



Structural assessment of a population of *Anacardium humile* subjected to fire during different periods of the year

Diego Guimarães de Sousa^{1*}  and Héli da Ferreira da Cunha² 

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ABSTRACT

Understanding how fire affects the plant biota of the Cerrado is essential for formulating conservational strategies. We evaluated the effects of fires during different periods of the year on the populational structure of *Anacardium humile*. The research was carried out in areas of typical cerrado *stricto sensu* in the territory of the Kalunga, state of Goiás, Brazil. These areas, which comprise the same population, were submitted to the following treatments: unburned (control), burned in May 2016 (early fire - EF), and burned in September 2016 (late fire - LF). In July 2018, we delimited two contiguous transects of 100 x 20 m, subdivided into 10 plots of 20 x 20 m, in each area. Fire stimulated the development of branches from basal regrowth in EF and LF. No differences were found in height and diameter of individuals among LF, EF, and the control area. Individuals of EF had size patterns similar to the control individuals, indicating a lesser effect of early fire. The greatest differences regarding all significant parameters were found between LF and control individuals. Early prescribed fires, depending on periodicity, may be less harmful to *A. humile*.

Keywords: Anacardiaceae, burning, Cerrado, fire, impact, regimes

Introduction

Fire can change the structure, dynamics, and phenological behavior of Cerrado plant communities and populations (Medeiros & Miranda 2005; Libano & Felfili 2006). For at least 10 million years, the Cerrado coexists with fire (Simon *et al.* 2009), which resulted in the adaptation of plants (Coutinho 1990; Eiten 1994). Natural fires are caused by lightning and are more frequent at the end of the dry season and during the rainy season (Ramos-Neto & Pivello 2000). However, about 35,000 years ago, the occurrence of fires started to change due to human actions (Watanabe *et al.* 2003). In recent history, these anthropogenic fires have been increasingly frequent and concentrated in the dry

season (Fidelis & Pivello 2011), becoming one of the main threats to the Cerrado biodiversity (Durigan *et al.* 2007).

Consecutive fires affect the reproduction and phenology of Cerrado plants (Whelan 1995). The success of regrowth is higher in wood and shrub species in savanna-like phytophysionomies (Coutinho 1990; Ramos 1990; Hoffman 1998; Felfili *et al.* 1999). However, for other species, such as monocotyledons that occupy the lower strata, sexual reproduction is stimulated through post-fire flowering (Maitre & Midgley 1992; Abrahamson 1999; Munhoz & Felfili 2005; 2007; Miola *et al.* 2010).

The timing and frequency of fires can affect flowering and fruiting (Miranda 1995; Sanaiotti & Magnusson 1995; Miola *et al.* 2010; Palermo & Miranda 2012; Françoso *et al.* 2014; Deus *et al.* 2016; Sousa & Cunha 2018b), seed banks and dispersal (Cirne & Miranda 2008; Xavier 2011),

¹ Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, 74605-090, Goiânia, GO, Brazil

² Unidade Universitária, Universidade Estadual de Goiás, 75132-903, Anápolis, GO, Brazil

* Corresponding author: diegoagro97@hotmail.com



recruitment and mortality rates of many species (Medeiros & Miranda 2005; Bouchardet *et al.* 2015), and the size and distribution of regrowth (Silva *et al.* 2009; Dodonov *et al.* 2014), especially in dryer months (Sato 2003). The short intervals between fires prevent seedling development and recruitment, and successive regrowth results in depletion of storage organs (Whelan 1995; Medeiros 2002). This changes the population structure of species, and as a consequence, the entire plant community (Whelan 1995; Sano *et al.* 2008).

How fire negatively affects the reproduction of Cerrado plants depends on spatial and temporal variations of the fire, edaphoclimatic factors, as well as flame height, speed, and intensity (Miranda *et al.* 2010). Besides, it depends on the inherent attributes of each species such as size, architecture, phenology, reproductive success, mechanisms of seed protection, and seedling resprouting (García-Núñez *et al.* 2001; Bouchardet *et al.* 2015; Lucena *et al.* 2015; Gawryszewski *et al.* 2019). Furthermore, the amount and moisture of plant fuel and the structure and organization of plant communities influence the fire behavior (Castro & Kauffman 1998; Rissi *et al.* 2017).

Anthropogenic forest fires occurring during the dry season usually have higher coverage and intensity (França *et al.* 2007). In this sense, there are ongoing discussions to approve a national policy to prevent and fight forest fires by using prescribed fires as a conservation tool in public and private areas (Durigan & Ratter 2016; Fidelis & Pivello 2011). In this case, the use of prescribed fires at the end of the rainy season or beginning of the dry season (early fires) may reduce the amount of dead fuel that accumulates during the dry season. This would mitigate the risk of large-scale and intense fires (Pivello *et al.* 2010; Fidelis & Pivello 2011), cited as having the greatest impact on Cerrado biodiversity.

In the cerrado *stricto sensu*, early fires tend to be less intense and to have lower temperatures in comparison to mid (August, when most anthropogenic fires occur) and late fires (September, the end of the dry season), because of the lower amount of dry biomass, mainly grasses. This results in lower mortality, less damage to woody stems (Ramos-Neto & Pivello 2000; Sato 2003; Miranda *et al.* 2006; Miranda *et al.* 2009), and therefore, lower greenhouse gas emissions in the other periods (Russell-Smith *et al.* 2009). Moreover, mid and late fires occur during the period of significant phenological activity for many species of the Cerrado that lose leaves and bear fruit during the dry season (Oliveira 2008; Pirani *et al.* 2009; Silvério & Lenza 2010; Lucena *et al.* 2015). Thus, these fires can limit regrowth since part of the carbohydrate and nutrient reserves were spent on the vegetative and reproductive phenological activity of the plants (Hoffmann & Solbrig 2003; Pirani *et al.* 2009; Françoso *et al.* 2014; Dodonov *et al.* 2018).

However, there are still many gaps regarding the effect of these fires in the Cerrado biota, which requires more research to support public policies that favor the adequate use of this conservation tool (Medeiros & Fiedler 2004;

Durigan & Ratter 2016). Therefore, in this study, we aim to assess the effect of fires during different periods of the year (early and late dry season) on the population structure of *Anacardium humile* in typical cerrado *stricto sensu* areas. Changes in populations - as addressed in the present study - depend on individual characteristics (Bond & Wilgen 1996) that are essential to recognize the ecosystem responses to fire. These individual characteristics can be observed in a shorter period than those related to the effect of the season and frequency of fires on communities and ecosystems (Giroldo 2016).

Anacardium humile is a small shrub and subshrub species, abundant in the territory of the Kalunga, in the state of Goiás (Sousa & Cunha 2018a), and it is subject to damage directly caused by high- or low- intensity fires (Carvalho *et al.* 2005), which influenced its choice as model species for this experiment. We hypothesize that there will be differences in the population structure of *A. humile* among areas subjected to fires during different periods of the year. Moreover, we expect individuals subjected to early fire (May) to have a population structure more similar to those in the control area than to individuals subjected to late fire (September). In this case, the early fire would have less impact on the population of *A. humile*, reinforcing the use of this tool for forest fire prevention and species conservation.

Material and methods

Study area

The study was carried out in a cerrado *stricto sensu* area within the territory of the Kalunga community, municipality of Cavalcante, north region of the state of Goiás, Brazil (13°36'09" S and 47°27'26" W). Climate is tropical Aw (Köppen-Geiger classification) with two defined seasons, a rainy season between October and April and a dry season between May and September. The mean precipitation is around 1300 and 1500 mm and the mean temperature is 25 °C (Fundação Grupo Boticário 2011). The population of *A. humile* is found in altitudes varying between 950 and 1052 m. The soil is sandy with rocky outcrops and gravel, classified as litholic dystrophic Neossolo (EMBRAPA - Solos 2006; Fundação Grupo Boticário 2011).

Studied specie

Anacardium humile A.St.-Hil. (Anacardiaceae), commonly named cajuí or caju-do-campo, is a heliophyte and melliferous plant (Almeida *et al.* 1998) that often occurs in *campo rupestre* and cerrado *stricto sensu* phytophysognomies (Agostini-Costa *et al.* 2016). The species is widely distributed in the Brazilian Cerrado and can also be found in Bolivia and Paraguay (Agostini-Costa *et al.* 2016). It reaches 30 to 150 cm height and has a shrubby and subshrubby habit with an underground stem (Almeida *et al.* 1998; Silveira *et al.*



2009). This small size makes the species more susceptible to anthropogenic land use and fire damage (Carvalho *et al.* 2005). On the other hand, it has deep roots, and the largest portion of its stem biomass is underground. The presence of xylopodium provides protection and resistance to fire and drought (Agostini-Costa *et al.* 2016), which makes it frequent in burned environments (Loiola *et al.* 2010). In the territory of the Kalunga, the flowering occurs between May and September, with fruiting occurring from July to September (Sousa & Cunha 2018b). The high ratio of 4:1 between male and hermaphrodite flowers (Almeida *et al.* 1998), the inability of some hermaphrodite flowers to turn into fruits, the tendency of stamen pollen grains to remain attached to the anther after dehiscence, and the existence of only one fertile stamen in the staminate flowers are mentioned as reasons for its poor pollination (Ferrão 1995). The true fruit is reniform, with hard and dry pericarp, brown in color, reaching its final size before the pedicel thickens and modifies to a berry shape (Barroso *et al.* 1999). False fruits and true fruits are valued locally as a food source (Almeida *et al.* 1998).

Experimental design and inventory

In 2015, the Centro Nacional de Prevenção e Combate aos Incêndios Florestais (PREVFOGO) of the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) started to perform prescribed fires in the territory of the Kalunga. In 2016, in agreement with the actions of IBAMA/PREVFOGO, we subdivided an area without fire records for at least five years, which comprises the same population of *A. humile*, into two areas. The first area, with about three hectares, was subjected to prescribed fire on May 14th, 2016 (beginning of the dry season), and became the experimental area 1, hereafter called early fire - EF. The second area, with just over 30 hectares and adjacent to the burned area, remained protected from fire and became our control area. However, in September 2016 (end of the dry season), a fire occurred in the control area and consumed approximately five hectares. This area was then used as the experimental area 3, hereafter called late fire - LF. The flames in the EF area were, on average, 0.33 m height, with average fire spread of 0.019 m/s, and in the LF area, the flames were, on average, 2.86 m height, with average fire spread of 0.11 m/s.

In July 2018, we delimited two contiguous transects of 100 x 20 m, subdivided into 10 plots of 20 x 20 m, totalizing a sampling surface of 4,000 m² in each experimental area. We performed a census of all individuals within each plot. For each surveyed specimen, we collected the geographic location within the plot (latitude and longitude) and the number of branches. We also recorded the total height (from ground level to the stem apex) and basal diameter at the ground level of the main branch (the one with the highest total height) of each plant. Finally, we measured the crown

area of each individual from the crown projections in N, S, E, and W directions, starting with the main branch.

Statistical analysis

For analysis and understanding of the results found, we emphasize that the entire area comprising the population of *A. humile* is rich in rocky outcrops. All the transects contained rocky outcrops, but the transects located in the LF (late fire) treatment had the largest area with outcrops. Since the late fire was caused by an unexpected fire, it was not possible to relocate the transects to other areas because the objective was to inventory the individuals under that condition.

Rocky outcrop areas influence the community structure because they have few and small spaces for plants, shallow soils with low water storage capacity, constant organic matter accumulation, and great daily thermal amplitude and high insolation, besides undergoing long periods of water deficit and short periods with excessive water and floods (Harley 1995; Conceição & Giuliatti 2002; Conceição & Pirani 2005; Conceição 2006). These characteristics also influence the fire behavior since the lower amount of fuel in the exposed rock limits the fire progression and contributes to the formation of a mosaic of burned areas, with vegetation islands not directly affected by the fire (Conceição & Pirani 2005; Neves & Conceição 2010).

Considering the influence that rocky outcrops have on the abundance of *A. humile*, and the need to evaluate the effect of fires on the post-fire species abundance, the local species density before the fire events was adopted as a parameter of comparison. These species density data were published by Sousa & Cunha (2018a). The density of *A. humile* before the fire events was 104.25 ind ha⁻¹ (± 60.35), with an amplitude of 46 to 189 ind ha⁻¹. The greater the number of rocky outcrops within the plot, the greater the abundance of *A. humile*, which can be up to 70 % greater than in areas without rocky outcrops.

Statistical analyses were performed using non-parametric tests because of the non-normal distribution of data. Median values of abundance, total height, basal diameter, number of branches, and crown area of individuals in the different experimental areas were compared using a Kruskal-Wallis test (H test; $\alpha=0.05$) and a Student-Newman-Keuls as post-hoc test. We generated histograms of total height and basal diameter and compared them using the G-test ($\alpha=0.05$) to assess the differences in the population structure of *A. humile* among the experimental areas. Class intervals were defined by the formula A/K , where A represents the amplitude of mean values (height and basal diameter) and K , the number of class intervals defined by the Sturges' formula: $K = 1 + 3.3 \times \text{Log}(N)$, where N is the number of individuals (Paixão 1993).

Descriptive statistics and the G-test were performed in the Biostat program version 5.0 (Ayres *et al.* 2007) and the



H-tests were performed in the R software (R Development Core Team 2018), using the *vegan* (Oksanen *et al.* 2018) and *agricolae* (Mendiburu 2019) packages, respectively.

Results

We surveyed 120 individuals of *A. humile*, where 24 were in the control area, 22 in EF, and 74 in LF areas. The abundance of individuals were different among the areas ($H = 9.1792$, $p = 0.0102$). The number of plants were greater in LF than in control ($H = 9.9000$, $p = 0.0119$) and EF ($H = 10.5000$, $p = 0.0077$) areas. The abundance of individuals showed no difference between the control and EF ($H = 0.6000$, $p = 0.8789$) areas. The estimated density was 60 ind. ha⁻¹ in the control area, 55 ind. ha⁻¹ in the EF area, and 185 ind. ha⁻¹ in the LF area.

Although the control area showed the highest amplitude of total height and basal diameter, we found no significant difference in the median values between the studied areas (Total height: $H = 1.838$, $p = 0.3989$; Basal diameter: $H = 3.460$, $p = 0.177$) (Tab. 1). The median number of branches per individual was significantly higher in the EF (5.50 branches ind.⁻¹) and LF (4.50 branches ind.⁻¹) areas than in the control area (2.00 branches ind.⁻¹) ($H = 14.377$, $p = 0.0008$). The total amplitude of the number of branches per individual was also higher in the burned areas (EF and LF) than in the control area (Tab. 2). We found no significant difference in the median values of crown areas among the experimental areas ($H = 2.102$, $p = 0.349$). The crown area

showed a high coefficient of variation in all areas studied (Tab. 2).

Regarding the distribution of individuals by height classes, we found significant differences only between the control and LF ($G = 12.215$, $p = 0.03$) areas. The individuals in the control area reached the 165 to 198 cm in height class, while in the LF area, the individuals only reached the 99 to 132 cm class. In all areas, the class with the largest number of individuals was 66 to 99 cm in total height. Individuals taller than 165 cm were observed only in the control area. We found no individuals with a total height above 132 cm in the LF area, and in the EF area, the individuals found did not exceed the class of 132 to 165 cm (Fig. 1).

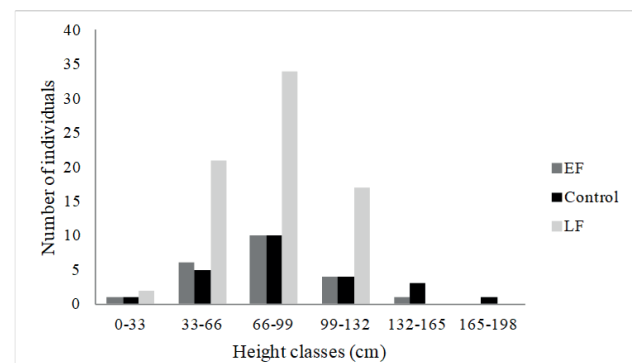


Figure 1. Height classes of *Anacardium humile* individuals surveyed in the cerrado *stricto sensu* areas with early fire (EF), without fire record for seven years (Control), and with late fire (LF), in the municipality of Cavalcante, state of Goiás, Brazil.

Table 1. Descriptive statistics of total height and basal diameter of *Anacardium humile* A. ST.-Hill individuals surveyed in the cerrado *stricto sensu* areas with early fire (EF), without fire record for seven years (Control), and with late fire (LF), in the municipality of Cavalcante, state of Goiás, Brazil.

	EF (N= 22)		Control (N= 24)		LF (N= 74)	
	Total height (cm)	Basal diameter (cm)	Total height (cm)	Basal diameter (cm)	Total height (cm)	Basal diameter (cm)
Minimum	33.00	0.50	24.00	0.30	25.00	0.40
Maximum	140.00	2.00	208.00	3.40	132.00	2.00
Total amplitude	107.00	1.50	184.00	3.10	107.00	1.60
Median	73.50 a	1.00 a	84.50 a	1.20 a	79.50 a	1.00 a
Mean	79.14	1.08	92.17	1.33	78.27	1.01
Standard deviation	28.23	0.40	40.17	0.74	24.60	0.33
Coefficient of variation (%)	35.00	36.00	43.00	55.00	31.00	32.00

Table 2. Descriptive statistics of the number of branches and crown area of *Anacardium humile* A. ST.-Hill individuals surveyed in the cerrado *stricto sensu* areas with early fire (EF), without fire record for seven years (Control) and with late fire (LF), in the municipality of Cavalcante, Goiás, Brazil.

	EF (N= 22)		Control (N= 24)		LF (N= 74)	
	Branches (unid.)	Crown area (m ²)	Branches (unid.)	Crown area (m ²)	Branches (unid.)	Crown area (m ²)
Minimum	1.00	0.18	1.00	0.09	1.00	0.08
Maximum	29.00	7.60	12.00	8.44	30.00	5.18
Total amplitude	28.00	7.42	11.00	8.35	29.00	5.10
Median	5.50 b	1.16 a	2.00 a	0.49 a	4.50 b	0.63 a
Mean	8.73	1.64	3.37	1.33	5.81	1.03
Standard deviation	7.28	1.89	3.05	1.86	4.76	1.06
Coefficient of variation (%)	83	115	90.00	139	82	103



We found significant differences in the distribution of basal diameter classes only between the control and LF areas ($G = 11.571$, $p = 0.041$). In the control area, the individuals reached the basal diameter class of 2.80 to 3.36 cm, while in the LF area, the individuals were limited to the class of 1.68 to 2.24 cm. Most of the surveyed individuals in all areas were distributed in the basal diameter class of 0.56 to 1.12 cm. The LF area had the largest number of individuals in the first basal diameter class (Fig. 2).

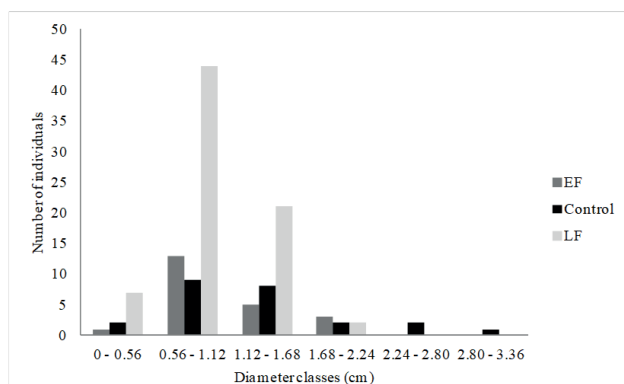


Figure 2. Basal diameter classes of *Anacardium humile* individuals surveyed in the cerrado *stricto sensu* areas with early fire (EF), without fire record for seven years (Control), and with late fire (LF), in the municipality of Cavalcante, state of Goiás, Brazil.

Discussion

The abundance of individuals was not different between the control and EF areas, and the higher abundance in the LF area may be related to the large number of rocky outcrops observed within the plots. Although the rocky area within the plots was not calculated, the LF area had a higher number of rocky outcrops than the other areas. As a result, about 60 % of the LF individuals were in rocky outcrop sites, which are preferred environments of the local population of *A. humile* (Sousa & Cunha 2018a). In this case, the fire had no influence on the abundance of individuals in the EF and LF areas.

Anacardium humile has a low potential for sexual reproduction (Carvalho *et al.* 2005). In 2016, the fruit production by the studied population was low (Sousa & Cunha 2018b). Therefore, we believe that natural regeneration had a low contribution to the abundance observed in the LF area. Nevertheless, the species germinates and develops well in sandy soils (Rodrigues *et al.* 2016; Zuffo 2018), and have high growth rates and increased leaf numbers in fire-disturbed environments (Fernandes 2012).

The fire stimulated underground or basal regrowth in individuals located in the EF and LF areas because the number of branches per individual in these areas was significantly higher than in the control area. Vegetative reproduction or branch regrowth occurs in response to

events such as fires and are common in woody plants of the Cerrado (Coutinho 1990; Muramaki & Klink 1996; Hoffmann 1998; 1999; Hoffmann & Solbrig 2003; Sato 2003; Ribeiro *et al.* 2012). Plants with heights between 1.0 and 1.5 m have higher rates of topkill and subsequent regrowth in the epigeal part of gemmiparous roots or basal stem, as a measure of rapid post-fire recovery (Miranda & Sato 2005; Vale & Lopes 2010; Ribeiro *et al.* 2012). In the specific case of *A. humile*, after losing the aerial parts due to fires, the plagiotropic shoots reactivate, reversing the growth direction. This differentiation is rapid and occurs before the grass and herbaceous regenerative organs cover the soil surface (López-Naranjo & Pernía 1990).

The median values of total height and basal diameter were not different among the areas, probably because this species is a fast-growing shrub after a fire disturbance (López-Naranjo & Pernía 1990; Fernandes 2012; Sousa & Cunha 2018a). Thus, after about two years of the fire disturbance in the areas, the individuals had similar height and basal diameter. This occurred due to the rapid growth from natural regeneration through sexual reproduction, and especially, regrowth through asexual reproduction. Considering the small size of *A. humile* individuals and the great post-fire regrowth, we found that for a single fire event, regardless of the season (early or late fire) and in at least two years, both the height and the diameter are not decisive parameters for the species survival. This pattern is likely to apply mainly to species with underground reproductive structures such as *Coccoloba cereifera* (Furst *et al.* 2017). Considering the fire recurrence, experiments have demonstrated that the diameter and regrowth capacity of individuals are key factors for their survival (Hoffmann 1998; 1999; Medeiros & Miranda 2005; Miranda & Sato 2005). In these circumstances, woody species, such as *Guapira graciliflora* and *Guapira noxia*, with low regrowth capacity, show lower survival rates (Rios *et al.* 2019) than species with underground reproductive structures (gemmiparous roots, xylopodia, and rhizophores), such as *Rourea induta*, *Myrsine guianensis*, and *Piptocarpha rotundifolia* (Hayashi 2003; Hoffmann & Solbrig 2003; Diniz & Franceschinelli 2014).

The fire regime and behavior (higher flame height and spread rate in the LF area) explain the differences observed in the distribution of individuals in the diameter and height classes between the control and LF areas. We did not find these differences between the control and EF areas, and EF and LF areas. Individuals in the highest height and diameter classes were found almost exclusively in the control area and were absent from the LF area. This shows the mass topkill effect in the LF area, which eliminated the structures with larger diameter and height. The process was followed by intense basal regrowth of *A. humile* individuals, which after a little more than two years of the fire occurrence, demonstrated smaller amplitudes.

The late fire had higher flame height (mean of 2.86 m) and spread rate (0.11 m/s) than the early fire (mean flame



height: 0.33 m; spread rate: 0.019 m/s). Considering the average height of individuals in the control area (92.17 cm), which represent the size of those within the burned areas at the time of fire spread, the flames in the LF area exceeded the size of the plants over 2 m, thus, with a great damage potential to *A. humile* individuals. Individuals in this area were more vulnerable to mass topkill, different from the EF area, where the flames had an average height of 0.33 m, lower than the average height of their individuals.

The lower values of flame height and spread rate in the EF area indicate less fire intensity. The less intense early fire resulted in a lower impact on *A. humile* individuals that showed intermediate size structures, and thus, not significantly different from those located in the control and LF areas. It is important to emphasize that, considering at least two years after the early and late fires, the fire did not threaten the local existence of the species in both EF and LF areas. This result highlights the evolutionary behavior of this species regarding fire events. One of the survival strategies of this species consists of regrowth and emission of post-fire branches in both low- and high-severity fires. Similar results were found by Dodonov *et al.* (2014) for the shrub species *Miconia albicans*.

Conclusion

Fire changed the population structure of *A. humile* individuals subjected to fires during different periods of the year, by stimulating the production of sprouts and reducing the diameter and height of their individuals. The most significant differences occurred between the LF and control areas, evidencing the effect of the higher fire intensity. As expected, individuals of the EF area evidenced an intermediate pattern between the control and LF areas. This result suggests that, depending on the periodicity, fires at the beginning of the dry season are more suitable to reduce the surface fuel of the Cerrado and to maintain the *A. humile* populations feasibly conserved.

Height and diameter parameters should not be considered as limiting factors for the survival of *A. humile*, and this pattern is related to the presence of underground reproductive structures. The regrowth capacity and rapid post-fire growth of *A. humile* individuals stand out for their ability to reproduce sexually, and they are likely the main resilience mechanisms of this species in the Cerrado. Studies assessing the effect of fire frequency and periodicity on *A. humile* populations may indicate the limit of species resilience (exhaustion of regrowth capacity) and collaborate with strategies for its conservation.

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