva does not make this a problem due to its less requirement (Eilert et al., 2017), around 100 and 450 HF (Hauagge and Tsuneta, 1999), exhibiting a particular characteristic, showing prominence among other apple tree cultivars in

Table 1. Degree Days (DD) and days (d) acumullated in different phenological phases of cultivar Eva, after the dominancy broken, in Palmas, Paraná State, Brazil.

	2013		2014		2015		2016		2017		2018		2019	
	DD	d	DD	d	DD	d	DD	d	DD	d	DD	d	DD	d
A	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	49	7	13	7	34	3	125	22	87	9	42	7	131	14
C	21	5	17	3	43	4	10	4	63	7	72	14	109	14
D	3	3	70	11	38	4	10	4	66	7	35	7	69	7
E	18	6	45	10	109	10	51	14	275	23	15	7	55	7
F	78	13	46	9	116	8	18	8	58	5	19	7	76	7
G	27	4	142	19	78	6	17	3	53	4	33	7	65	7
H	37	4	21	4	33	3	17	3	39	3	16	7	20	3
I	124	24	41	7	49	4	55	13	89	7	41	7	82	8
J	735	81	761	75	1074	112	854	107	1104	99	822	98	1232	108
Σ	1093	147	1156	145	1574	154	1157	198	1834	164	1096	161	1838	175

A= Dormancy bud; B= Green bud; C= Pink bud; D= start of flourishing; E= developed flowers; F= end of flowering; G= drop of petals; H= effective fruiting; I= green fruits; J= ripe fruits; Σ = total.

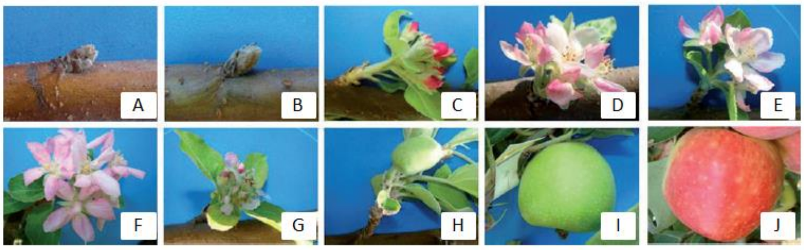

Figure 1: Characterization of phenological phases of the apple tree, cultivar IAPAR 75 Eva. A: dormant bud; B: green bud; C: pink button; D: the start of flourishing; E: flower completely developed; F: end of flowering; G: drop of petals; H: effective fruiting; I: green fruits; J: ripe fruits. Adapted from Oliveira et al. (2013a).

Table 2. Degree-Day (DD) and chilling hours (CH) during the dormancy period and the dates of emergence of the dormancy bud and harvest of the apple tree Eva, from 2013 to 2019 in Palmas, Paraná State, Brazil.

	2013	2014	2015	2016	2017	2018	2019	Média
DD dormancy	1618	1590	1689	1539	1579	1566	1650	1604
CH dormancy	281	156	84	326	96	176	11	161
Date A	01/08	23/07	22/07	02/07	01/07	03/07	26/06	-
Date J	26/12	15/12	23/12	25/12	12/12	11/12	18/12	-

DD: degree-days; CH: chilling hours; Date A: date when we verified the dormancy bud; Date J= harvest date.

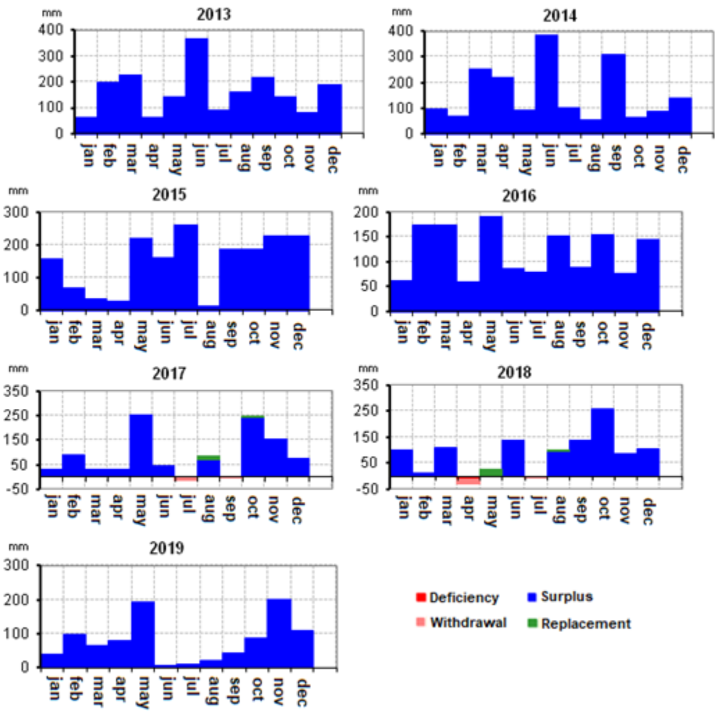

Figure 2. The Climatological Water Balance (CLIMWB) of Thornthwaite e Mather (1955) from 2013 to 2019, in the municipality of Palmas, Paraná State, Brazil.

Table 3. Average air temperatures (°C) for different phenological phases (B to J) and average total of the cycle, during the reproductive phase of apple tree cultivar IAPAR 75 Eva, from 2013 to 2019.

Year	Phenological Phases									
	B	C	D	E	F	G	H	I	J	ΣTotal
2013	17.11	12.89	7.65	14.74	14.84	16.41	19.96	14.49	19.25	17.24
2014	11.08	16.13	15.64	14.87	14.05	17.45	14.68	16.19	20.15	17.79
2015	12.12	13.80	17.83	18.90	16.54	15.55	14.72	18.18	19.19	18.38
2016	12.98	13.53	15.36	14.01	11.59	13.70	18.23	13.79	18.26	16.41
2017	12.72	14.86	10.60	14.82	12.62	16.29	18.85	18.80	19.11	17.30
2018	14.69	12.73	13.83	11.33	11.86	13.92	11.51	15.34	18.41	16.51
2019	12.37	14.91	16.01	11.76	14.19	14.86	13.75	16.74	18.59	17.56
Average	13.30	14.12	13.85	14.35	13.67	15.45	15.96	16.22	18.99	17.31
Stardand Deviation	2.00	1.23	3.53	2.49	1.77	1.38	3.09	1.85	0.64	0.69
CV(%)	15,07	8,72	25,53	17,38	12,92	8,91	19,38	11,38	3,40	4,01

A= Dormancy bud; B= Green bud; C= Pink bud; D= start of flourishing; E= developed flowers; F= end of flowering; G= drop of petals; H= effective fruiting; I= green fruits; J= ripe fruits; Σ = total.

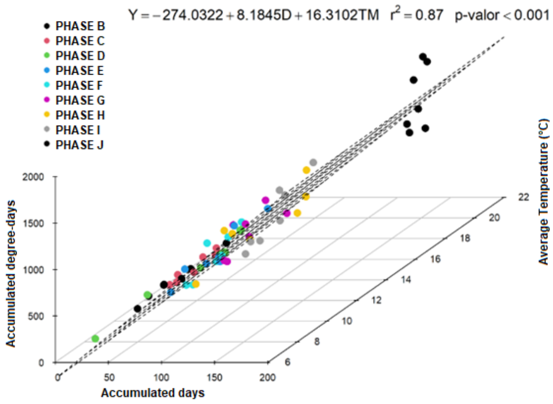

Figure 3. Multiple correlations between air temperature and duration of phenological phases, in accumulated degree days and days, of cultivar IAPAR 75 Eva, in Palmas, Paraná State. A= Dormancy bud; B= Green bud; C= Pink bud; D= start of flourishing; E= developed flowers; F= end of flowering; G= drop of petals; H= effective fruiting; I= green fruits; J= ripe fruits.

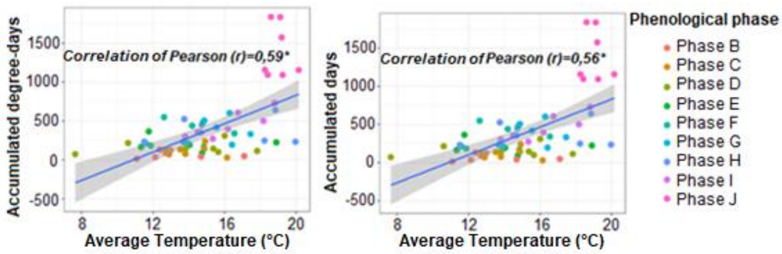

Figure 4. Simple correlation between the duration of phenological phases, in degree-days and days with the variable air temperature, of cultivar IAPAR 75 Eva, in Palmas, Paraná State. A= Dormancy bud; B= Green bud; C= Pink bud; D= start of flourishing; E= developed flowers; F= end of flowering; G= drop of petals; H= effective fruiting; I= green fruits; J= ripe fruits.

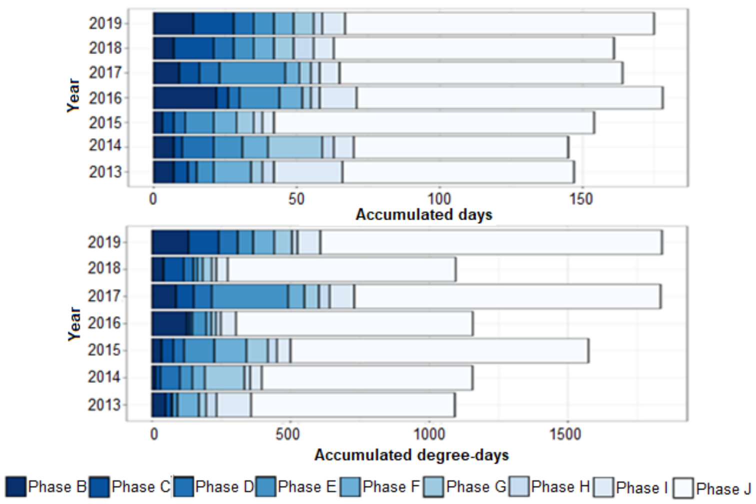

Figure 5. Degree-days and seven years of observation accumulated, according to the phenological phase of apple tree, cultivar IAPAR 75 Eva, in Palmas, Paraná State.

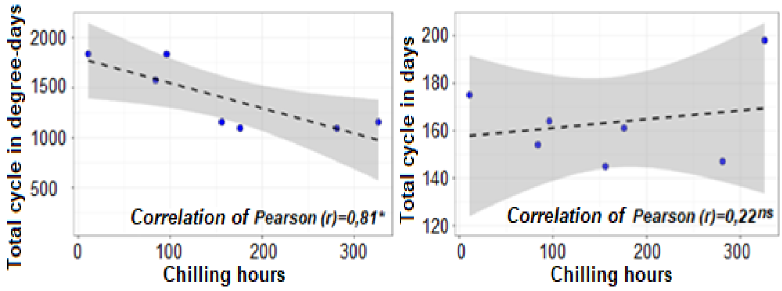

Figure 6. Simple correlation between the duration of total cycle in degree-days (DD) and days, with the total accumulated of chilling hours (CH) during the dormancy, in cultivar IAPAR 75 Eva, in Palmas, Paraná State.

subtropical conditions, resisting higher temperatures than in the Southern States, where the apple tree was traditionally cultivated (Chagas et al, 2012; Oliveira et al., 2017).

In addition, we verified CH values below the recommendations, during the years evaluated. Every year, we used products for broken of dormancy due regardless of the accumulation of CH, when the apple tree emitted the dormancy bud, the product was applied, becoming a standard. The cultivar also showed independent of the accumulation of CH, an accumulation of DD in the dormancy around 1600 GD for the appearance of dormancy buds (Table 2). It is observed that the years 2015, 2017 and 2019 (Figure 5) exhibited the greatest accumulation of DD (despite they were not in all cases the longest in days), both to reach full flowering and for the total cycle. The other years, on the other hand, had a less DD accumulation due to the greater amount of CH accumulated by the culture (Table 2). Therefore, the plants respond positively to the greater accumulation of CH, needing to accumulate less DD to advance in the phenological phases (Figure 5).

The occurrence of the effect of the variation in the phenological phases of the apple tree with the accumulation of CH during dormancy was also observed by Harrington et al. (2010) and Lopes et al. (2013), who mentioned that the lower the accumulation of CH in the dormancy period, the greater the need for DD in the development of the apple tree, in phenological stages in general. Similar results were also obtained by Oliveira et al. (2013) when evaluating the phenology of the apple tree in two years, observed a delay for full flowering, when the apple tree received less CH during dormancy, in the initial phases of the development of the apple tree.

Contributing the understanding of the influence of CH on dormancy, in the total cycle of culture in DD, Figure 6 shows that there was a positive correlation of HF influencing the accumulation of DD, and CH not being correlated with the cycle in days. We can attribute that if the apple tree achieves an accumulation of CH above the quantities required to cultivate it, the average air temperature is responsible by the phenological speed of development. However, when that does not occur, the development of the apple tree is delayed, needing to accumulate more DD to develop.

Corroborating with the present study Lopes et al. (2012), also attribute the increase in time elapsed in the phenological phases and in the total cycle of the apple tree in different years, due to the lack of accumulation of CH required for the apple tree. With the meteorological information obtained and the phenological phases of the cultivar Eva of several years, Table 1 and 2 and Figure 5 can be used as information to assist in the prediction of the phenological phases and harvest date. In addition, it is possible, with the accumulation of DD in dormancy, to predict when the appearance of dormant buds will be arriving, and with the accumulated value of CH to be able to estimate the forecast of the cultivar cycle, and the duration of phenological stages through DD according the weather conditions from the local.

Thus, this information from the local microclimate and the knowledge of the apple tree cycle, are important to farmer and the planning of installing orchards for different regions (Morais and Carbonieri, 2015).

Materials and Methods

Characterization of the area of Study

The study was carried out at the Experimental Station of the Rural Development Institute of Paraná (IAPAR-EMATER) in the municipality of Palmas, Southern of Paraná State, Southern of Brazil (latitude 26°27'56''S; longitude 51° 58'33''W; altitude 1088 m) in a dystrophic Red Latosol, with a clay texture (Embrapa, 2013).

The climate classification is “Cfb”, characterized by chill Winters and moderate temperature on Summers, with no specific dry periods, according to the Köppen classification (Nitsche, 2020). In addition, the hottest month with an average temperature of 20.3°C and the coldest, 11.7°C and the average annual precipitation is 2110 mm (Nitsche, 2020).

Conduction of experiment and procedures

The evaluated cultivar of apple tree was IAPAR 75 Eva, planting in 2012. Plant spacing was two meters between plants and four meters between rows. The study started with one-year-old apple trees. The evaluations were carried out in the years of 2013, 2014, 2015, 2016, 2017, 2018 and 2019, in order to characterize the different phenological phases of the cultivar. The evaluations were carried out on ten plants chosen randomly from the orchard, which were analyzed in the seven years of studies. We accepted a change of phenological stage when more than 50 % of the plants in the orchard were in the same stage according to the Figure 01. We followed the methodology of Gautier (1988) to describe all phenological phases of the cultivar, with modifications: dormant bud (A); green bud (B); pink bud (C); flourishing (D); flower completely developed (E); fall of flowering (F); drop of petals (G); effective fruiting (H); green fruits (I) and ripe fruits (J). For the purpose to obtain precision and qualified results, we used the same agricultural practices, in orchards under evaluations, considering the agricultural recommendations of Integrated Apple Production, as fertilization, phytosanitary products and conservationist crop management. To broke the dormancy and standardize sprouting and flowering, we used a dormancy breaking product, every year, with hydrogenated cyanamide (Dormex®) at 0.8% and mineral oil

(Aureo®) 3.0 %, following the recommendations for apple tree showed by Petri and Palladini (1999).

Meteorological data for the study

The meteorological information was obtained from a station located 500 m from the experimental area, and we used its data to determine the variables degree-days (DD), chilling hours (CH) and the climatological water balance (CLIMWB).

For determination of degree-days (DD), we used values of average daily air temperature and basal temperature, according to this expression: DD = Σ (T-Tb), where T is the average air temperature and Tb basal temperature, considered as 10°C (STANLEY et al., 2000). The accumulation of CH was estimated with the hourly values of the minimum air temperature, with the accumulation of CH computed whenever we verified the temperature less than 7.2°C. The climatological water balance (CLIMWB) was carried out using the classical method of Thornthwaite and Mather (1955). The available water capacity (AWC) was determined according to Wrege et al. (2018), who considered a 100 mm AWC for the soil of clay texture for apple tree cultivation.

The results were analyzed by simple correlation considering the duration of the phenological stages (degree-days and days) and meteorological variables (average air temperature and chilling hours), and multiple correlation between degree-days, accumulated days and the variable average temperature donate. The analyzes were carry out using the R® Program.

Conclusions

In the seven years evaluated, the accumulation of chilling hours (CH) during dormancy was 281, 156, 84, 326, 96, 76 and 11, respectively, and the consequent accumulation of (DD) from the broken in dormancy until fruit harvest was 1093, 1156, 1574, 1157, 1834, 1096 and 1838 degree-days (DD) respectively. The accumulation of DD, during dormancy, for the appearance of dormant buds was an average of 1604 DD. Despite the accumulation of CH is not a limiting variable for cultivar IAPAR 75 Eva, it has influence on the amount of DD accumulation required to advance its phenological stages. Higher temperatures influenced by the phenological speed of development of the apple tree, increasing the cultivar precocity, if there is an accumulation of CH within the cultivar requirements. With the accumulated values of CH in dormancy, and the DD counting in all phenological phases and in the dormancy period, it is a relevant information that can be used to position the cultivar Eva, and will serve as a guide for farmers to estimate the time of harvesting, collaborating with agricultural planning.

Conflict of interests

The authors apoint that there is not any conflict of interests.

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