Phenology and agronomic components of first and second-cycle strawberry

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ABSTRACT

Several strawberry growers have cultivated the same plants for two consecutive cycles aiming a greater economic return after seedling transplant. However, the phenological development and the agronomic potential of second-cycle strawberry have to be estimated. This research was installed to estimate the thermal need, leaf appearance rate, phyllochron and yield of strawberry cultivars in two consecutive crop cycles in the region of the Third Planalto Paranaense. Cultivars Camarosa, Camino Real, Albion, Aromas, Monterrey and San Andreas were evaluated in the first and second growing cycles using completely randomized blocks and four replications. Leaf appearance rate was estimated by linear regression coefficient between the number of leaves and the accumulated thermal sum. Phyllochron was estimated by the inverse of regression coefficient. Aromas was the only cultivar with an increased fruit production in the second cycle. On the contrary, there was a considerable reduction of production for 'Camino Real', 'Albion', 'Monterrey' and 'San Andreas' in that same cycle. The highest number and mass of marketable fruits of the second and first cycles were observed for 'Camarosa' and 'Camino Real', respectively. In the second crop cycle, strawberry cultivars required a lower thermal sum to begin flowering and fruit harvest. The plants presented a higher leaf appearance rate and low phyllochron values.

Keywords: *Fragaria x ananassa*, leaves emission, phyllochron, fruit production, thermal sum.

RESUMO

Fenologia e componentes agronômicos de morangueiros de primeiro e segundo ciclo

Em busca de maior retorno econômico após o transplantio das mudas, muitos produtores de morango têm feito o cultivo por dois ciclos consecutivos. No entanto, há necessidade de estimar o desenvolvimento fenológico e avaliar o potencial agronômico do morangueiro nesse sistema. O objetivo deste trabalho foi comparar a necessidade térmica, a taxa de aparecimento foliar, o filocrono e a produtividade de cultivares de morangueiro no segundo ciclo de cultivo, em comparação ao primeiro, na região do Terceiro Planalto Paranaense. Avaliaram-se as cultivares Camarosa, Camino Real, Albion, Aromas, Monterrey e San Andreas, utilizando o delineamento experimental de blocos ao acaso e com quatro repetições. A taxa de aparecimento foliar foi estimada a partir do coeficiente angular da regressão linear entre o número de folhas e a soma térmica acumulada, enquanto o filocrono foi estimado pelo inverso do coeficiente angular da regressão. Observou-se que Aromas foi a única cultivar que aumentou a produção de frutos no segundo ciclo. Ao contrário, nesse mesmo ciclo houve considerável redução da produção para 'Camino Real', 'Albion', 'Monterrey' e 'San Andreas'. Destacaram-se com maior número e massa de frutos comerciais do segundo e primeiro ciclo, 'Camarosa' e 'Camino Real', respectivamente. No segundo ciclo de cultivo, as cultivares de morangueiro necessitaram menor soma térmica acumulada para iniciar o florescimento e colheita dos frutos e, apresentaram maior taxa de aparecimento foliar e menores valores de filocrono.

Palavras-chave: *Fragaria x ananassa*, emissão de folhas, filocrono, produção, soma térmica.

Strawberry (*Fragaria* x *ananassa*) is cultivated in a wide geographic distribution due to its ability to adapt to different soil and climatic conditions (Morales *et al.*, 2012). This small fruit is the most widely cultivated and consumed fruit in the world (Tazzo *et al.*, 2015). In Brazil, it is mainly produced in small rural properties. In recent years, there has been a considerable increase in its production (Witter *et al.*, 2012).

The main strawberry cultivars in Brazil derive from genetic improvement programs conducted in the United States, with emphasis on 'Oso Grande', 'Camarosa', 'Aromas', 'Diamante', 'Camino Real', 'Albion', Monterey', 'San Andreas', 'Palomar' and 'Portola', developed at the University of California; 'Dover', 'Sweet Charlie' and 'Florida Festival', were developed at the University of Florida. These materials

should be evaluated on productivity, quality, growth and vegetative development (Tazzo *et al.*, 2015).

Aiming greater economic returns after seedling transplanting, many strawberry producers have cultivated the same plants for two or more consecutive cycles. Family farmers in the municipality of Guarapuava-PR, located in the region of the Third Planalto Paranaense, have reported

that production is lower in the second production cycle than in the first one. However, fruits are produced earlier, thus guaranteeing a high market value. In that municipality, approximately 60 tons of strawberry were harvested in 2017, amounting approximately R$ 900,000. However, there is yet no scientific information on the productive potential of strawberry in the second cycle compared to the first one.

The knowledge on the phenological behavior of a particular plant species or cultivar is of extreme importance since it is a tool for forecasting events and making decisions regarding crop management (Pereira et al., 2010; Tomazetti et al., 2015). Among the factors closely related to changes in phenological stages, temperature is the most relevant. It results in thermal energy and drives vegetative development and growth (Liu & Heins, 2002). In first-cycle strawberry plants, there is a close relationship between temperature and vegetative canopy formation (Mendonça et al., 2012a,b,c; Tazzo et al., 2015). However, similar to the productive potential, second-cycle plants may present a different developmental response to air temperature.

A biologically realistic measurement for estimating growth and development regarding air temperature is the thermal sum (°C days) (Streck et al., 2008; Heldwein et al., 2010; Lucas et al., 2012). It has a greater meaning regarding plants than calendar days. Based on the thermal sum, it is possible to estimate the number of leaves in strawberry by means of phyllochron (°C day leaf⁻¹), which is the time interval between the appearance of two successive leaves in the main canopy (Xue et al., 2004; Streck et al., 2005).

Studies using the phyllochron concept have been carried out on several agricultural species, such as barley and wheat (Xue et al., 2004), safflower (Streck et al., 2005), lettuce (Hermes et al., 2001), eucalyptus (Martins et al., 2007) and tomato (Pivetta et al., 2007). Regarding strawberry, Tazzo et al. (2015) evaluated the phyllochron in two selections ('SEL1' and 'SEL2') and in the cultivars Camino Real, Camarosa, San Andreas and Albion. The authors

verified that there was variability among them, with a lower phyllochron value for selection 1 (69.96º day leaf⁻¹) and a higher value for the Albion cultivar (135.61º day leaf⁻¹). Mendonça et al. (2012a) verified a variation in phyllochron values among strawberry cultivars in strawberry intercropped with fig trees and in single crop.

Although there is information on phyllochron for strawberry cultivars, it is necessary to identify their phenological performance at the site of cultivation (Tazzo et al., 2015). In addition, there is a need to determine the growth, development and agronomic potential of second-cycle strawberry. Considering the aforementioned information, the objective of this study is to estimate thermal needs, leaf emission rate, phyllochron and yield of strawberry cultivars in second crop cycle in comparison to the first cycle in the Terceiro Planalto region of Paraná.

MATERIAL AND METHODS

The experiments were conducted at the Center for Research on Vegetables of the Department of Agronomy of the State University of the Center-West (UNICENTRO) located in the municipality of Guarapuava, Paraná (25°38'S, 51°48'W, 1,100 meters altitude). This region belongs to the Third Planalto Paranaense. The climate, according to Köppen's classification, is Cfb (humid mesothermic subtropical), temperate, with no defined dry season, hot summers and moderate winters (Wrege et al., 2011). The soil is classified as typical dystroferric Bruno Latosol (Embrapa, 2013).

The strawberry cultivars Camarosa, Camino Real (short-day cultivars), Albion, Aromas, Monterrey and San Andreas (neutral day cultivars) were evaluated in the second and first cycles in 2014. The experimental design was randomized blocks with four replications, with each plot consisting of twelve useful plants. The two crop cycles were studied in individualized experiments.

Second-cycle plants were commercial seedlings imported from

Chile in 2013, certified and diseases free, cultivated during the 2013-2014 harvest. Seedlings were kept in the same place of cultivation of the previous cycle in 2014, in a low tunnel. They were managed according to climatic elements, subjected to removal of all leaves (toilet) on June 20, 2014, and then used to conduct one of the experiments. The first-cycle plants were commercial seedlings imported from Chile in 2014, and transplanted to the field at the beginning of July in order to conduct the other experiment.

The cultivars of both cycles were planted in a 0.8 m-high tunnel system, covered with a transparent 75-micra low-density polyethylene film (LDPE), on beds 1.0 m wide and 0.25 m high, covered with a 50-micra black polyethylene film. Plants were arranged in a quincunx, on 30x30 cm spacing.

Based on chemical analysis, the soil was corrected three months before transplanting by applying 50.0 g per m² of dolomitic limestone (75% PRNT), in order to reach 80% base saturation. At the moment of transplanting the first-cycle and pruning second-cycle leaves, 200 g single superphosphate, 25 g potassium chloride, 25 g urea and 2.5 kg cattle manure were applied on the surface of each plot and incorporated into the soil, as recommended by Henschel et al. (2017).

Phytosanitary control was performed using preventive sprays of commercial products containing thiamethoxam (Actara) and azoxystrobin + diphenoconazole (Amistar Top) according to technical manufacturer recommendations. Irrigation was performed by micro-drips according to practical observations of crop's water requirement.

During the experimental periods, daily data of minimum (Tn) and maximum (Tx) air temperatures were collected at the automatic meteorological station of the Center-West State University, located 120 m from the experiment. In second-cycle plants, the number of leaves (NL) of each plant was counted after thinning. For the first cycle, NL count was performed after leaf emission. A leaf is new when it is at least 1 cm long. The

NL count was performed every five days until the beginning of fruit harvest. During the cycle, the time when plants started flowering was also recorded. It was defined when 50% of the plants had at least one inflorescence per plant. The beginning of the harvest was defined when at least 50% of plants had at least one fruit at harvest stage.

The fruits were harvested at a maturation stage with 2/3 red staining. They were evaluated in their production components: number of marketable fruits (NCF, plant fruit^{-1}), total number of fruits (TNF, plant fruits^{-1}), mass of marketable fruits (MCF, g plant^{-1}) and total fruit mass per plant (TFM, g plant^{-1}). Fruits were considered marketable with a mass greater than 10 g without defects (wilted, deteriorated, malformed, mechanically damaged or attacked by diseases or pests).

The daily thermal sum (TSd, °C day) was calculated as proposed by Arnold (1960): TSd = (Tm - Tb) * 1 day (1). The mean air temperature (Tm) was determined by the arithmetic average between Tn and Tx of the air. Tb is the base temperature for strawberry leaf emission, below which there is no emission of new leaf structures. The adopted Tb was 7.0°C (Mendonça *et al.,* 2012a; Tazzo *et al.,* 2015). The accumulated thermal sum (TSa, °C day) was defined by summing the daily values (TSa = ΣTSd). The leaf appearance rate (LAR, leaf °C day^{-1}) was estimated using linear regression coefficient between the NL and the accumulated thermal sum (TSa, °C day). The phyllochron (°C day leaf^{-1}) of each plant was estimated by the inverse of the linear regression coefficient between NL and TSa (Streck *et al.,* 2005; Martins *et al.,* 2007; Pivetta *et al.,* 2007).

The data of the evaluated characteristics were tested for normality and homogeneity of residual variances by Lilliefors & Bartlett tests, respectively, and later submitted to analysis of variance, individually and combining both experiments. When the F test was significant, means were submitted to comparison by Tukey test at 5% probability and analyzed using the ASSISTAT software, version 7.7 (Silva & Azevedo, 2016).

RESULTS AND DISCUSSION

Due to the significant interaction between cycles and genotypes, results will be presented separately.

During the observation periods (June to October 2014) for second-cycle strawberry cultivars, the minimum temperature values (Tn) ranged from -2.0ºC (July 1st) to 15.6ºC (September 2nd) and the maximum temperatures (Tx) ranged from 11.0ºC (July 25th) to 27.2ºC (August 24th). For average air temperatures (Tm), the range was from 8.0ºC (July 1st) to 20.0ºC (August 24th). For first-cycle plants, Tn values ranged from -2.0ºC (July 1st) to 19.2ºC (October 15th), Tx ranged from 11.0ºC (July 25th) to 33.6ºC (October 17th), and Tn values ranged from 8.0ºC (July 1st) to 25.0ºC (October 10th). During the observations, there was an incidence of minimum temperatures below the base temperature (7.0ºC) at 14 and 12 days for second and first-cycle plants, respectively (Figure 1).

The values of daily thermal sum (TSd) for cultivars in the second cycle ranged from 1 to 13ºC day. In the first cycle, values ranged from 1 to 18ºC day. The beginning of flowering of all cultivars in the second cycle occurred with an accumulated thermal sum (TSa) of 188.8ºC day, lower than the first cycle, which was 381.9ºC day for short-day cultivars and 316.4**ºC** for neutral-day cultivars (Table 1).
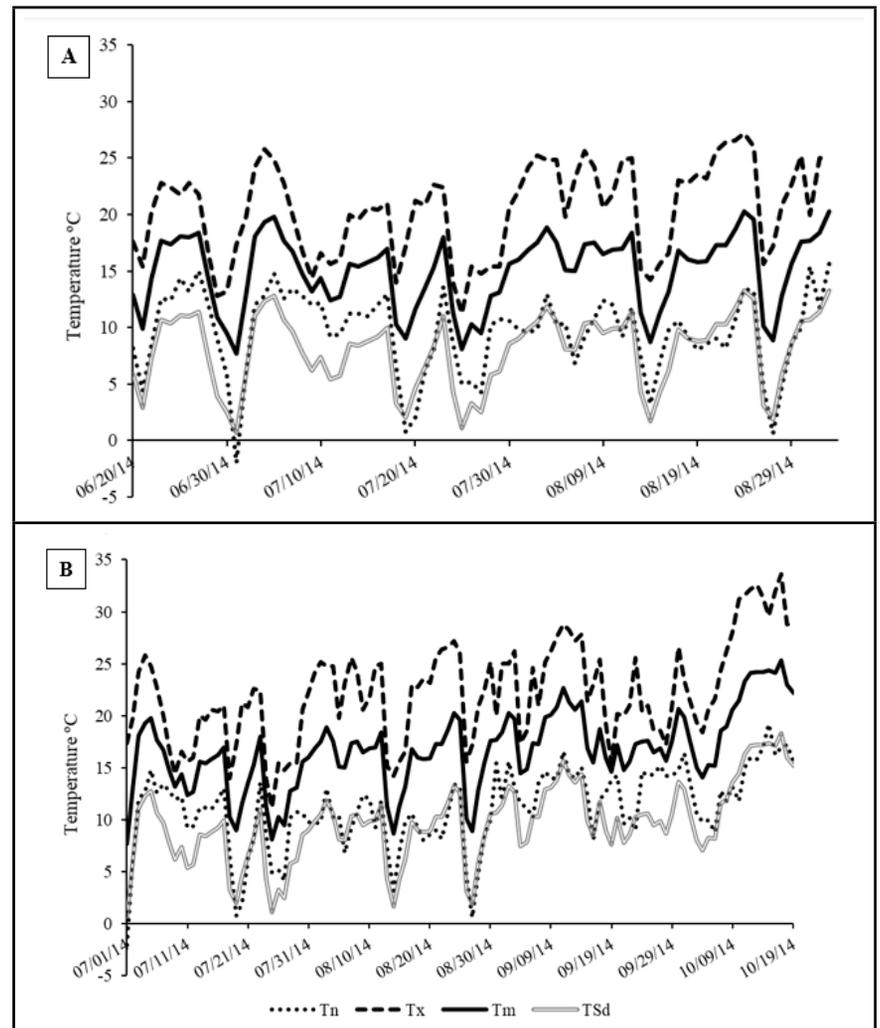

Figure 1. Minimum (Tn, °C), maximum (Tx, °C) and average air temperatures (Tm, ºC) and daily thermal sum (TSd, ºC day) during the periods considered to estimate phyllochron in strawberry cultivars of second (A) and first (B) cycles in the Third Planalto Paranaense region. Guarapuava, UNICENTRO, 2014.

Table 1. Phenological cycle of defoliation/transplanting at the beginning of flowering (D/T - Fl) and defoliation/transplanting at the beginning of fruit harvest (D/T - BFH) of strawberry cultivars of second and first cycles in the Third Planalto Paranaense region. Guarapuava, UNICENTRO, 2014.

Genotype	Second cycle		
	Defoliation	D - Fl (TSd)	D - BFH (TSd)
Camarosa	06/20/2014	07/13/2014 (188.8°C day)	09/02/2014 (598.5°C day)
Camino Real	06/20/2014	07/13/2014 (188.8°C day)	09/02/2014 (598.5°C day)
Albion	06/20/2014	07/13/2014 (188.8°C day)	09/02/2014 (598.5°C day)
Aromas	06/20/2014	07/13/2014 (188.8°C day)	09/02/2014 (598.5°C day)
Monterrey	06/20/2014	07/13/2014 (188.8°C day)	09/02/2014 (598.5°C day)
San Andreas	06/20/2014	07/13/2014 (188.8°C day)	09/02/2014 (598.5°C day)
	First cycle		
	Transplanting	T - Fl (TSd)	T - BFH (TSd)
Camarosa	07/01/2014	08/19/2014 (381.9°C day)	10/19/2014 (1,076.5°C day)
Camino Real	07/01/2014	08/19/2014 (381.9°C day)	10/17/2014 (1,045.3°C day)
Albion	07/01/2014	08/10/2014 (316.4°C day)	10/12/2014 (961.9°C day)
Aromas	07/01/2014	08/10/2014 (316.4°C day)	10/12/2014 (961.9°C day)
Monterrey	07/01/2014	08/10/2014 (316.4°C day)	10/12/2014 (961.9°C day)
San Andreas	07/01/2014	08/10/2014 (316.4°C day)	10/06/2014 (873.0°C day)

Table 2. Leaf appearance rate (LAR), phyllochron and coefficient of determination (R^2) of linear regressions between the number of leaves and the accumulated thermal sum of strawberry cultivars of second and first cycles in the Third Planalto Paranaense region. Guarapuava, UNICENTRO, 2014.

Genotype	LAR (leaf°C day^{-1})		Phyllochron (°C day leaf^{-1})		R^2	
	Second	First	Second	First	Second	First
Camarosa	0.0244 Ab*	0.0085 Babc	41.0 Bb*	117.9 Ac	0.95	0.96
Camino Real	0.0171 Ac	0.0084 Babc	58.6 Ba	120.0 Ac	0.95	0.96
Albion	0.0163 Ac	0.0070 Bbc	61.3 Ba	142.4 Ab	0.95	0.97
Aromas	0.0241 Ab	0.0109 Ba	41.8 Bb	91.8 Ae	0.95	0.96
Monterrey	0.0326 Aa	0.0062 Bc	31.0 Bc	160.8 Aa	0.93	0.94
San Andreas	0.0155 Ac	0.0097 Ba	66.8 Ba	103.5 Ad	0.96	0.97
CV (%)	8.7		5.1		-	

*Means followed by different uppercase letters on lines and different lowercase letters in columns differ by Tukey test, <5% probability.

Due to the early flowering of second-cycle cultivars, the beginning of fruit harvest was also anticipated, beginning when TSa reached 598.5°C day. In the first cycle, a higher TSa was required to reach the fruit harvest point. The thermal accumulation for the cultivar San Andreas was 873.0°C day, for Albion, Aromas and Monterrey was 961.9°C day, for Camino Real was 1,045.3°C day, and for Camarosa was 1,076.5°C day (Table 1).

The TSa values of this work for the beginning of flowering and harvesting of first-cycle fruits are close to those observed by Tazzo *et al.* (2015) for the cultivars Camino Real, Camarosa, San Andreas and Albion. This demonstrates that the thermal sum is a realistic measurement to estimate the growth and development of strawberry from a biological point of view.

Among the cultivars in the first cycle, there was variation of TSa needs to start the flowering and maturation of fruits (Table 1). This indicates that the phenological behavior based on thermal energy should also be taken into account in the choice of cultivars to be planted in a given geographic region. The knowledge on the response of phenological stages enables the prediction of management activities and the scheduling of the harvest period of strawberry fruits (Tazzo *et al.*, 2015).

The regressions between the number of leaves (NL) and TSa carried out to obtain leaf appearance rate (LAR) and phyllochron estimates showed a close relation ($R^2 \geq 0.93$) for combinations (cultivars x cycles) (Table 2). $R^2 \geq 0.93$ values indicate the existence of linearity between NL and TSa. The values also indicated that air temperature is an abiotic element highly related to the appearance of leaves in strawberry cultivars. This corroborates with the studies by Mendonça *et al.* (2012a) and

Tazzo et al.(2015).

By comparing second-cycle cultivars, Monterrey presented the highest LAR (0.0326 leaf °C day^{-1}) and the lowest phyllochron (31.0°C day leaf[-1]). For the same cycle, cultivars Camino Real, Albion and San Andreas presented the lowest values of LAR and the highest values of phyllochron. In the first cycle, Monterrey had the lowest LAR (0.0062 leaf °C day^{-1}), without differing from Camarosa, Camino Real and Albion. It also had the highest phyllochron (160.8°C day leaf[-1]). Cultivars Aromas and San Andreas had the highest LAR, without differing from Camarosa and Camino Real. Aromas obtained the lowest phyllochron (Table 2).

There was a higher LAR and a lower phyllochron for all cultivars in the second cycle (Table 2). If LAR is high and phyllochron is low, plants should have a greater efficiency for emission of leaves in function of air temperature. Higher LAR, lower phyllochron and anticipation of flowering start and harvest of fruits, of plants managed in the second cycle, possibly are due to the

fact that plants presented a developed root system and were acclimatized to the environmental conditions after transplanting. On the other hand, first-cycle cultivars underwent stresses due to the transplant process and used the first assimilates for the growth and development of the root system. In addition, there were several lateral "canopies" in the second-cycle plants. Each canopy emitted several leaves. On the contrary, seedlings initially present a single canopy in first-cycle plants, which represents a low number of leaves, low LAR and a greater phyllochron.

Only cultivar Aromas showed a gain in production components in the second cycle compared to the first cycle. Camino Real, Albion, Monterrey and San Andreas presented higher total number of fruits (TNF), total fruit mass (TFM), number of marketable fruits (NCF) and mass of marketable fruits (MCF) in the first crop cycle (Table 3).

For Camarosa, there was no difference in production components between both crop cycles. When compared to the other cultivars, the

second-cycle Camarosa showed the highest TNF (82.6 fruits) (without differing from Aromas), the highest TFM (719.2 g) and NCF (35.3 fruits) (without differing from Aromas), and the highest MCF (410.7 g). In general, although Camarosa did not stand out for production components related to marketable fruits in the first cycle, it presented the highest potential to be cultivated for two consecutive cycles (Table 3).

In relation to the first cycle after transplanting, Camino Real obtained the highest TNF (112.3 fruits) (without differing from Camarosa, Monterrey and San Andreas), the highest TFM (1,012.7 g), the highest NCF (66.7 fruits) (without differing from Albion) and the highest MCF (907.0 g). However, when Camino Real was cultivated for the second consecutive cycle, it presented a decrease in TNF, TFM, NCF and MCF (Table 3): 43.9, 40.9, 30.6 and 24.0%, respectively.

Although the cultivars Camino Real, Albion, Monterrey and San Andreas showed lower yields in the second cycle, compared to the first cycle, the use of second-cycle strawberry plants is an interesting alternative because it allows costs reduction in importation of seedlings, anticipation of fruit harvest and a greater market value. However, strawberry plants cultivated in second cycle present higher risk of pests and diseases incidence. The pruning of leaves in late fall is required, associated with preventive phytosanitary crop management.

Phenological components, in function of thermal sum calculated by the representation of biological time, are a widely used method. This method allows improving the prediction of dates of vegetative development stages (Zeist et al., 2017). Based on these components, the strawberry cultivars analyzed in this work, cultivated on the second consecutive cycle, require less thermal energy for emission of leaves, for flowering and for harvest. Such thermal values make it possible to stipulate the duration of development stages according to thermal conditions. It allows a better decision-making regarding the most appropriate

Table 3. Total number of fruits (TNF), total fruit mass (TFM), number of marketable fruits (NCF) and mass of marketable fruits (MCF) of strawberry cultivars of second and first cycles in the Third Planalto Paranaense region. Guarapuava, UNICENTRO, 2014.

Genotype	TNF (plant fruits[-1])		TFM (g plant[-1])	
	Second	First	Second	First
Camarosa	82.6 Aa	99.32 Aab	719.2 Aa	773.3 Ac
Camino Real	49.3 Bbc	112.3 Aa	414.1 Bc	1012.7 Aa
Albion	19.5 Bc	83.3 Ab	166.3 Bd	882.7 Ab
Aromas	74.3 Aa	49.7 Bc	621.6 Ab	354.0 Bd
Monterrey	59.1 Bb	95.0 Aab	571.4 Bbc	777.6 Ac
San Andreas	57.3 Bb	101.0 Aab	444.2 Bc	768.1 Ac
CV (%)	17.3		19.7	
	NCF (plant fruits[-1])		MCF (g plant[-1])	
	Second	First	Second	First
Camarosa	35.3 Aa*	37.0 Ac	410.7 Aa	482.0 Ad
Camino Real	20.4 Bb	66.7 Aa	218.3 Bc	907.0 Aa
Albion	9.0 Bc	67.0 Aa	105.0 Bd	784.3 Ab
Aromas	30.9 Aa	13.7 Bd	343.7 Ab	160.0 Be
Monterrey	25.1 Bb	59.7 Ab	321.8 Bb	643.0 Ac
San Andreas	21.5 Bb	57.3 Ab	226.6 Bc	622.8 Ac
CV (%)	16.2		18.5	

*Means followed by different uppercase letters on lines and different lowercase letters in columns differ by Tukey test,<5% probability.

management in two consecutive cycles of cultivation. However, depending on the strawberry cultivar, there is a considerable decrease in fruit production in the second crop cycle.

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