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The fertilization, pruning and controlled fires on the growth of Feijoa sellowiana (O. Berg) O. Berg.

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Abstract

Feijoa sellowiana (O.Berg) O. Berg is an ornamental and food plant, as well as an important species for ecological restoration and landscaping that still requires much research before consolidating it in the tropical market. To understand if the implementation of techniques focusing on improving fruit production at its wild condition would affect the species' development, we planted 216 saplings of various mother trees in an incomplete factorial block design applied in nine treatments. We tested formative aerial pruning (drastic intensity), fertilization (chemical and organic), and the effect of controlled fires prior to planting. We evaluated biomass alterations by systematically measuring the third sapling of each treatment, quantifying fresh and dry matter in two periods. We also measured changes in height (H), root collar diameter (RCD), and the H/RCD ratio. We carried out nine measurements during 27 months and used linear mixed-effects models to consolidate the long-term evaluation. Our results indicate a positive effect from the organic fertilization on the plants' height, a momentary increase in RCD caused by programmed fires, and an increase in the H/RCD ratio due to formative aerial pruning (increasing resistance). Fertilization did not accelerate the increase in RCD and had no effect on the H/RCD ratio.

Keywords: biomass, chemical fertilization, organic fertilization, tree clipping, tropical fruits

Introduction

Brazil is the most biodiverse country in the world, with at least 46,097 plant species, 43% of them are endemic (Costa & Peralta, 2015; Maia et al., 2015; Menezes et al., 2015; Prado et al., 2015; The Brazil Flora Group, 2015). Given this immense diversity, knowledge gaps on native species are widespread, even for economically relevant species. Understanding the biology and ecology of these species in an agricultural setting is necessary to make their production commercially viable (Rodrigues et al., 2009).

Feijoa sellowiana (O.Berg) O. Berg (Myrtaceae), popularly known as feijoa, is native to the Atlantic Forest and Pampa biomes in Brazil (The Brazil Flora Group, 2015, Lima, 2020). This species distributes in Ombrophillous Mixed Forest and transition zones with grasslands (Lima, 2020). Feijoa is popularly used for restoration, landscaping, and agriculture (Coradin et al., 2012; Moretto et al., 2014). It is a shrub that can reach up to 6 m in height (Santos et al., 2011; Keles et al., 2012) with vigorous blooming (Coradin et al., 2012, Ciotta et al., 2020). The fruits are popular and cultivated in eight countries (Ruberto & Trigali, 2004). In Brazil, feijoa is still sparsely produced and consumed (Moretto et al., 2014).

Advancements have enabled a more effective production of feijoa in Brazil, especially regarding its management (Coradin et al., 2012). Studies also focused on the species' genetics (Borsuk et al., 2017, Klabunde et al., 2014) and morphological aspects (Sarmento et al., 2018). Nonetheless, studies on its cultivation and development in Brazil are still scarce (Nava et al., 2016). Outside Brazil there is a wide variety of research (Mosbah et al., 2018).

It is understood that the appropriate agricultural management of a fruit crop can significantly influence its fruiting, and aerial pruning is one of the most used techniques for this. It can be applied differently, according

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to the specific goal (Scarpare Filho, 2013). It is known that intense aerial pruning can improve plant vitality and fruit production (Azevedo et al., 2013, Marchi et al., 2015). Data on performing and applying aerial pruning is still scarce (Mora et al., 2020). Another potential agricultural care is fertilization since very little is known regarding its nutritional requirements. It is known that fertilization and substrate type can influence the growth of feijoa (Nave et al., 2016). Despite their risks and legal limitations, the use of controlled fires can positively affect the plants since it is a possible event in their natural habitat (Serger et al., 2013).

Our main questions were: (i) can drastic aerial formative pruning have a positive effect even in young plants?; (ii) will fertilization (chemical or organic) positively affect the plants' growth?; and (iii) are controlled fires beneficial when carried out prior to planting?

Material and methods

The experiments were carried out at a farm in the municipality of Campo Largo, Paraná. The study area is located at 956 m MSL in a Mixed Ombrophilous Forest (AF) region (Maack, 2012). The climate is Subtropical Moist (Cfb), mesothermic, with cool summers and, without a dry season (Maack, 2012). The average temperature during the warm season is 24.2ºC and 17ºC during the cold season. The mean annual rainfall is 1,333 mm (Nitsche et al, 2019).

The experiment was divided into four stages: sapling production, experimental design implementation, and *in situ* sapling growth evaluation; and statistical analyses.

Sapling production

Seeds were collected from mother trees over 100 m apart (in Palmas, Paraná) to avoid low genetic variability during the experiment and, consequently, genotypic and phenotypic interferences in the results (Hoffmann, 2015). Mature fruits were directly collected from different mother trees or the ground during March 2017. Fruit and seed processing and seed storage and planting followed Sociedade Chauá (2018). We selected 216 saplings from six different mother trees, according to planting aptitude standards of height (H) above 15 cm, root collar diameter (RCD) between 5 and 10 mm, and H/RCD ratio below 10 cm/mm^{-1} (Gomes & Paiva, 2011).

Experiment design and implementation

The experiment was conducted over a flat topography and homogeneous and high fertility soils - pH from 7.42 to 7.50, 42.82 g/dm^3 organic matter, 118.83 mg/dm^3 of phosphorous, 76.8 mg/dm^3 of potassium, 8.56 cmol$_c$/dm^3 of magnesium, 10.88 cmol$_c$/dm^3 of calcium, SMP index of 7.42, and cation-exchange capacity (CEC) at 7.0 pH of 23.14 cmol$_c$/dm^3. The experimental design aimed to test the effects of chemical and organic fertilization and drastic formative aerial pruning on the saplings' height, diameter, and biomass. Furthermore, it also aimed to test if controlled fires previous to planting can be beneficial to these treatments.

We planted each sapling 0.8 m apart from each other, arranged in rows 1.0 m apart. This arrangement resulted in eight incomplete rows since there was a variation in the number of treatments (Bittencourt et al., 2003). We opted for a factorial design to test each factor under different degrees, carrying out interest estimates based on their main effects and interaction (Bittencourt et al., 2003). A total of 408 saplings were used, from which just 216 were evaluated, with the remaining saplings planted around the experiment to reduce external effects. The pits were dug with the aid of a moto-digger (15 cm in diameter by 30 cm in depth). Watering was performed every other day during the first month (2 liters/ sapling), except on rainy days.

Plots were arranged in lines to avoid contamination and interferences related to fertilizing and soil fertility, which is also divided into two sections: (i) without fire influence; and (ii) with fires influence on the superficial layer of the organic matter (in this case the fires were carried out before planting. To ensure a standardized burning, the dry matter was spread uniformly on the section.).

Nine different treatments were tested: T1 – control; T2- chemical fertilizing, aerial pruning; T3 – organic fertilizing, aerial pruning; T4 – chemical fertilizing; T5 – organic fertilizing; T6 – burned area, chemical fertilizing, and aerial pruning; T7 – burned area, organic fertilizing, and aerial pruning; T8 – burned area and chemical fertilizing; and T9 – burned area and organic fertilizing. A total of 24 saplings were planted in each treatment, with six saplings from each origin (mother tree) in each repetition (**Figure 1**).

To perform the treatments, we made use of chemical (macronutrients) and organic fertilization, performed during planting and repeated every three months as a topsoil cover. For chemical fertilization, we followed the specifications indicated for species of Myrtaceae (Moraes Neto et al., 2003), with some modifications: 35 g mixed granulated mineral fertilizer (NPK 15-10-10) per sapling. We used compost produced by the Horto Municipal de Campo Largo for organic

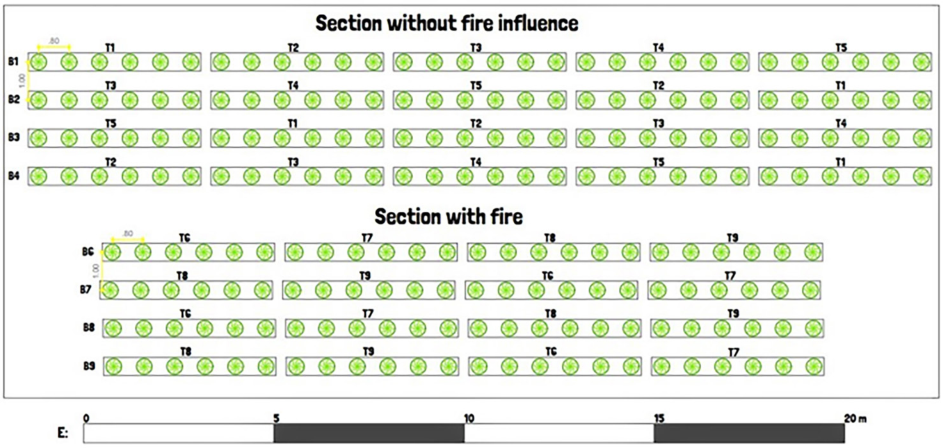

Figure 1: Distribution of saplings, plots, and treatments in the experiment

fertilization, mixed with organic residues, with two liters applied per plant (Moraes Neto, 2003).

Aerial pruning was carried out only once, on the same day as planting, using sheers to reduce the plants' average height from 65 to 35 cm (measured from the root collar) by cutting the trunk and not leaving any branches. This represents drastic formative pruning (Scarpare Filho, 2013). Despite being uncommon to carry out drastic pruning during planting, we performed to verify if saplings would have a more immediate response, improving their vitality.

In situ sapling growth assessment

We measured the saplings' height (H) with a millimeter ruler and their root collar diameter (RCD) with a digital caliper (0.05 mm precision). The experiment started on December 19th of 2017, with nine new measurements carried out during the following 27 months at January 9th of 2018, February 11th of 2018, March 2nd of 2018, April 22nd of 2018, June 10th of 2018, August 9th of 2018, October 8th of 2018, January 2nd of 2019, and April 15th of 2020. We calculated the increase of H and RCD during that period based on the difference between consecutive measurements.

We consider that the saplings' initial survival and growth in situ are directly associated with biomass values to evaluate the biomass. Therefore, they provide means of assessing the saplings' growth and quality, indicating their rusticity aspects (Gomes & Paiva, 2011).

We collected data for biomass evaluations on October 24th of 2018 and April 23rd of 2020. We used an analytic scale with 0.0001 g precision for measurements. During the first assessment, we removed the third sapling of each treatment in each block, resulting in 36 saplings. In case the selected sapling was dead, the subsequent one was used. Firstly, roots were washed under running water to remove all substrate. Then, the saplings were placed in a shades area left to air dry, removing the excess tissue water. This material was separated into roots, stems, and leaves.

During the second biomass assessment, using the same logical sequencing as the first evaluation, comprising a total of 36 saplings (one for each treatment in each block), we only collected the plants' aerial portions. This decision was made considering it would be impossible to collect the complete root system of plants that size properly. The measurements were done using the fresh biomass of each plant and each organ (e.g., stems/branches, leaves, flowers, fruits). Dry biomass was measured after the sorted material was properly labeled, allocated into paper bags, and placed in a plant drier at 60°C for 48 hours.

Aside from measuring fresh and dry biomass, for the first assessment, we calculated the Dickson quality index, which demonstrates the balance between total dry biomass (TDB), aerial dry biomass (ADB), radicular dry biomass (RDB), aerial height (H), and root collar diameter (RCD) (DICKSON et al., 1960):

$$DQI = \frac{TDB}{\frac{H}{RCD} + \frac{ADB}{RDB}}$$

Where: DQI = Dickson quality index; TDB = total dry biomass (g); H = aerial height (cm); RCD = root collar diameter (mm); ADB = aerial dry biomass (g); and RDB = radicular dry biomass (g).

Statistical analyses

The diameter increase, height increase, and HDR variables were analyzed based on linear mixed-effects models, which allowed us to model repetitive measurements through time (Zuur et al., 2009). The models' fixed effect was parameterized using the treatment, rows, and evaluation periods variables (associated with the treatments). The random effect was parameterized to have random intercepts for each individual.

The homoscedasticity and normality of the residuals assumptions and the presence of outliers were visually checked (Zuur et al., 2010). In case of lack of homogeneity, weighted models with different variance structures were used. These weights were fixed variance (function *varPower*) and different variance per stratum (function *VarIdent*) (Pinheiro & Bates, 2000). The latter was parameterized so that each treatment varied in each evaluation period. When necessary, the logarithmic transformation of the data was used to reach the residuals' normality.

The significance of the variables was evaluated using the x^2 Wald test with the sum of squares type III, as the models were parameterized with interactions based on unbalanced data (the number of sampling units -individuals- was unequal for all treatments and inconsistent over time). Statistical analyzes for biomass were performed using simple linear models. Block effect was not tested, as only one individual was removed from each treatment in each assessment. The ANOVA test was used to assess the effect of different treatments, using a 95% confidence interval. Analyzes were carried out using the *R v.4.0.2* software (R Core Team, 2020). The '*nlme*' package was used to adjust the linear mixed-effects models, the '*car*' package (Fox & Weisberg, 2011) was used to perform the Wald test, the '*lsmeans*' package (Lenth, 2016) was used to estimate measurements, confidence intervals and the *Tukey* contrast, and the '*ggplot2*' package (Wickham, 2016) was used for graph preparation.

Results and Discussion

The treatments showed no positive effect in increasing the plants' height, based on the individual measurements. However, the analysis of the measurements throughout the study shows positive effects during the last three periods. It is worth highlighting T2, T3 and T6, all of them including aerial pruning and either of the fertilization types. Treatment 3 (organic fertilization + aerial pruning) stood out during the last period, demonstrating significant growth (**Figure 2**).

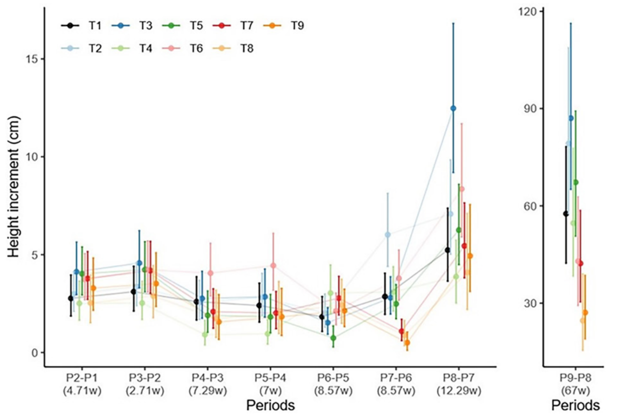

Figure 2: Mean result values for the treatments right after analyzing the increase in height (H)
****Vertical bars** represent confidence intervals of 95%. Treatments: T1 – control; T2 – chemical fertilization and aerial pruning; T3 – organic fertilization and aerial pruning; T4 – chemical fertilization, T5 – organic fertilization; T6 – controlled fire, chemical fertilization and aerial pruning; T7 – controlled fire, organic fertilization and aerial pruning; T8 – controlled fire and chemical fertilization; T9 – controlled fire and organic fertilization.

We observed increases in RCD during period 5 (P6-P5), where treatments T6 and T9 stood out. During the final period (P9-P8), treatments T1 and T5 had the best improvements. However, compared with the control, it is possible to conclude that the increase was not significant (**Figure 3**).

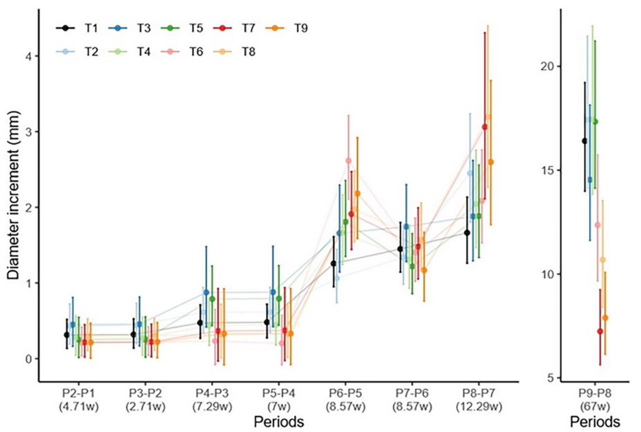

Figure 3: Mean result values for the treatments regarding the increase in root collar diameter (RCD)
**Vertical bars represent confidence intervals of 95%. Treatments: T1 – control; T2 – chemical fertilization and aerial pruning; T3 – organic fertilization and aerial pruning; T4 – chemical fertilization, T5 – organic fertilization; T6 – controlled fire, chemical fertilization and aerial pruning; T7 – controlled fire, organic fertilization and aerial pruning; T8 – controlled fire and chemical fertilization; T9 – controlled fire and organic fertilization.

The treatments affected the H/RCD ratio, considering the average value throughout the study. Treatment T3 (organic fertilization and aerial pruning) showed slightly better results than other treatments. However, considering the whole experiment, period 5

(P6-P5) shows an inversion of the treatments' effects. From this period on, treatments without aerial pruning (T1, T4, T5, T8, and T9) showed a significant reduction in efficiency, while the treatments with aerial pruning (T2, T3, T6, and T7) showed a growth interruption to slight reduction (**Figure 4**).

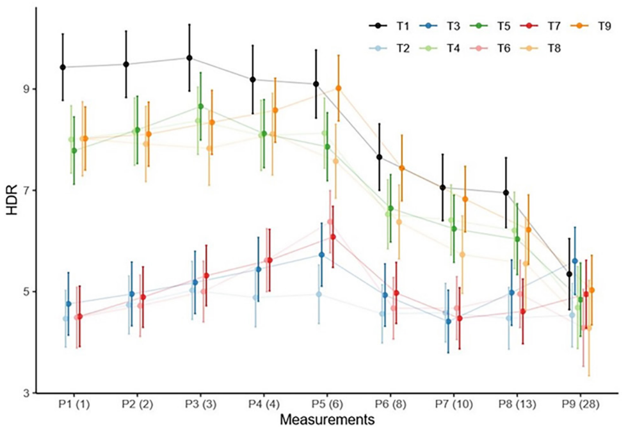

Figure 4: Mean result values for the treatments throughout the experiment regarding the height/root collar diameter (H/RCD) ratio
****Vertical bars** represent confidence intervals of 95%. Treatments: T1 – control; T2 – chemical fertilization and aerial pruning; T3 – organic fertilization and aerial pruning; T4 – chemical fertilization, T5 – organic fertilization; T6 – controlled fire, chemical fertilization, and aerial pruning; T7 – controlled fire, organic fertilization, and aerial pruning; T8 – controlled fire and chemical fertilization; T9 – controlled fire and organic fertilization.

Drastic formative aerial pruning promoted a stable H/RCD ratio during the experiment. However, fertilization did not have a significant effect. No treatment stood out in the increase of biomass during our assessments (**Figure 5**) and showed no influence over the Dickson quality index (DQI) (**Table 1**).

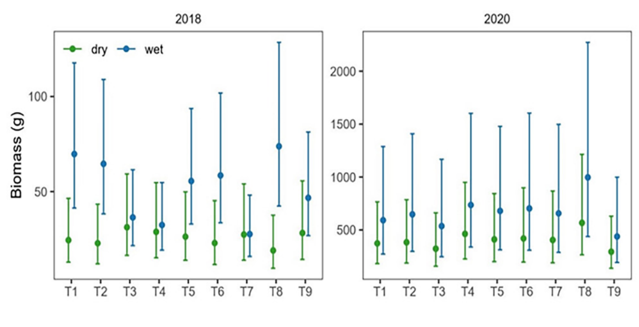

Figure 5: Result values for the treatments during two biomass (fresh and dry) assessments (October 24th of 2018 and April 23rd of 2020)
****Vertical bars** represent confidence intervals of 95%. Treatments: T1 – control; T2 – chemical fertilization and aerial pruning; T3 – organic fertilization and aerial pruning; T4 – chemical fertilization, T5 – organic fertilization; T6 – controlled fire, chemical fertilization and aerial pruning; T7 – controlled fire, organic fertilization and aerial pruning; T8 – controlled fire and chemical fertilization; T9 – controlled fire and organic fertilization.

Table 1 – Analysis of variance for the Dickson quality index (DQI) for different treatments during the first biomass assessment (X months after planting)

Variável	SQ	Mean SQ	F value	p value
Dickson quality	1.517	0.190	0.56	0.80
index	8.795	0.338	-	-

Caption: SQ – square sum; F value – calculated F value; p value – calculated p value

In Brazil, studies on domestication and introduction in the cultivation of feijoa were commenced during the 1980s by the EPAGRI, a state government agricultural research company (Santos et al., 2011). Summarizing the convictions about the plant, it is known that is hardy and frost-resistant, withstanding up to -13°C (Ruberto & Trigali, 2004) and has a good germination rate (Sociedade Chauá, 2018). Our results extend the discussions about the species.

We observed that the height increase was affected by organic fertilization, which is confirmed by T3 treatment during the last period. This treatment had organic fertilization as a differential among the treatments that stood out. This outcome was expected since each species' nutritional demands influence the establishment and survival of saplings *in situ* (Soreano et al., 2012). The significantly positive effects, especially during the final assessment period, indicate that a slowly triggered nutritional fertilization is beneficial for this species' cultivation. In naturally fertile soils, it is possible to predict that 27 months after planting, fertilization becomes a relevant factor in the saplings' development. *Feijoa sellowiana* is known for its high organic matter and phosphorous demand, its sensibility to excessive nitrogen levels, and its preference for pH corrected soils (Manica, 2002). The growing conditions during this experiment (soil quality and treatment) and the significant positive effects caused by the organic fertilization in the increase oh height, even only during the last assessment period, reinforce this information.

The lack of significant positive fertilization (chemical and organic) results in increasing RCD are unexpected since fertilization is a generally decisive factor in Myrtaceae cultivation (Dalanhol et al., 2016). This result may be related to indications that feijoa does not respond to the application of nutrients in the first years of cultivation (Nava et al., 2016). It is also possible that the fertilization used by us was insufficient to affect the plants positively. Thus, it is necessary to carry out further studies with different and increased fertilization approaches. It is important to stress that research on the nutritional management of this crop is scarce, which makes fertilisation and liming recommendations difficult, whether before or after planting the seedlings (Nava et al., 2016).

We found that the nutritional behavior of *Feijoa sellowiana* can lead to an increase in productivity, reduced costs, and reduced environmental impacts, as observed for several forest species (Souza et al., 2006). A study with Myrtaceae species (*Eugenia uniflora* L. and *Campomanesia xanthocarpa* O. Berg) showed that fertilization increased the growth of (Dalanhol et al., 2016). This increase goes as high as doubling the growth of the fertilized plants compared with the control group.

The increase in RCD was significantly positive in treatments T6 and T9, which can be attributed to controlled fires. It is important to highlight that the increase was temporary and observed only during specific periods. It is known that fires can increase N, P, K, Ca, and Mg levels in the soil through the resulting ashes (Rheinheimer et al., 2003). Depending on the application time and temperature, fire can work as a nutrient mineralization agent, making them available in the soil for short periods (i.e., a few months). This sudden availability of nutrients directly affects the fertilization recommendations for the plants and soil management (Simon et al., 2016). Fires' negative effects are generally associated with a reduction of pH and the increase of aluminum in the soil (Rheinheimer et al., 2003). A hypothesis that would justify the results for treatments T6 and T9 would be that due to the soil's pH and macronutrient conditions, the fire favored only the positive nutritional aspects, even if for a short period.

The results of the H/RCD ratio demonstrate that the drastic formative aerial pruning caused the stability of the H/RCD during the experiment. This interpretation is supported by this being the factor that stood out during successful treatments, especially T3. Our experiment also demonstrated that fertilization had no positive effect on the plants' H/RCD ratio. Since higher H/RCD values resulted in plants being less resistant to adverse environmental conditions (Silva et al., 2007), it is possible to infer that drastic formative aerial pruning increased the plants' resistance and vitality without causing not decrease in growth. According to Silva et al. (2007), the smaller this ratio, the greater the plant's body balance and survival chances. Therefore, the tendency to decrease the H/RCD ratio after assessment period 5 (Figure 4) represents a positive result. Positive results of aerial pruning in improving the fruit set of mature individuals of *Feijoa sellowiana* (Nonante and Alcântara cultivars), in quality and quantity, were recorded by Mora et al. (2020), the fruits of the pruned trees showed a significant increase in diameter and length, increasing the total weight of the fruits by 12.7% for the cultivar Alcântara and 35.4% for the cultivar Nonante.

The biomass values were not significantly affected by the treatments and were kept within the species' natural variation range. The DQI was also not significantly affected by the treatments, but on average remained (0.29), remained above the recommended value (0.20) (Gomes & Paiva, 2011). This demonstrates that the saplings, at least initially, remained within quality standards. Furthermore, during the experiment, these indexes' mean values increased gradually, which indicates a proportional increase of the plants' life quality (Gomes & Paiva, 2011).

Conclusions

Feijoa sellowiana showed a positive response to (i) organic fertilization, increasing its growth in height; (ii) drastic formative aerial pruning, increasing the plants' resistance; and (iii) controlled fires, increasing the RCD during a short period. Despite controlled fires being beneficial, we do not recommend their implementation since their effects were temporary and not complementary to the other agricultural cares. These results can help improve this species' cultivation and serve as a basis for establishing future experiments.

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