FIREFIGHTING COMBAT WITH FIRE RETARDANTS AT DIFFERENT CONCENTRATIONS

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Resumo

Combate a incêndios florestais com uso de retardantes de fogo em diferentes concentrações. Os incêndios florestais são responsáveis pela destruição de milhões de hectares de florestas no mundo e geram diversos prejuízos econômicos, sociais e paisagísticos. Assim, o desenvolvimento de técnicas de combate torna-se cada vez mais necessário. Neste contexto, objetivou-se avaliar a eficiência de diferentes retardantes de fogo e suas concentrações no combate aos incêndios florestais, levando em consideração os tempos e intensidades de queima do material combustível. O estudo foi conduzido no interior de um plantio de *Eucalyptus* spp., sendo conduzido o experimento em três retardantes de fogo (Silv-Ex; F-500; e HoldFire) e em três concentrações (1%; 1,5%; e 2%), além da testemunha composta apenas por água no combate. Para isso, foi utilizado um delineamento inteiramente casualizado e a análise estatística foi feita a partir de arranjos experimentais (fatorial 3x3). As variáveis avaliadas durante o processo de queima foram: os tempos de queima (tempos gastos para que as chamas consumissem todo o material combustível das extremidades com e sem o produto) e a intensidade de queima. Os resultados a respeito do tempo e intensidade de queima em relação às dosagens mostraram uma tendência de decréscimo à medida que se aumentavam as doses, classificando a maior dose (2%) como a mais eficiente. Já no caso dos retardantes, todos foram eficientes, destacando-se o Silv-Ex como o mais indicado visto que diminuiu significativamente a intensidade de queima e elevou o tempo de queima do material combustível.

Palavras-chave: intensidade de queima, proteção florestal, material combustível.

Abstract

Forest fires are responsible for the destruction of millions of hectares of forest worldwide, and they lead to diverse economic, social, and landscape damage. Thus, the development of techniques to combat them has become increasingly necessary. In this context, this study aims to evaluate the efficiency of different fire retardants at different concentrations in fighting forest fires, considering the burning times and intensities of forest fuel. The study was conducted inside Eucalyptus spp. stands using three fire retardants (Silv-Ex, F-500, and HoldFire) at three concentrations (1%, 1.5%, and 2%), in addition to a water-only control. A completely randomized design was used, and the statistical analysis was completed based on experimental arrangements (factorial 3x3). Variables evaluated during the burning process were as follows: burning times (the time required for the flames to consume all forest fuel within the sample, with and without the retardant) and intensity of burning. Results regarding the time and intensity of burning in relation to the concentrations indicated a decreasing trend as the latter were increased, classifying the highest dose (2%) as the most efficient. For the retardants, all were observed to be efficient, with Silv-Ex being the most appropriate as it significantly reduced the burning intensity and increased the burning time of the forest fuel.

Keywords: burning intensity, forest protection, fuel materials.

INTRODUCTION

Forest fire can be understood as any uncontrolled fire that occurs in vegetation and is either anthropic or natural in origin. In general, forest fires are responsible for the destruction of millions of hectares of forests worldwide and generate widespread economic, social, landscape, and soil damage, which may occur in reforestation areas, conservation units, preservation areas, farms, roadsides, and surrounding urban areas (WESTERLING; BRYANT, 2008; SOUTO *et al.*, 2009; TORRES *et al.*, 2011; BOSCARDIN *et al.*, 2014; McKENZIE *et al.*, 2014; KNELMAN *et al.*, 2017; RODRÍGUEZ *et al.*, 2017).

In Brazil, fires are classified as the biggest catastrophe that a forest stand can suffer, as they cause economic damage, contribute to climate change, and endanger human and animal lives. (DINIS; CARVALHO, 2011; SOUZA *et al.*, 2012). The National Institute for Space Research (INPE) recorded an annual average of 38,609 outbreaks of fires in the Brazilian territory from 2012 to 2018, and statistical evidence shows that the number of fires tend to increase as a result of unusual or cyclical global climate changes related to El Niño and La

Niña and from the indiscriminate and irrational use of fire by humans (BATISTA, 2009; TETTO *et al.*, 2015; TORRES *et al.*, 2016; INPE, 2017).

Although there are numerous preventive and firefighting techniques, these do not solve or prevent all occurrences (FIEDLER *et al.*, 2015). Thus, the improvement of such techniques is always of high importance to eradicate or at least minimize the damage caused by the conflagrations.

The evolution of forest firefighting methods highlights an increase in the use of chemical products incorporated in water to enhance their efficiency, called flame or fire retardants (BATISTA, 2009). The potentiating characteristics of fire retardants are extremely important because of the difficulty of obtaining water in the regions of fire occurrence, and the favored ones provide this function at a relatively low cost (CANZIAN *et al.*, 2018).

Brazil is not yet endowed with legislation that regulates the use and quality of these products, or even advises users in the correct methods and quantities to be used (PIERONI *et al.*, 2017). One of the biggest limitations on the use of fire retardants in Brazil is high prices, as the vast majority of them are imported.

From the above information, it is evidently necessary to study different retardants and the possibility of maintaining the quality of their performance at lower concentrations, to maximize the effects of water with such products and to reduce costs. Thus, the objective was to evaluate the effectiveness of combatting forest fires using the fire retardants in different concentrations. The hypotheses that guide the present study are as follows: a) the natural base retardant used in the present research will present statistically inferior results to the chemical ones; and b) higher product concentrations will ensure more promising results.

MATERIAL AND METHODS

Study area

The study was conducted in an experimental area of the Federal University of Espirito Santo, located in the municipality of Jerônimo Monteiro, southern Espírito Santo State, Brazil, between the coordinates 20°47'45"S and 41°24'21"W. The climate is classified, according to Köppen, by the Aw type, whose average annual temperature is 23 ºC and average rainfall of 1200 mm year^{-1} (INCAPER, 2013).

Fuel material used

In all plots, 2.5 kg m^{-2} of dry *Eucalyptus* spp. included in floor-mounted windrows (Figure 1) was used as standardized fuel material to be treated with the retardants.
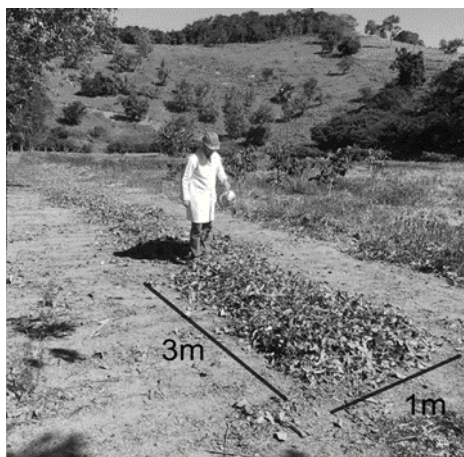

Figure 1. Preparation of plots with litter.
Figura 1. Confecção das parcelas com serapilheira.

The moisture and dry matter quantification of the fuel material was determined by oven drying (65 ºC) it until it reached a constant weight. Subsequently, a sample of 3 kg of forest fuel was allocated to a template of 1 m^2.

The moisture content of the fuel material was determined by a three-repetition sample of 1 m^2 of the fuel material, which corresponded on average to 2.95 kg m^{-2} wet litter.

Methods used

Each plot was subjected to a controlled application of 0.5 L of solution or water (control) per square meter (m²), as proposed by Fiedler *et al.* (2015), with retardant treatments differentiated by type and concentration (1%, 1.5%, and 2%). The concentration recommended by the manufacturers is 1%; however, it was decided that higher

concentrations would be applied to determine whether the efficiency of the products would increase proportionally with the consequent reduction in the amount of water. This is especially important considering the difficulty in obtaining water at the time of firefighting. The retardants used in this study were as follows:

- Silv-Ex (SV): A liquid used for Class A fires, with recommended concentrations ranging from 0.1% to 1% in fresh, brackish, or saltwater;
- F-500 (F5): A liquid with recommended concentrations that can range from 0.5% to 3% according to fire class (Classes A, B, and D); and
- HoldFire (HF): A biodegradable additive that enhances water use in Class A fires.

With the aid of an adjustable sprayer, the solution containing the fire retardant was mixed with water to achieve the desired concentration in the intended spaces (1 m x 1 m), and then was homogeneously applied before combustion began.

Sampling procedure

The experimental area consisted of 30 plots, with dimensions of 1 m x 3 m. Within a plot, the retardant application area was 1 m x 1 m, and the ignition area of the fire that defined the direction of fire was the remaining 2 m x 1 m (Figure 2). In total, there were nine treatments with three repetitions each. The other plots were the control plots treated with water only.
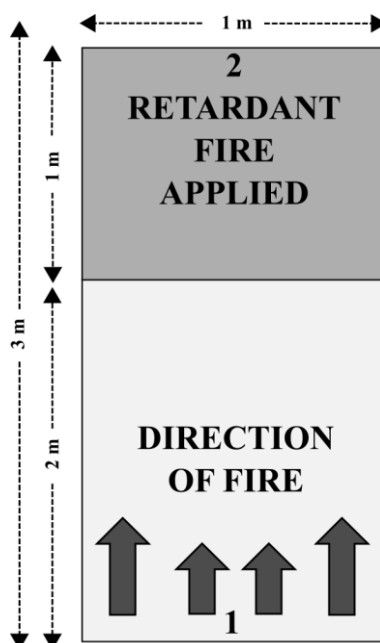

Figure 2. Retardants and fire application scheme.
Figura 2. Esquema de aplicação dos retardantes de fogo.

After the application of the retardants, each fire was ignited in the forest fuel so that the flames followed the direction of propagation until they reached the end that was subjected to the treatments. The first part of the windrows only served to form the line of fire, while the distance, used for calculation purposes, was accounted for only in the second part.

Fire characterization

Relative humidity, wind speed, and plot burning time with and without the product were evaluated. The characterization of fire behavior was performed using the burning intensity equation (1), proposed by Byram (1959).

$$I = H.w.r \tag{1}$$

Where, I = burning intensity (kcal.m^{-1} s^{-1}); H = calorific value of dominant fuel material (4.947 kcal); w = load of available forest fuel (kg m^{-2}); and r = fire propagation velocity (m s^{-1}).

Statistical analysis

For statistical analysis of time and intensity values, the experimental arrangement was factorial, considering the types of retardants and their concentrations, the control with water (treatments), and three plots as

repetitions. Initially, the analysis of variance (ANOVA) was applied, and subsequently, for the comparison of means, the Tukey test was applied at 5% probability of error with the aid of the SISVAR 5.6 program.

Using Excel 2013 software, it was verified, based on linear regression, that a functional relationship existed between the independent variables (product concentrations) and the dependent variables (burning times and intensities).

RESULTS

The mean values and their respective standard deviations of mass, humidity, height, and density of the forest fuel are presented in Table 1.

Table 1. Average values of the mass of the forest fuel, humidity, height, and apparent density.
Tabela 1. Valores médios da massa do material combustível, umidade, altura e densidade aparente.

Wet Fuel Material (kg m^{-2})	Dry Fuel Material (kg m^{-2})	Dry Fuel Material (Mg ha^{-1})	Moisture (%)	Height Fuel Material (cm)	Apparently density (kg m^{-3})
2.5 ±0.09	2.09 ±0.15	20.9 ±1.48	19.61 ±4.55	15	16.66 ±0.58

Table 2 presents the results of the analysis of variance (ANOVA) for the burning times and intensities.

Table 2. Results of the ANOVA of the burning times and intensities of three fire retardants applied at three different concentrations.
Tabela 2. Resultados da ANOVA dos tempos e intensidades de queima em três retardantes de fogo submetidos à três diferentes concentrações.

Variation source	Sum of squares	Medium square	Fc (significance)
		Time (seconds)	
Retardant (A)	38817.85	19408.93	41.30*
Dose (B)	22814.52	11407.26	24.27*
Retardant x concentration	5854.37	1463.59	3.11*
Average	-	521.81	-
-	-	Intensity (kcal s^{-1} m^{-1})	
Retardant (A)	313.4	156.7	33.42*
Dose (B)	183.48	91.74	19.50*
Retardant x concentration	40.37	10.09	2.15^{ns}
Average	-	47.89	-
R^2	-	0.987	-

The ANOVA results for burning times demonstrated the existence of significant interaction between the main factors (retardants and doses) by Tukey test at 5% probability of error, which led to the need to proceed with the unfolding of such factors (Table 3).

Table 3. Interaction between the AxB and BxA treatments and the control.
Tabela 3. Interação entre os tratamentos AxB e BxA e a testemunha.

		Time (seconds)				
		Concentration on Retardants				
1%	**SV**	508.7 a	**1,5%**	**SV**	585.3 a	**2%**
	HF	504.3 a		**HF**	501.0 b	
	F5	454.0 b		**F5**	464.0 b	
	Witness treatment	273.0 c		**Witness treatment**	261.0 c	

2%		
SV	614.3 a
HF	552.7 b
F5	512.0 b
Witness treatment	255.0 c

		Retardants on Concentration				
SV	**1%**	501.0 b	**HF**	**1%**	508.7 b	**F5**
	1,5%	504.3 b		**1,5%**	585.3 b	
	2%	552.7 a		**2%**	614.3 a	
	Witness treatment	273.0 c		**Witness treatment**	261.0 c	

F5		
1%	454.0 b
1,5%	464.0 b
2%	512.0 a
Witness treatment	255.0 c

Where: *Means followed by the same letter in the column do not differ from each other by the Tukey test at 5% probability.

The analysis of variance for the burning intensity showed no significant interaction between the main factors (retardants and doses) by Tukey test at 5% probability of error (Table 4).

Table 4. Intensity of burning of three concentrations of fire retardants and of the control without retardant.
Tabela 4. Intensidade de queima de três doses de retardantes químicos de fogo e da testemunha sem retardante.

Burning intensity (kcal m^{-1} s^{-1})			
Concentrations		**Retardants**	
Witness treatment	94.12 a	**Witness treatment**	94.12 a
1%	50.83 b	**F5**	52.12 b
1,5%	48.34 b	**HF**	47.75 c
2%	44.49 c	**SV**	43.78 d

From the graphical representation in Figure 3, it is seen that as the retardant concentration increases, the burning intensities decrease, and the burning times increase.
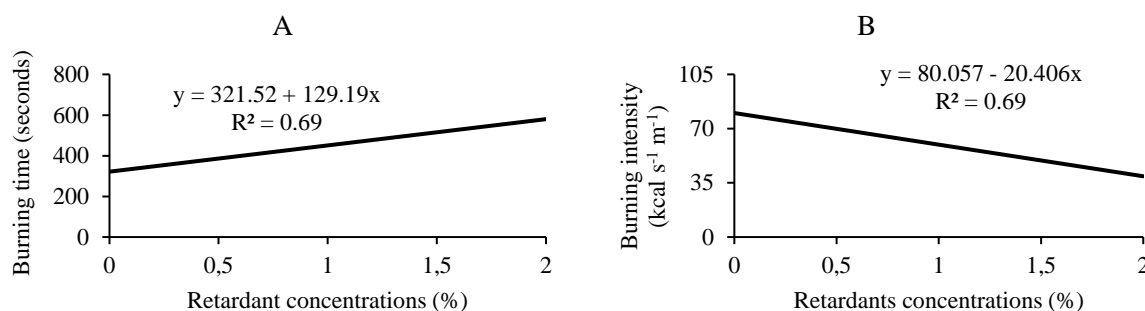
A

y = 321.52 + 129.19x
R² = 0.69

B

y = 80.057 - 20.406x
R² = 0.69

Figure 3. (A) Burning time (s); and (B) Intensity of burning (kcal m^{-1} s^{-1}) of three different treatments with retardants in their respective concentrations and the control.
Figura 3. (A) Tempo de queima (segundos); e (B) Intensidade de queima (kcal m^{-1} s^{-1}) em três diferentes tratamentos com retardantes em suas respectivas doses e a testemunha.

DISCUSSION

The amount of dry forest fuel used in the present study was 20.9 Mg ha^{-1}. This value meets the reality of Brazilian planted forests, because according to Souza *et al*. (2003), the amount of surface forest fuel in a 7-year-old *Eucalyptus dunii* Maiden forest approached 22 Mg ha^{-1}. Already, the density of the material, when compared to the results found by White *et al*. (2014) in eucalyptus forests on the northern coast of Bahia State, Brazil, was considered low, as they found it to be 19.95 kg.m^{-3}, approximately 17% more than that found in this research (16.66 kg.m^{-3}).

The results on the intensity of burning were very interesting, since the expected fire retardants and higher concentrations led to a decrease of these values. Regarding the concentrations, the concentration of 2% emerged prominent, as it reduced the burning intensity by approximately 53% in comparison to the control with only water. These results corroborate those found by Canzian *et al*. (2016), who obseved an inversely proportional relationship between retardant doses and burning intensity.

The retardant that obtained the best results on burning intensity was the SV, showing a reduction close to 54% compared to the control with water alone. It is also noteworthy that HF is an organic-based retardant that is little-known in the market, and it was able to reduce the intensity of burning by 51% compared to the control. Similar results were found by Maraboti *et al*. (2016) when studying the intensity of burning in forest fuels subjected to different fire retardants. The authors found, SV to be the best treatment, coincidentally, the F5 to be the worst.

Regarding the burning times, the trend remained as expected, with the highest doses producing the best results. However, it is noteworthy that SV was more effective at all doses, and only at 1% dosing did it match the HF results. The SV showed its best results in the highest dosage (2%), presenting about 102% increase in the burning time compared to the control without retardant. The HF presented similar results in the doses of 2% and 1.5%, presenting increase in the burning time in relation to the control, in the class of 125% and 124%, respectively. The F5 was more efficient in the dosage of 2%, which improved the burning time by 101% compared to its control.

CONCLUSIONS

- Among the three retardants studied and the water-only control, the treatment that presented the best results, at all concentrations, both for time and intensity of burning, was Silv-Ex; therefore, it was considered the most efficient under the conditions analyzed;
- Concentrations tended to decrease burning intensity and increase burning time of the forest fuel as they were increased, rendering the highest dose (2%) the most efficient; and

- As organic-based retardant is a newly developed product, it was quite effective in combating forest fires given the results presented.

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