



## Litterfall and herbaceous plants regeneration in planted forests at post prescribed fire in the Cerrado-Amazon transition

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**ABSTRACT:** Information on the effects of prescribed burning in forest areas is essential for numerous environmental and forest production applications, including preventive maintenance against forest fires. In this article, we evaluated the effects generated at different interfaces (borders) of a homogeneous area of eucalyptus, after the occurrence of prescribed burns. The litter recovery and the regeneration of herbaceous material were evaluated, which may compose the combustible material for the occurrence of new fires. The forest inventory include measurements of circumference at breast height (CBH), commercial and total height, canopy density percentage, and number alive and dead trees. The percentage of herbaceous plants and litterfall differentiation were determined through photos taken in the field and subjected to pixel analysis in the Adobe Photoshop Cs6 program. The litterfall was classified into leaves, barks, and branches, and the herbaceous plants was subjected to identification and quantification of phytosociological variables. The prescribed fire did not affect the survival and development of trees, since the values were consistent with the community age. Leaves represented the highest litterfall fraction (47.69%) and thick branches the lowest (1.79%), both in the eucalyptus/agriculture interface. The herbaceous plants totalized 120 individuals, with predominance of grass species and had higher abundance in the eucalyptus/agriculture and eucalyptus/forest interfaces.

**Keywords:** planted forests; prescribed fire; post-fire; combustible matter; regeneration; forestry.

### Serrapilheira e regeneração herbácea em floresta plantada pós queimas prescritas na transição Cerrado-Amazônia

**RESUMO:** Informações sobre os efeitos da queima prescrita em áreas florestais são essenciais para inúmeras aplicações ambientais e para a produção florestal, incluindo a manutenção preventiva contra incêndios florestais. Neste artigo, avaliamos os efeitos gerados em diferentes interfaces (bordas) de uma área homogênea de eucalipto, após a ocorrência de queimadas prescritas. Foi avaliada a recomposição da serrapilheira e a regeneração do material herbáceo, que serão os componentes do material combustível para a ocorrência de novos incêndios. O inventário da floresta plantada incluiu medidas de circunferência à altura do peito (CBH), altura comercial e total, percentual de densidade de copa e número de árvores vivas e mortas. A porcentagem de plantas herbáceas e a diferenciação da serrapilheira foram determinadas por meio de fotos tiradas no campo e submetidas à análise de pixels no programa Adobe Photoshop Cs6. A serrapilheira foi classificada em folhas, cascas e galhos, e as plantas herbáceas foram submetidas à identificação e quantificação de variáveis fitossociológicas. O fogo prescrito não afetou a sobrevivência e o desenvolvimento das árvores, pois os valores foram condizentes com a idade da comunidade. As folhas representaram a maior fração de serrapilheira (47,69%) e galhos grossos a menor (1,79%), ambas na interface eucalipto/agricultura. As plantas herbáceas totalizaram 120 indivíduos, com predominância de espécies gramíneas e tiveram maior abundância nas interfaces eucalipto/lavoura e eucalipto/floresta.

**Palavras-chave:** florestas plantadas; fogo prescrito; pós-fogo; matéria combustível; regeneração; silvicultura.

## 1. INTRODUCTION

The forest sector in Brazil has a large representativeness in the international market of forest products, occupying the first and second place in cellulose exports and production, respectively, after only the United States (IBGE, 2021). Brazil has approximately 9.93 million hectares (ha) of planted forests ((trees planted, harvested and replanted in previously degraded areas), with 7.53 million hectares of eucalyptus plantations (IBÁ, 2022), with increasing expansion in all states of Brazil.

In the state of Mato Grosso, the planted area with eucalyptus in 2021 was 188.605 ha, with a mean increase of 28% from 2009, and an estimation of 700,000 hectares for 2028 (IBÁ, 2022). Currently, the hybrid *Eucalyptus urograndis* (*Eucalyptus urophylla* × *Eucalyptus grandis* H-13) have been planted in Mato Grosso for energy purposes focused on meeting the wood demand due to the implementation of several maize ethanol production industries in the region, and demands for drying of agricultural products and slaughterhouses (ZIERO et al., 2021).

However, homogeneous forests present high risk of fire due to the continuous accumulation leaves and branches in the ground from plants and ground vegetation that have low decomposition rates, which serve as combustible matter for fires (BORGES et al., 2012). This is worrisome, mainly in Mato Grosso, since the state presents a dry period that favors even more the incidence of fires (CASAVECCHIA et al., 2019).

The litterfall deposition and accumulation dynamics is highly variable, since the quantity of matter is affected by climate dynamics and other factors, such as the ecosystem category, plant age, planting spacing, and plant-environment interaction (CIZUNGU et al., 2014; ALONSO et al., 2015). The quantification of litterfall assists in the forest protection management for fast-growth species, such as eucalyptus, since the biomass management can be preventively done depending on the class of combustible matter, using efficient prevention techniques and control of fires (BORGES et al., 2012; ALVES et al., 2017).

Several alternatives can be adopted to mitigate or prevent the occurrence of forest fires, which are chosen depending on many factors, such as financial and technological resources and state policies (BATISTA, 2009; RAMALHO et al., 2021). The partial or total removal of combustible matter through prescribed fire is among these options; it presents positive results in biomass control and mitigation of negative effects of fires (MCCAW, 2013; ALVES et al., 2017).

Prescribed or controlled fire has been widely used as a management tool in production systems with planted forests, maintaining the habitat quality and stimulating regeneration in the managed areas (BOWMAN et al., 2009; VOGELMANN et al., 2015). According some studies, this is a practical and efficient method for decreasing combustible matter and prevent fires in eucalyptus forests that do not affect tree development and assists in decreasing weed competition, insects, fungi, and litterfall, when rationally applied (BERENHAUSER, 1972; MCCAW, 2013; GUIMARÃES et al., 2014; LIMA et al., 2020a).

Controlled fire in Brazil was legalized by Brazilian Forest Code (law 12.651/2012) and the Federal Decree no. 2.661, of 8 of July 1998, whose Article 2 considers the use of fire for the production and management in agroforestry or forest activities, and for scientific and technological researches in

areas with previously defined limits (BRASIL, 1998). However, the inconsequent use of fire can reach catastrophic proportions, by decreasing biodiversity, releasing high levels of greenhouse gases, hindering local and regional air quality, facilitating the entry and proliferation of invasive species, and modifying the structure and standards of production processes (SHLISKY et al., 2007; GUIMARÃES et al., 2014).

Therefore, information on the dynamics of *Eucalyptus* sp. regarding the production of combustible matter (litterfall and herbaceous plants) in the sub-forest, and on fire characteristics and periods more prone for prescribed fire is important (ALVES et al., 2017; LIMA et al., 2020a,b). Thus, the objective of this work was to survey, evaluate, and estimate the availability of combustible matter formed by the litterfall and regeneration of herbaceous plants in the sub-forest of a planted forest of eucalyptus in the Cerrado-Amazon transition region of the state of Mato Grosso, Brazil, in different environmental interfaces and post-controlled fire periods.

## 2. MATERIALS AND METHODS

### 2.1. Area of study

The study was developed in the Santo Antônio Farm, which belongs to the BRF Company (Brazil Food SA), in the municipality of Sorriso, Mato Grosso, Brazil (12°51'44"S, 55°52'34"W, and altitude of 365 m). The predominant climate in Sorriso is AW, hot and wet, according to the Köppen classification, with two well-defined seasons: rainy (October to April) and dry (May to September) (SOUZA et al., 2013).

The experimental area was covered with forest plantations of the species *E. urograndis* (hybrid clone of *E. urophylla* and *E. grandis* - H13) with 6.5 years of age in April 2018, with spacing of 3 × 3 meters. The plantations were in different environmental interfaces, with a border interface with agriculture (soybean/maize/cotton) at West and an interface with native riparian forest with plant formations typical of arborized savannas and submountain semi-deciduous seasonal forest at East (Delmon et al., 2013), termed in this study as eucalyptus/agriculture (EA), eucalyptus/eucalyptus (EE) and eucalyptus/ remnant of native forest (EF) interfaces (Figure 1). The eucalyptus plantation area in the EF interface were partially flooded due to proximity of a lake and the rainfall regime between October to April.

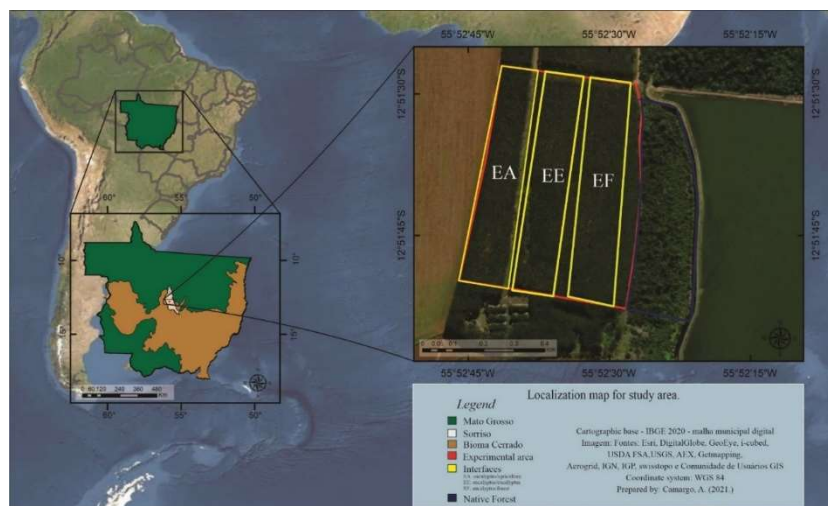


Figure 1. Experimental area with *Eucalyptus urograndis* plantation and delimitation of sampled plots in Sorriso, MT, Brazil.  
Figura 1. Área experimental de *Eucalyptus urograndis* e delimitação das parcelas amostrais em Sorriso, MT, Brasil.

Three prescribed fires were carried out in May 2015, September 2015, and August 2016 in the EA, EE, and EF interfaces of the experimental area (distant 30.0 m from the borders), thus, they were evaluated at 36, 32, and 21 months after the controlled fire, respectively, since the collections of litterfall and herbaceous plants took place in April 2018. The plots with prescribed fire were 3.0 m wide and 20.0 m long; they were designed following the planting line and were at the same level, with 1.0-m firebreaks in all interfaces. Three replications were used for each interface and post-fire periods. The control plots (reference areas) were considered in the same environmental interfaces, however they did not receive controlled burning and the plants were 77 months old.

## 2.2. Plantation inventory

The plantation homogeneity was evaluated in the different interfaces considering the following variables of trees in the plots: circumference at breast height (CBH), using a diametric tape; commercial (CH) and total height (TH), using a clinometer; canopy density percentage, using a leveled convex spherical densiometer in the combustible matter collection points; and number alive and dead trees.

## 2.3. Combustible matter collection

Combustible matter, litterfall, and herbaceous plants in the ground surface were collected in April 2018, in the three environmental interfaces (Figure 2), following the recommendations of Alves et al. (2017). Sampling points at 5, 10, and 15 m were selected in each plot; they were marked and identified after the fire. A polyvinyl chloride frame with area of 1.0 m<sup>2</sup> (Figure 2) was used to delimitate the sampling points, and thin and thick branches were sectioned in the limits of the sampling frame; then, all litterfall was collected and stored in black plastic bags, labeled, and sent for screening. The classification followed the methodology used by Rothermel (1972) and Alves et al. (2017), considering the following classes: leaves, barks, and branches. Branches were classified according to their diameters (cm) as thin ( $\leq 0.7$ ), medium ( $\geq 0.7$  and  $\leq 2.50$ ), or thick ( $\geq 2.50$ ) and then placed in paper bags (Figure 3).

The herbaceous plants within the frame area were previously classified as weeds, lianas, shrubs, and forest species, and the plants were quantified, measured for maximum height up to 1.80 m, and identified according to Lorenzi (2008). Then, the plants were uprooted with the whole root system, weighed in the field to obtain the fresh weight, and stored in labeled paper bags.

The samples of areas without fire (controls) were collected parallelly at 10.0 m distant from each plot, in interrows. In this case, five treatments were established: control, native forest, and different post-fire periods: May 2015 (36 months), September 2015 (32 months), August 2016 (21 months).

The percentage of herbaceous plants and litterfall differentiation in post-fire areas were determined through photos taken from the sampling frame areas using an above ground camera at 1.30 m height, with three replications/plots for areas with prescribed fire and one replication for controls. The images were evaluated in the Adobe Photoshop Cs6 program to determine the percentage, by counting the pixels of the images (Figure 4).

The combustible matter collected was placed in forced air-circulation oven, with temperature of  $65 \pm 2$  °C for 72 hours and then weighed in an analytical balance with precision of 0.0001 g to assess its dry weight.

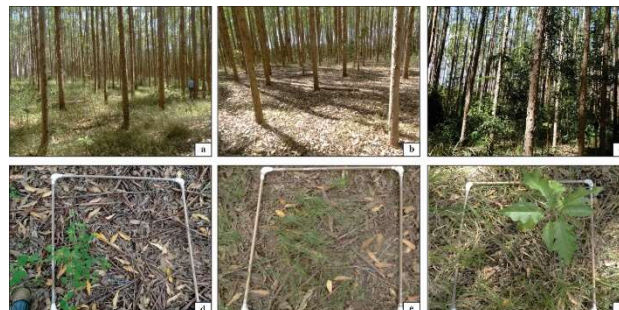


Figure 2. Environmental interfaces and frame used for the collection of combustible matter after 36-months of controlled post-fire in a *Eucalyptus urograndis* plantation in Sorriso, MT, Brazil. Wherein: EA = *Eucalyptus*/Agriculture (a and d); EE = *Eucalyptus*/*Eucalyptus* (b and d); EF = *Eucalyptus*/Forest (c and d).

Figure 2. Interfaces ambientais e quadrantes utilizados para a coleta de material combustível em 36 meses de pós-queima controlada, em plantio de *Eucalyptus urograndis* em Sorriso, MT, Brasil. Em que: (a) e (d) *Eucalyptus*/Agriculture (EA); (b) e (d) *Eucalyptus*/*Eucalyptus* (EE); (c) e (d) *Eucalyptus*/Forest (EF).



Figure 3. Classification of litterfall in *Eucalyptus urograndis* plantations into: (a) leaves; (b) bark; (c) thin branches  $\leq 0.7$ ; (d) medium branches ( $\geq 0.7$  and  $\leq 2.50$ ); (e) thick branches ( $\geq 2.50$ ); (f) storage of the screened matter.

Figura 3. Triagem da serapilheira de *Eucalyptus urograndis* em classes: (a) folhas; (b) casca; (c) galho fino  $\leq 0,7$ ; (d) galho médio ( $\geq 0,7$  e  $\leq 2,50$ ); (e) galho grosso ( $\geq 2,50$ ); (f) armazenamento do material triado.



Figure 4. Percentages of the regenerated matter: (a) sampling frame image; (b) image evaluation in the Adobe Photoshop Cs6 program; (c) statistical specifications of the image, highlighting in red the percentage of green matter collected in the interfaces with *Eucalyptus urograndis* plantations.

Figure 4. Quantificação do percentual de material regenerado: (a) imagem do quadrante amostral; (b) imagem avaliada no Software Adobe Photoshop Cs6; (c) especificações da estatística da imagem, destaque em vermelho do percentual de material verde coletado nas interfaces de *Eucalyptus urograndis*.

## 2.4. Phytosociological analysis of the burnable herbaceous plants

The following phytosociological variables of burnable herbaceous plants were analyzed: frequency (F); relative frequency (Fr); density (D), which enables to determine the quantity of plants of each species per unit of area; relative density (Dr); abundance (A); relative abundance (Air); importance index (IVI) (Mueller-Dombois; Ellenberg, 1974) and relative importance index (IVIr) (Braun-Blanquet, 1979). The variables Fr, Dr, and Air shows information on the relation between the species found in the area, and are used to obtain the IVI (Sena et al., 2019).

## 2.5. Statistical analyses

The data of the inventory were subjected to analysis of variance (ANOVA) in a 3×4 factorial arrangement consisted of litterfall and regenerated herbaceous plants, and when the means showed differences, the Tukey's test at 5% probability level was applied, both using the Sisvar statistical program (FERREIRA, 2011).

The herbaceous plants were subjected to inferential analyses following the specificities of the variables, considering the wealth, abundance, and presence/absence of species in the plant community. The analyses were carried out in the R environment. Graphics were developed using the R basic packages, and the R ggplot2 package (WICKHAM, 2016).

The rarefaction curves and extrapolation of species to the community were based on the series of Hill, using the iNEXT package (HSIEH et al., 2019), and compared considering the periods with and without fire and the EA and EF interfaces. The rarefaction indicates the wealth observed as a function of the sampling effort used, and the extrapolation.

A general linearized mixed model (GLMM) was developed to determine the variation in wealth as a function of periods of post-fire and control (VENABLES; RIPLEY, 2002). This methodology was chosen due to the existing argument in the function that corrects the spatial data with possible effect of autocorrelation. Thus, the plots were used as random variable in the model to control the spatial autocorrelation. The test for statistical significance was carried out by analysis of type II square deviations (FOX; WEISBERG, 2019).

The ordering of species of the plant community by non-metric multidimensional scaling was carried out for the

abundance analysis (OKSANEN et al., 2019). Abundance data tend to present high variation, therefore, locations that presented no occurrence were excluded before the analyses, and the transformation of Hellinger (OKSANEN et al., 2019) was applied to equal the variance, since the calculation of distances in matrices of abundance does not admit zero values.

The dimensional solutions for abundance and presence/absence data were used as dependent variable in the statistical model, since they represent the highest recovered variability of the plant community (abundance:  $r^2_{adj} = 0.46$ ,  $p < 0.001$ ; presence/absence:  $r^2_{adj} = 0.62$ ,  $p < 0.001$ ).

Multivariate models of analysis of variance were developed to determine whether abundance and presence/absence variations (represented by dimensional solutions - NMDS) are associated with the post-fire, post-fire period, or interface.

## 3. RESULTS

### 3.1. Plantation Inventory Analysis

The forest community evaluated was very homogeneous, considering that all plants had the same age (6.5 years). The effects of prescribed fire and forest and agriculture interfaces on the growth and development of the eucalyptus plantation was low.

Regarding the number of trees, a mean of 16 trees per plot was found in the areas with and without fire, with no significant difference between plots. No significant difference in tree survival rate was found between the controls and areas with fire for the interfaces EA, EE, and EF by the Tukey's test (Table 1).

The survival rate in the community was high, with minimum rate of 77.5% (32 months) and maximum of 93.75% (36 months), both in the EF interface. Regarding the mortality rate, the areas with fire showed similar results to areas without fire, with no significant difference between environmental interfaces, nor between the periods with and without fire. The maximum mortality found was 22.50% (32 months), and the minimum was 6.25% (36 months), both in the EF interface.

Regarding the CBH, the performance of the forest community showed increases as expected, considering the age of the plant, differing statistically only in the EA interface, with circumference of 51.83 cm for the 36-month post-fire and 65.95 cm for areas without fire.

Table 1. Total number of trees, percentage of living and dead trees, circumference at breast height (CHC) *Eucalyptus. urograndis* (Clone H13) plantations in three environmental interfaces over 21-, 32-, and 36-month post-fire periods and without fire (control), Sorriso, MT, Brazil. Tabela 1. Número de árvores total, percentual de árvores vivas e morta, circunferência a altura do peito (CAP) em área de *Eucalyptus urograndis* - Clone H13 em três interfaces com 21, 32, 36 meses pós-queima e sem queima, em Sorriso, MT, Brasil.

Period	Number of trees			Percentage of living (%)			Percentage of dead (%)			CBH (cm)		
	EA	EE	EF	EA	EE	EF	EA	EE	EF	EA	EE	EF
21	15.67 Aa	17.33 Aa	16.33 Aa	82.98 Aa	80.77 Aa	81.63 Aa	17.02 Aa	19.23 Aa	18.37 Aa	59.39 ABa	59.50 Aa	61.32 Aa
32	16.00 Aa	20.00 Aa	13.33 Aa	89.58 Aa	78.33 Aa	77.50 Aa	10.42 Aa	21.67 Aa	22.50 Aa	61.58 ABb	55.58 Aab	51.81 Aa
36	14.33 Aa	17.33 Aa	10.67 Aa	81.40 Aa	90.38 Aa	93.75 Aa	18.60 Aa	9.62 Aa	6.25 Aa	51.83 Aa	53.25 Aa	56.91 Aa
Without fire	15.33 Aa	16.67 Aa	14.33 Aa	86.96 Aa	82.00 Aa	81.40 Aa	13.04 Aa	18.00 Aa	18.60 Aa	65.94 Bb	58.32 Aab	51.83 Aa

wherein: EA (eucalyptus/agriculture); EE (eucalyptus/eucalyptus); EF (eucalyptus/ remnant of native forest). \* Means followed by equal uppercase letters in the column and lowercase in the row do not differ by Tukey's test at 5% probability.

em que: EA (eucalipto/agricultura); EE (eucalipto/eucalipto); EF (eucalipto/remanescente de floresta nativa). \* Médias seguidas por letras iguais maiúsculas na coluna e minúsculas na linha, não diferente entre si pelo teste de Tukey a 5% de probabilidade.

The analysis of variance for commercial height showed no significant differences between post-fire periods and controls for the EA and EF interfaces, presenting higher commercial heights when compared to trees in the center of the parcel (EE). The EE interface showed different commercial heights from the EA and EF interfaces for areas with fire in the 36- and 21-month post-fire periods, and EE and EF differed in areas without fire (Table 2).

The same result was found for total height; periods with and without fire did not differ from each other in the EA and EF interfaces, whereas for EE, the total height for the 21-month post-fire period (30.90 m) were different from that of areas without fire (36.88 m).

The percentage of occupation of canopy in the absence of fire showed differences between environmental interfaces; EF had higher percentage (72.67%), differing from EE (65%)

and EA (63%). In areas with fire, the interface EE differed statistically from the EF interface (Table 2).

### 3.2. Combustible matter analysis - Litterfall

The analyses in areas with and without fire showed no significant differences in litterfall accumulation between the EA, EE, and EF interfaces by the Tukey's test. The mean accumulation in control areas with 6.5 years of age were 23.61 Mg ha<sup>-1</sup> (EA), 18.95 Mg ha<sup>-1</sup> (EE), and 23.76 Mg ha<sup>-1</sup> (EF), denoting decreases in the center of the community (Table 3). The highest accumulation rate in the period of 21-month post-fire period was found for the EF interface (14.77 Mg ha<sup>-1</sup>). In the 32- and 36-month post-fire periods, the EA interface presented higher accumulation, 20.70 Mg ha<sup>-1</sup> and 20.71 Mg ha<sup>-1</sup>, respectively.

Table 2. Commercial to total height ratio and percentage of occupation of canopy in *Eucalyptus. urograndis* (Clone H13) plantations in three environmental interfaces over 21-, 32-, and 36-month post-fire periods and without fire (control), Sorriso, MT, Brazil.

Tabela 3. Altura comercial/total e percentual de ocupação de copa em área de *Eucalyptus. urograndis* (Clone H13) em três interfaces com 21, 32, 36 meses pós-queima e Sem Queima (testemunha), Sorriso, MT, Brasil.

Período	Commercial height (m)			Total height (m)			Canpoy percentagem occupation (%)		
	EA	EE	EF	EA	EE	EF	EA	EE	EF
21	35.61 Ab	28.98 ABa	38.91 Ab	39.99 Ab	30.90 Aa	42.26 Ab	67.66 ABab	61.33 Aa	72.33 Ab
32	34.42 Aa	31.83 ABa	33.75 Aa	39.21 Aa	35.57 ABa	38.88 Aa	73.67 Bb	68.00 ABab	66.00 Aa
36	37.98 Ab	27.28 Aa	37.27 Ab	39.92 Ab	30.66 Aa	40.12 Ab	61.33 Aa	70.33 Bb	66.00 Aab
Without fire	35.17 Aab	32.52 Ba	37.97 Ab	40.39 Aa	36.88 Ba	39.92 Aa	63.00 Aa	65.00 ABa	72.67 Ab

wherein: EA (eucalyptus/agriculture); EE (eucalyptus/eucalyptus); EF (eucalyptus/ remnant of native forest). \* Means followed by equal uppercase letters in the column and lowercase in the row do not differ by Tukey's test at 5% probability.

em que: EA (eucalipto/agricultura); EE (eucalipto/eucalipto); EF (eucalipto/remanescente de floresta nativa). \* Médias seguidas por letras iguais maiúsculas na coluna e minúsculas na linha, não diferente entre si pelo teste de Tukey a 5% de probabilidade.

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Table 4. Classes of combustible matter (Mg ha<sup>-1</sup>) in *Eucalyptus. urograndis* (Clone H13) plantations in three environmental interfaces over 21-, 32-, and 36-month post-fire periods and without fire (control), Sorriso, MT, Brazil.

Tabela 5. Classes de material combustível (Mg ha<sup>-1</sup>) em áreas de *E. urograndis* (Clone H13) em três interfaces com 21, 32, 36 meses pós-queima, e áreas Sem Queima (testemunha), em Sorriso, MT, Brasil.

Period	Interface	Leaf	Bark	T1	T2	T3	MH	Total
21	EL	4.56 Aa	4.99 Aa	1.73 Aa	2.04 Aa	0.25 Ab	0.41 Aa	13.98 Aa
	EE	4.74 Aa	4.02 Aa	1.72 Aa	1.71 Aa	0.00 Aa	0.00 Aa	12.19 Aa
	EF	4.58 Aa	2.27 Aa	1.71 Aa	3.42 Aa	0.00 Aa	2.79 Bb	14.77 Aa
32	EL	6.93 ABa	4.94 Aa	3.88 ABa	4.70 Aa	0.00 Aa	0.23 Aa	20.70 Aa
	EE	6.37 Aa	2.27 Aa	2.92 Aa	3.39 Aa	0.00 Aa	0.63 Aab	15.59 Aa
	EF	6.35 Aa	3.19 Aa	2.54 Aa	3.89 Aa	0.00 Aa	2.09 ABb	18.05 Aa
36	EL	6.03 Aa	3.18 Aa	4.81 Bb	6.67 Aa	0.00 Aa	0.03 Aa	20.71 Aa
	EE	7.04 Aa	5.13 Aa	3.57 Aab	4.13 Aa	0.00 Aa	0.00 Aa	19.88 Aa
	EF	6.34 Aa	2.62 Aa	2.66 Ab	4.56 Aa	0.00 Aa	2.05 ABb	18.22 Aa
Without fire	EL	11.26 Ba	3.72 Ab	4.44 Bb	4.13 Aab	0.00 Aa	0.06 Aa	23.61 Ab
	EE	7.26 Aa	3.27 Ab	3.70 Ab	4.72 Aab	0.00 Aa	0.00 Aa	18.95 Aab
	EF	9.19 Aa	3.01 Aab	3.36 Aab	7.64 Ab	0.00 Aa	0.56 Aa	23.76 Ab

wherein: EA (eucalyptus/agriculture); EE (eucalyptus/Eucalyptus); EF (eucalyptus/ remnant of native forest); T1 = thin branches with diameters (d) < 0.7 cm; T2 = medium branches (0.7 < (d) < 2.5 cm); T3 = thick branches (d) > 2.5 cm); EP = herbaceous plants, Mg ha<sup>-1</sup> = megagrams per hectare. \*Means followed by the same uppercase letter in the columns or lowercase letter in the rows are not different from each other by the Tukey's test at 5% probability level.

em que: EA (eucalipto/agricultura); EE (eucalipto/eucalipto); EF (eucalipto/remanescente de floresta nativa); T1: galhos finos diâmetro (d) < 0,7 cm; T2: galhos médios 0,7 < (d) < 2,5 cm; T3 grossos (d) > 2,5 cm); MH. (Material Herbáceo), Mg ha<sup>-1</sup> (megagramas por hectare). \* Médias seguidas por letras iguais maiúsculas na coluna e minúsculas na linha, não diferente entre si pelo teste de Tukey a 5% de probabilidade.

Leaves represented the highest fraction among the litterfall classes, since areas without fire presented higher deposition, standing out the EA interface, with 11.26 Mg ha<sup>-1</sup>, representing 47.69% of all combustible matter (Figure 5a), differing from the EE (7.26 Mg ha<sup>-1</sup> / 38.31%) (Figure 5b) and EF (9.19 Mg ha<sup>-1</sup> / 38.68%) (Figure 5c) interfaces; EE and EF were not different from each other.

A higher percentage of occurrence of the bark class was found in the 21-month post-fire period in the EF (32.62%) and EE (38.88%) interfaces (Figures 5a and b). No significant difference in bark deposition after the fire was found by Tukey's test, presenting means (21-, 32-, and 36-month post-fire periods) of 4.36 Mg ha<sup>-1</sup> (EA); 3.81 Mg ha<sup>-1</sup> (EE), and 2.69 Mg ha<sup>-1</sup> (EF). These results were similar those in the

control period, which were 3.72 for EA, 3.27 for EE, and 3.01 Mg ha<sup>-1</sup> for EF.

Thin branches were not much representative; however, similar results were found for the EA interface between the 36-month post-fire period (4.81 Mg ha<sup>-1</sup>) and without fire (4.44 Mg ha<sup>-1</sup>). Thick branches were found only in the EA interface in the 21-month post-fire period, with 0.25 Mg ha<sup>-1</sup>, representing 1.79% (Figure 5a).

The regeneration of herbaceous plants was lower when compared to the litterfall class. The interface that presented the highest regeneration percentage was the EF (Figure 5c), with 18.89% (21 months), 11.58% (32 months) and 11.25% (36 months). The regeneration in the EE interface occurred only in the 32-month post-fire period. The proportion of herbaceous plants was low in the controls, and was found in the EA (0.25%) and EF (2.35%) interfaces, which did not differ statistically from each other (Table 3).

The total deposition of combustible matter in the remaining native forest fragment next to the eucalyptus community was 13.66 Mg ha<sup>-1</sup>, with no significant difference when compared to the total litterfall deposition of the *E. urograndis* plantation (22.11 Mg ha<sup>-1</sup>) with 6.5 years of age. Bark and thick branch depositions did not occur in the forest, leaf deposition presented the highest fraction in the total mean accumulation of combustible matter, with 9.92 Mg ha<sup>-1</sup>, representing of 72.62% (Table 4 and Figure 6).

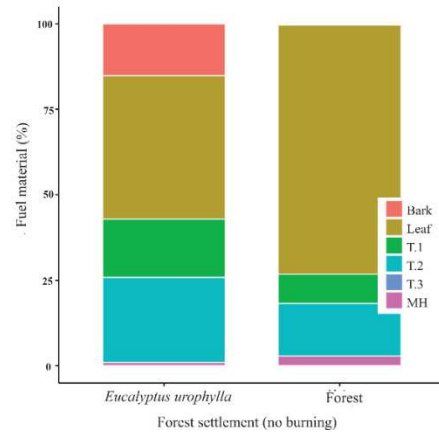


Figure 6. Class distribution of litterfall in *Eucalyptus urograndis* (Clone H13) plantations and in a native forest fragment in the Cerrado-Amazon transition in Sorriso, MT, Brazil. wherein: G1 = thin branches with diameters (d) < 0.7 cm; G2 = medium branches 0.7 < (d) < 2.5 cm; G3 = thick branches (d) > 2.5 cm; EP = herbaceous plants.

Figura 6. Distribuição da serapilheira por classes na floresta plantada de *Eucalyptus urograndis* (Clone H13) e na Floresta Nativa remanescente transição Cerrado-Amazônia, em Sorriso - MT. em que, T1: galhos finos diâmetro (d) < 0,7cm; T2: galhos médios 0,7 < (d) < 2,5 cm; T3 grossos (d) > 2,5 cm; MH - Material Herbáceo.

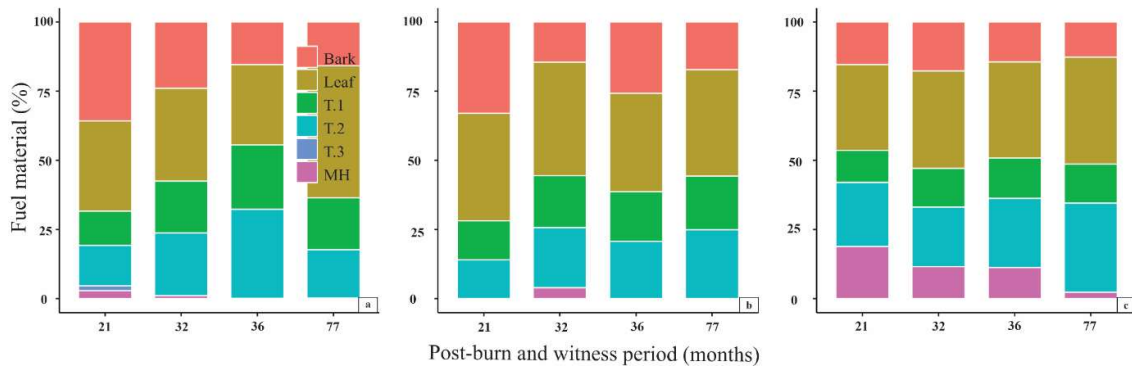


Figure 5. Distribution of litterfall by classes within the interfaces eucalyptus/agriculture (a), eucalyptus/eucalyptus (b), and eucalyptus/remnant of native forest (c) in areas with *Eucalyptus urograndis* (Clone H13) plantations in Sorriso, MT, Brazil, with different controlled post-fire periods (21, 32, and 36 months) and without fire (77 months of age). wherein: T1 = thin branches with diameters (d) < 0.7 cm; T2 = medium branches 0.7 < (d) < 2.5 cm; T3 = thick branches (d) > 2.5 cm; MH = herbaceous plants.

Figura 5. Distribuição da serapilheira por classes nas interfaces (a) eucalipto/agricultura; (b) eucalipto/eucalipto; (c) eucalipto/remanescente de floresta nativa, das áreas de *Eucalyptus urograndis* (Clone H13) em Sorriso, MT, Brasil, com diferentes períodos pós-queima controlada (21, 32 e 36 meses), e sem queima (77 meses – idade do plantio). em que: as classes foram descritas como: T1: galhos finos diâmetro (d) < 0,7 cm; T2: galhos médios 0,7 < (d) < 2,5 cm; T3: galhos grossos (d) > 2,5 cm; MH (Material Herbáceo).

Table 6. Dry mass of the classes of combustible matter (Mg ha<sup>-1</sup>) in areas with *E. urograndis* (Clone H13) plantations and in a remnant of native forest in Sorriso, MT, Brazil.

Tabela 7. Massa seca das classes de material combustível (Mg ha<sup>-1</sup>) em áreas de *E. urograndis* (Clone H13) e em um remanescente de floresta nativa, em Sorriso, MT, Brasil.

Area	Leaf	Bark	T1	T2	T3	MH	Total
<i>Eucalyptus urograndis</i>	9.24 Aa	3.34 Aa	3.83 Aa	5.50 Aa	0.00 Aa	0.21 Aa	22.11 Aa
Forest	9.92 Aa	0.06 Aa	1.17 Aa	2.10 Aa	0.00 Aa	0.39 Aa	13.66 Aa

### 3.3. Combustible matter analysis - regenerated herbaceous plants

The surveying of regeneration of green biomass in the three interfaces in the post-fire periods and in the control period (77 months) totalized 120 individuals, distributed into 17 genus, and one indeterminate, from 9 botanical families (Table 5 and Figure 7). The regeneration of herbaceous plants in post-fire areas was higher in the EA and EF interfaces,

predominating grass species from the Poaceae family, whereas the bushy plants were more representative in the areas without fire. Four species of the Poaceae family were found in the experimental area, namely, *Panicum maximum*, *Paspalum maritimum*, *Panicum pernanbuensis*, and *Brachiaria decumbens*. *P. maritimum* presented higher abundance in all interfaces and periods with and without fire (Figure 7a). The more frequent species in the 21-month post-fire period in the

interface EA was *Machaerium* sp. (33.3%); *P. maritimum* (29.6%) presented the highest IVIr (Table 5). *P. maximum* and *P. maritimum* represented more than half of all population present in the EF interface, with frequency of 53.8%; *P.*

*maximum* presented the highest IVIr, with 38.3%. The samples of the EE interface showed no regeneration of herbaceous plants.

Table 5. Statistical variables of occurrence of regenerated species in areas with *Eucalyptus urograndis* (Clone H13) plantations post prescribed fire in different environmental interfaces in Sorriso, MT, Brazil.

Tabela 5. Variáveis estatísticas da ocorrência de espécies regeneradas em áreas de *Eucalyptus urograndis* (Clone H13) pós-queimas prescritas em diferentes interfaces ambientais, em Sorriso, MT, Brasil.

Burn	Interface	Period	Specie	Family	Popular name	Fr	Dr	Ar	IVIr			
						(%)						
Yes	EL	21	<i>Machaerium</i> sp.	Fabaceae	Cipó	33.3	26.7	26.7	28.9			
			<i>Panicum maximum</i>	Poaceae	Capim-mombaça	22.2	13.3	13.3	16.3			
			<i>Melampodium divaricatum</i>	Asteraceae	Flor-amarela	11.1	6.7	6.7	8.1			
			<i>Paspalum maritimum</i>	Poaceae	Capim-pernambuco	22.2	33.3	33.3	29.6			
			<i>Brachiaria decumbens</i>	Poaceae	Brachiária	11.1	20.0	20.0	17.0			
Yes	EF	21	<i>Panicum maximum</i>	Poaceae	Capim-mombaça	26.9	44.0	44.0	38.3			
			<i>Paspalum maritimum</i>	Poaceae	Capim-pernambuco	26.9	26.7	26.7	26.8			
			<i>Blainvillea biaristata</i>	Asteraceae	Picão	7.7	6.7	6.7	7.0			
			<i>Melampodium divaricatum</i>	Asteraceae	Flor-amarela	15.4	10.7	10.7	12.2			
			<i>Mezilaurus itauba</i>	Fabaceae	Itaúba	7.7	2.7	2.7	4.3			
Yes	EL	32	<i>Machaerium</i> sp.	Fabaceae	Cipó	15.4	9.3	9.3	11.4			
			<i>Machaerium</i> sp.	Fabaceae	Cipó	16.7	4.3	4.3	8.5			
			<i>Paspalum maritimum</i>	Poaceae	Capim-pernambuco	33.3	43.5	43.5	40.1			
			<i>Melampodium divaricatum</i>	Asteraceae	Flor-amarela	33.3	13.0	13.0	19.8			
Yes	EE	32	<i>Paspalum maritimum</i>	Poaceae	Capim-pernambuco	100.0	100.0	100.0	100.0			
Yes	EF	32	<i>Panicum maximum</i>	Poaceae	Capim-mombaça	15.0	23.7	23.7	20.8			
			<i>Rumex crispus</i>	Polygonaceae	Paciência	10.0	6.8	6.8	7.9			
			<i>Brachiaria decumbens</i>	Poaceae	Brachiária	10.0	13.6	13.6	12.4			
			Indeterminado			10.0	3.4	3.4	5.6			
			<i>Paspalum maritimum</i>	Poaceae	Capim-pernambuco	30.0	42.4	42.4	38.2			
			<i>Solanum paniculatum</i>	Solanaceae	Jurubeba	10.0	3.4	3.4	5.6			
			<i>Vismia guianensis</i>	Hypericaceae	Lacre-branco	5.0	1.7	1.7	2.8			
			<i>Melampodium divaricatum</i>	Asteraceae	Flor-amarela	5.0	3.4	3.4	13.6			
			<i>Croton lobatus</i>	Euphorbiaceae	Café-bravo	5.0	1.7	1.7	2.8			
			<i>Melampodium divaricatum</i>	Asteraceae	Flor-amarela	27.3	16.7	16.7	15.9			
Yes	EL	36	<i>Panicum permanbucensis</i>	Poaceae	Palha-branca	9.1	11.1	11.1	8.2			
			<i>Panicum maximum</i>	Poaceae	Capim-mombaça	9.1	5.6	5.6	5.3			
			<i>Spermacoce palustres</i>	Rubiaceae	Erva-de-lagarto	9.1	5.6	5.6	5.3			
			<i>Machaerium</i> sp.	Fabaceae	Cipó	27.3	44.4	44.4	30.4			
			<i>Paspalum maritimum</i>	Poaceae	Capim-pernambuco	18.2	69.7	134.6	17.2			
Yes	EE	36	<i>Paspalum maritimum</i>	Poaceae	Capim-pernambuco	100.0	100.0	100.0	100.0			
Yes	EF	36	<i>Solanum paniculatum</i>	Solanaceae	Jurubeba	13.0	5.4	5.4	7.9			
			<i>Brachiaria decumbens</i>	Poaceae	Brachiária	26.1	51.8	51.8	43.2			
			<i>Melampodium divaricatum</i>	Asteraceae	Flor-amarela	4.3	1.8	1.8	2.6			
			<i>Rumex crispus</i>	Polygonaceae	Paciência	13.0	5.4	5.4	7.9			
			<i>Blainvillea biaristata</i>	Asteraceae	Picão	4.3	7.1	7.1	6.2			
			<i>Paspalum maritimum</i>	Poaceae	Capim-pernambuco	4.3	3.6	3.6	3.8			
			<i>Panicum maximum</i>	Poaceae	Capim-mombaça	8.7	3.6	3.6	5.3			
			<i>Mezilaurus itauba</i>	Fabaceae	Itaúba	8.7	5.4	5.4	6.5			
			<i>Machaerium</i> sp.	Fabaceae	Cipó	8.7	3.6	3.6	5.3			
			<i>Spermacoce palustres</i>	Rubiaceae	Erva-de-lagarto	4.3	7.1	7.1	6.2			
			<i>Imperata brasiliensis</i>	Panicoideae	Sapê	4.3	5.4	5.4	5.0			
			No	EL	77	<i>Spermacoce palustres</i>	Rubiaceae	Erva-de-lagarto	50.0	75.0	75.0	66.7
						<i>Machaerium</i> sp.	Fabaceae	Cipó	50.0	25.0	25.0	33.3
No	EF	77	<i>Paspalum maritimum</i>	Poaceae	Capim-pernambuco	18.2	21.6	21.6	20.5			
			<i>Mezilaurus itauba</i>	Fabaceae	Itaúba	13.6	8.1	8.1	10.0			
			<i>Melampodium divaricatum</i>	Asteraceae	Flor-amarela	27.3	35.1	35.1	32.5			
			<i>Rumex crispus</i>	Polygonaceae	Paciência	4.5	2.7	2.7	3.3			
			<i>Ageratum conyzoides</i>	Asteraceae	Picão-roxo	4.5	2.7	2.7	3.3			
			<i>Machaerium</i> sp.	Fabaceae	Cipó	13.6	8.1	8.1	10.0			
			<i>Cyperus iria</i>	Cyperaceae	Tiririca	4.5	13.5	13.5	10.5			
			<i>Scleria melaleuca</i>	Cyperaceae	Campim-navalha	4.5	2.7	2.7	3.3			
			<i>Panicum maximum</i>	Poaceae	Capim-mombaça	4.5	2.7	2.7	3.3			
			<i>Brachiaria decumbens</i>	Poaceae	Brachiária	4.5	2.7	2.7	3.3			

wherein: EA (eucalyptus/agriculture), EE (eucalyptus/eucalyptus - central interface of the eucalyptus parcel); EF (eucalyptus/remnant of native forest); Fr = relative frequency; Dr = relative density; Ar = relative abundance; IVIr = Relative Importance Index.

em que: EA (eucalipto/agricultura), EE (parcela interface centro do talhão do eucalipto - eucalipto/eucalipto) e EF (parcela interface eucalipto/remanescente de floresta nativa); Fr (Frequência Relativa); Dr (Densidade Relativa); Ar (Abundância Relativa); IVIr (Índice de Valor de Importância Relativo).

The most abundant species found for the 21-month post-fire period was, in general, *P. maximum*, regardless of the interface (Figure 7b). The 21-month post-fire period presented higher occurrences of regeneration for EA and EF. The most representative species found for 32-month post-fire period in the EA interface was *P. maritimum*, with IVIr of 40.1%; this species presented the highest density and abundance. Grouping the post-fire periods, the species *P. maritimum* represented 100% (RF and IVIr) in the EE and 30% (RF) and 38.2% (IVIr) in EF; thus, it can be described as the most abundant species for the 32-month post-fire period (Figure 7c).

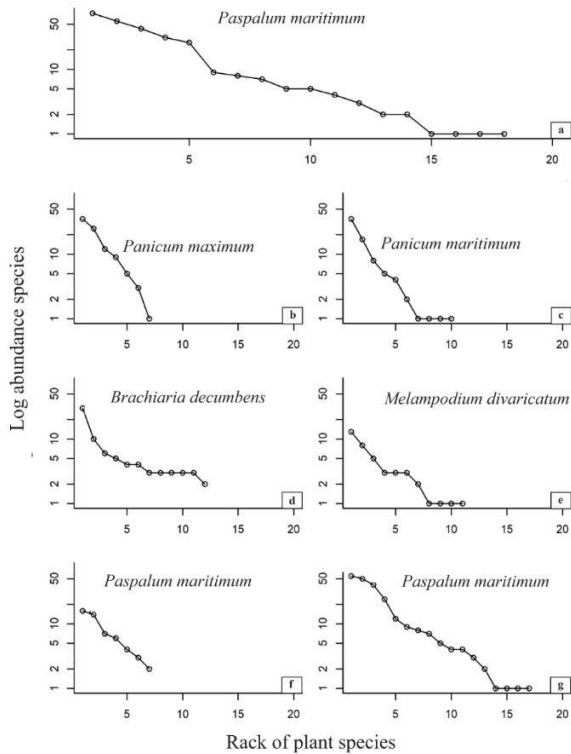


Figure 7. Distribution of abundance as a function of sampled plant species. Abundance is in logarithmic scale for a better view of the community standard. The relations presented are: total community (a), 21, 32-, and 36-month post-fire periods (b a d, respectively),

without fire for 77 months (e); and interfaces eucalyptus/agriculture – EA (f) and eucalyptus/remnant of native forest– EF (g).  
 Figura 7. Distribuição da abundância em função das espécies vegetais amostradas. Abundância está em escala logarítmica para melhor visualizar o padrão da comunidade. As relações apresentadas são: comunidade total (a), períodos pós-queima de 21, 32 e 36 meses (b a d, respectivamente), sem queima – 77 meses (e); e ainda, para interfaces eucalipto/agricultura (EA), (f) e eucalipto/remanescente de floresta nativa (EF) (g).

Consequently, higher diversity of species was found for the 36-month post-fire period; *Machaerium* sp. presented the highest representativeness in the EA interface, with IVIr of 30.4%; only *P. maritimum* was found in the EE interface, with 100% frequency and IVIr; the grass species *B. decumbens* presented the highest representativeness among the plants sampled in the EF interface, with 26.1% frequency and 43.2% IVIr (Table 5). The most abundant species found for the 36-month post-fire period was *B. decumbens* (Fig. 7d).

The species *Spermacoce palustre* and *Machaerium* sp. were found in areas without fire and in the interface EA, with 50% frequency and 66.7% and 33.3% IVr, respectively (Table 5). The species with higher frequency in the EF interface was *Melampodium divaricatum*, with 27.3% frequency and 32.5% IVr. No species was found in the interface EE. Considering the areas without fire, the most abundant species was *M. divaricatum* (Figure 7e). When comparing the regeneration of herbaceous plants in the interfaces, EA presented lower regenerated plants than EF (Figure 7f-g).

The regeneration of herbaceous plants was higher in the EF interface, regardless of the post-fire period (Figure 8); higher proportions were found for the 21-month post-fire period, with 55.4% for litterfall and 44.6% for regenerated herbaceous plants.

The rarefaction curves developed showed lower wealth of species in areas without fire and higher wealth in areas with controlled fire (Figure 9). The post-fire periods and control affected the abundance variation in the plant community and the presence/absence was also affected by the community interface (Table 6).

The similarity between areas with fire was low for the regeneration of herbaceous plants, abundance, and presence/absence (Figure 10). Similar results were also found for post-fire periods and control, and community interfaces.

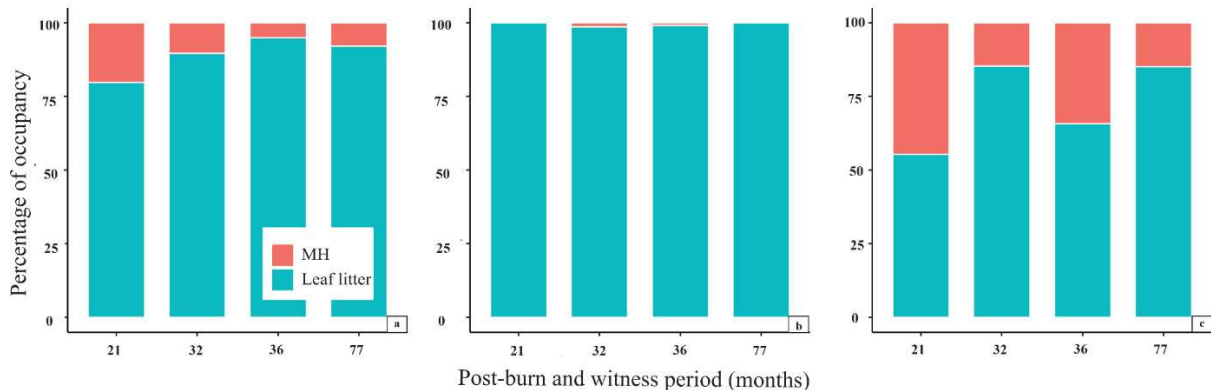


Figure 8. Percentage of area occupied by litterfall and herbaceous plants by post prescribed fire period. (a) EA [eucalyptus/agriculture]; (b) EE [eucalyptus/eucalyptus – center of the parcel]; (c) EF [eucalyptus/remnant of native forest].  
 Figura 8. Percentual de área ocupada por serapilheira e material herbáceo por tempo pós-queimas controladas. (a) EA [eucalipto/agricultura]; (b) EE [eucalipto/eucalipto – centro do talhão]; (c) EF (eucalipto/remanescente de floresta nativa).



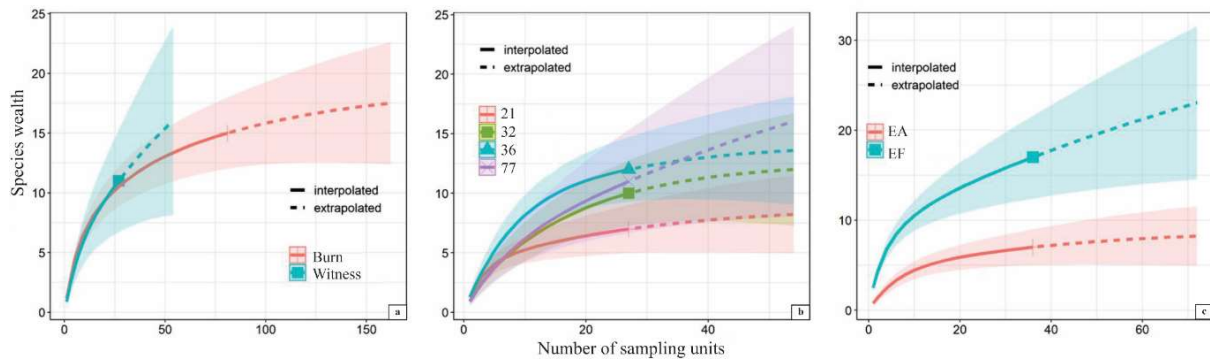


Figure 9. Wealth of plant species found (continuous line) and extrapolated wealth (dotted line) as a function of the sample effort. Rarefaction curves and extrapolations were calculated for (a) treatments with fire, (b) post-fire period, control without fire (77 months), and (c) interfaces of the community. The shaded area represents the confidence interval.

Figura 9. Relação da riqueza de espécies vegetais observada (linha contínua) e riqueza extrapolada (linha pontilhada) em função do esforço amostral. As curvas de rarefação e extrapolação foram calculadas para (a) tratamento de queima, (b) período pós-queima e testemunha (sem queima – 77 meses), bem como (c) interfaces do povoamento. A área sombreada representa o intervalo de confiança.

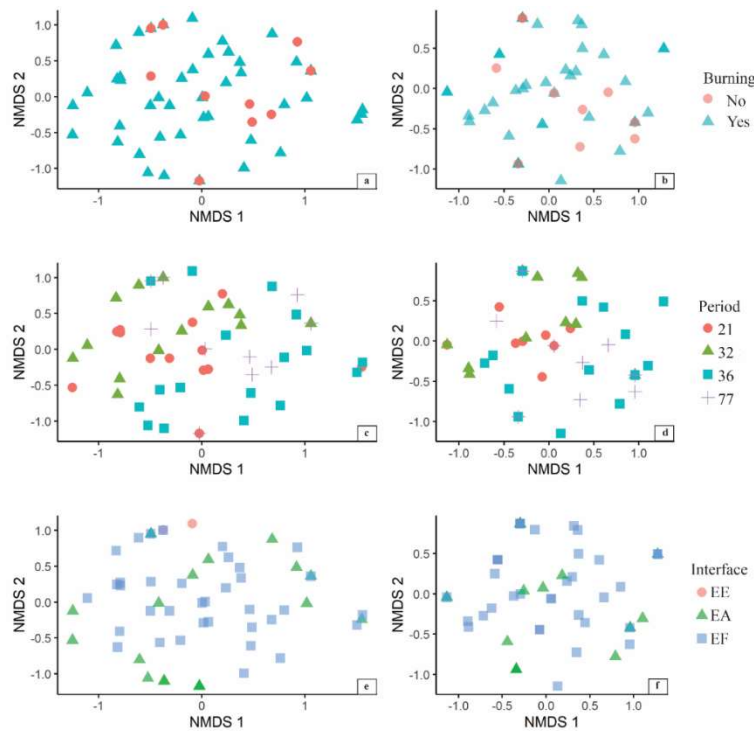


Figure 10. Tridimensional spatial distribution of samples of abundance (Bray-Curtis distance) (a, c, e) and presence/absence of herbaceous plants (Sørensen distance) (b, d, f), as a function of post-fire periods (a, b), post-fire period and control (c, d), and interface of the community (e, f) in a *E. urograndis* (Clone H13) plantation.

Figure 10. Distribuição tridimensional das amostras no espaço da abundância (distância de Bray-Curtis) (a, c, e) e presença/ausência de material herbáceo (distância de Sørensen) (b, d, f), em função dos períodos pós-queima (a, b), período pós-queima e testemunha (c, d) e interface do povoamento (e, f) em área de *E. urograndis* (Clone H13).

Table 6. Probabilities associated to the abundance and presence/absence (represented by dimensional solutions - NMDS) variables as a function of fire, post-fire periods, control, and interface of the community.

Tabela 6. Probabilidades associadas das variáveis abundância e presença/ausência (representadas pelas soluções dimensionais do NMDS) em função de queima, períodos de pós-queima e controle (testemunha), e interface do povoamento.

Source of variation	Abundance (NMDS)			Presence/Absence (NMDS)		
	gL	Pillai-Trace	P	gL	Pillai-Trace	P
Burn*	1	0.028	0.524	1	0.035	0.446
Post-burn period and control	2	0.311	0.003	2	0.232	0.020
Settlement interface	2	0.149	0.118	2	0.205	0.036
Burn*Interface	1	0.077	0.113	1	0.029	0.508
Period*Interface	3	0.146	0.296	3	0.037	0.938
Waste	47			47		

\* Considering only the occurrence of fire, regardless of the post-fire period.

\* Considerando apenas a ocorrência de queima, independentemente do período pós-queima.

## 4. DISCUSSION

### 4.1. Forest inventory

The prescribed fire had no effect on the community development, since the survival rate of trees was higher than 77%. This is connected to the low to moderate intensity of prescribed fires on the surface of the sub-forest, which seldom cause mortality of large-size trees (NOSS et al., 2006). Studies with *E. urograndis* presented high survival rates, varying from 91.8 to 95.9% in Roraima, and mortality rate of 18.92% in Mato Grosso (TONINI, 2006; MIRANDA et al., 2019).

The mortality of eucalyptus tends to increase in plants with age higher than 7 years, however other variables can be associated, such as soil nutrition, weather conditions, water availability, species adaptation, and inadequate silvicultural practices (CAMPOE et al., 2016; CARMO et al., 2018; MIRANDA et al., 2019).

Considering that the community analyzed had 6.5 years of age, it was within the expected standards for survival rates and mortality. Significant difference was found for CHC only for the EA interface; however, this variation is common in monospecific agriculture (VIERA et al., 2011). Therefore, it was considered as normal for this age, since CHC and height variables affect the wood volume, thus ensuring more profitability in wood production for generation of energy.

The tree heights in the center of the community varied, which is connected to the lower solar radiation incidence in the center of the parcel; the trunk length growth depends on light availability and trees in shading conditions tend to have lower heights or be suppressed (BINKLEY et al., 2010).

Canopy percentage is also important for this study, since the higher the canopy percentage, the lower the solar radiation incidence (Viera et al., 2011) in the sub-forest. It can affect the regeneration of herbaceous plants and decrease the combustible matter availability. Thus, the application of prescribed fire to the litterfall of the parcel is not a threat for the plantation development. The mean values of variables surveyed for the post-fire periods are similar those found in the control.

### 4.2. Combustible matter - litterfall

The litterfall in areas with H13 clone are composed of leaves, barks, thin branches, medium branches, and herbaceous plants. The deposition of combustible matter was, in general, similar in all interfaces, post-fire periods, and areas without fire, showing that border and central areas of the community do not affect the combustible matter production, and the accumulation increases and tend to be constant after 36 months. This similarity can be correlated with the biomass decomposition, which is slow for eucalyptus litterfall (SCHUMACHER et al., 2013).

The area without fire reached a maximum litterfall production of 23.7 Mg ha<sup>-1</sup> at 6.5 years of age; however, the plantation cut cycle is between 7 and 7.6 years, thus, it stops this combustible matter deposition. However, there are a risk of fire before cutting, since combustible matter depositions of 8 to 12 Mg ha<sup>-1</sup> are high, 12 to 20 Mg ha<sup>-1</sup> are very high, and > 20 Mg ha<sup>-1</sup> are extreme (MARSDEN-SMEDLEY, 2011).

Regarding the classification, leaves represented the highest fraction of the litterfall combustible matter in all interfaces and periods with and without fire. Previous studies, when the forest community presented 5 years of age

(CARMO et al., 2018), found that the leaf fraction was also the main litterfall formation fraction, varying from 51.76% (EF) to 60.99% (EE). It still presented 40.0% of leaves at 6.5 years of age (LIMA et al., 2020a,b). Other studies state that the leaf fraction stands out in the litterfall composition (NETO et al., 2014; INKOTTE et al., 2015; SANTOS et al., 2017), confirming the data found in the present study.

Although species of the *Eucalyptus* genus have several leaf predators, they are grown in abundance, favoring fire propagation, that threatens the plantation (SCHNEIDER, 2003). Thus, the adoption of controlled fire is required when the area reach high leaf loads (> 0.7 cm) (MARSDEN-SMEDLEY, 2011).

Barks are composed of dead tissues; its purpose is to protect and provide resistance to plants and a defense against abiotic and biotic threats (FERRENBURG; MITTON, 2014; PAUSAS, 2015). The prescribed fire did not cause stress in the trees, since the bark quantity in areas with fire were similar that in areas without fire.

Regarding the branch classes, which present low deposition, those with thickness < 0.7 cm were little representative, whereas those > 2.5 cm presented higher deposition in EA, representing 1.79% of deposition total of litterfall. Thus, branches with equal or lower thickness than this do not significantly affect fire propagation (MARSDEN-SMEDLEY, 2011).

The regeneration of herbaceous plants in areas without fire was lower than that in areas with fire, presenting higher regeneration next to the agriculture and forest borders. Other studies found similar results and attributed the absence or presence of herbaceous plants due to the light availability, which is higher in border areas (CIANCIARUSO et al., 2010; DEVECCHI et al., 2020). Fire can be beneficial to stimulate or facilitate several developmental phases of many of these species, mainly herbaceous plants (WROBLESKI; KAUFFMAN, 2003).

The combustible matter availability in the planted and native forest presented no significant difference regarding the litterfall deposition. However, the plantation age was close to the cutting time and the mature native forest age was not determined, denoting that eucalyptus plantations have high deposition of combustible matter and had no enough time for the decomposition of this matter due to its short cycle.

### 4.3. Regenerated burnable herbaceous plants

Fire can favor the reproduction of grass species from the Poaceae family, whereas it does not favor bush species, since it delays the regeneration time (CIANCIARUSO et al., 2010). Although grass species present high number of leaves, alive plants are not threat, since the higher the quantity of green matter, the lower the fire propagation (ALVES et al., 2017). However, it should be noted that the behavior of grasses does not always follow what is exposed in this work, making it possible to burn areas with this type of vegetation, even in the rainy season, due to the large amount of combustible material deposited below the green leaves. Furthermore, in dry periods, they become highly flammable, increasing the risk of fires and present higher temperatures over longer times (GORGONE-BARBOSA et al., 2016).

Grass species have efficient photosynthetic performances for the production and dispersion of diaspores and are highly invasive (SOUZA et al., 2005; GORGONE-BARBOSA et al., 2016). For example, *P. maritimum* is a species with high

capacity of invade crop areas, form homogeneous colonies, dominating the area over few years, and preventing the regeneration and development of other species (SOUZA FILHO, 2006).

The 21-months post-fire period presented higher regeneration for EA and EF, since the germination of lianas, herbaceous plants, and grass species in the first months after the controlled fire can be due to the overcoming of dormancy of seeds present in the litterfall and in the soil. These plants present ecological succession characteristics typical of pioneer species, with fast growth and development, and short life cycle (Ricklefs, 2003), which explains the high occurrence of these plants in sampled areas close to the forest and their survival time in the area.

The most abundant species in areas without fire was *M. divaricatum*; thus, fire can be beneficial for herbaceous plants, by stimulating or facilitate several phases of their development, and alter soil fertility (WROBLESKI; KAUFFMAN, 2003; SILVA; BATALHA, 2008) found higher organic matter, nitrogen, and clay contents in areas with fire occurrences, which are rapidly absorbed by grass species with shallow roots (CIANCIARUSO et al., 2010); thus, this is probably one of the reasons for the abundance of grass species in areas with controlled fire.

The regenerated herbaceous plants covered a larger area in the EF interface, regardless of the post-fire period. This is probably due to the presence of the native forest fragment in the border of the eucalyptus plantation and the higher water availability than in the other interfaces due to the proximity with a lake. The regeneration in the EE interface was low in the three periods analyzed because of the lowest seed dispersion and the lower solar radiation in the center of the parcel.

## 5. CONCLUSIONS

The eucalyptus plantations in the Cerrado-Amazon transition region subjected to prescribed fire presented, after 36 months, presented similar litterfall quantity and composition to areas without fire (77 months).

Leaves represented the highest combustible matter fraction (litterfall) followed by medium branches, barks, thin branches, herbaceous plants, and thick branches. This accumulation over time can favor the intensity and propagation of fire.

Thus, prescribed fire can be an important tool for the managing of dry and alive combustible matter in sub-forest of eucalyptus plantations in this transition region after four years of implementation by decreasing the litterfall surface layer, considering the state legislation, thus allowing the prevention of forest fires of large proportions.

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