EFFECTIVENESS OF WATER-RETAINING POLYMER AS FIRE RETARDANT IN INDIRECT USE

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ABSTRACT – The use of fire retardants increases efficiency in fighting forest fires, however, it still presents uncertainties regarding environmental contamination, recommendations for preparation, and it lack of regulation in Brazil. In this scenario, alternative products such as water-retaining polymers, that can reduce the rapid evaporation of water, can also have positive effects in terms of reducing fire behavior. Efficiency and ways of using the water-retaining polymer as a short-duration fire retardant (indirect combat) in controlled burns in eucalyptus plantations were evaluated. Five concentrations (dilution in water), three volumes of spray solution, and two post-application times on the combustible material available in the area were evaluated. Controlled burns were conducted downwind, between 10 am and 2 pm, during dry season in the region, with micrometeorological and fire behavior assessments (fire propagation speed and length of flames). Increased spray volume and concentration of water-retaining polymer led to reductions in the spread of fire. In eucalyptus combustible material, the water-retaining polymer can be used as a fire retardant of short duration (effective up to two hours after application), considering a spray volume of 2.0 L m^{-2} and concentration of 0.0060% (diluted in water).

Keywords: Forest fire; Fire behavior; Hydrogel.

EFICIÊNCIA DO POLÍMERO HIDRORETENTOR COMO RETARDANTE DE FOGO EM USO INDIRETO

RESUMO – O emprego de retardantes do fogo aumenta a eficiência no combate de incêndios florestais, todavia, ainda apresenta incertezas quanto a contaminações ambientais, recomendações de preparação e ausência de regulamentação no Brasil. Neste cenário, produtos alternativos como polímeros hidroretentores, que diminuem evaporação rápida da água, também podem apresentar efeitos positivos quanto a redução do comportamento do fogo. Foram avaliadas a eficiência e as formas de uso do polímero hidroretentor como retardante de fogo de curta duração (combate indireto) em queimas controladas em plantios de eucalipto. Foram avaliadas cinco concentrações (diluição em água), três volumes de calda de aplicação e dois tempos pós-aplicação sobre o material combustível disponível na área. As queimas controladas foram conduzidas a favor do vento, entre as 10 e 14 horas, na estação seca da região, com avaliações micrometeorológicas e do comportamento do fogo (velocidade de propagação do fogo e comprimento das chamas). O aumento do volume de calda e das concentrações do polímero hidroretentor propiciaram reduções na propagação do fogo. Em material combustível de eucalipto, o polímero hidroretentor pode ser usado como retardante de fogo de

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curta duração (efeitos até duas horas após a aplicação), considerando a calda de 2,0 L m^{-2} e concentração de 0,0060% (diluído em água).

Palavras-Chave: Incêndios florestais; Comportamento do fogo; Hidrogel.

1.INTRODUCTION

Forest fires are worrisome events on global, regional and local scales, due to the countless economic, social and environmental impacts they generate in the areas they affect. This scenario indicates the need to use operational management, prevention and combat systems that integrate the behavior of fire and its circumstances such as meteorological conditions, characteristics of the combustible material and topographic conditions (SOARES and BATISTA, 2007; BATISTA et al., 2013).

Knowledge of fire behavior can be used to establish procedures for training of firefighters, activities to prevent ignitions of anthropic origin, definition of levels of readiness and pre-positioning of the means of suppression, design of tactics and strategies for suppressing fire, and in the planning and execution of controlled fires.

In this context, several methods of direct and / or indirect fighting of forest fires have been developed; in this case, attention is given to chemical firebreaks composed of fire retardants (RIBEIRO et al., 2006; FILHO et al., 2012). The retardants are products associated with water, which inhibit the preheating and ignition of combustible material by conserving moisture for a prolonged period (LIODAKIS et al., 2003; CANZIAN et al., 2016; PLUCINSKI et al., 2017).

In the indirect fight against forest fires, the retardants available on the market are generally effective, but present drawbacks such as environmental impacts, high costs and lack of information regarding concentrations, spray volumes and duration of efficacy after application (DIETRICH et al., 2014; CANZIAN et al., 2016), associated with the lack of legislation relevant to Brazilian conditions (IBAMA, 2018).

In the search for solutions to minimize the severity of forest fires (in native or planted areas) and in crops (mainly in corn stover), alternative products have been studied as fire retardants. The water-retaining polymers (hydrogels) used in the agroforestry sector to retain moisture in the soil have characteristics that indicate the potential to conserve moisture in combustible forest materials, thus being able to influence the variables of fire behavior (BOURBIGOT and DUQUESNE, 2007; SOUZA et al., 2012).

The objective of this work was to evaluate the effectiveness and ways of using water-retaining polymer as a fire retardant, in indirect use, in controlled burns of combustible material from hybrid clones of *Eucalyptus grandis* x *Eucalyptus urophylla* cl. H13, in the Cerrado-Amazon transition of the state of Mato Grosso.

2.MATERIALS & METHODS

The study was carried out in the municipality of Sorriso, MT (12 ° 51'35.04” S and 55 ° 52'33.54” W, flat relief and 365 m altitude), in July and August 2017. The region is located in the Cerrado-Amazon biome transition. According to the Köppen classification, the climate is of the hot and humid (Aw) tropical type, with two well-defined seasons: dry (May to September) and rainy (October to April). The average annual precipitation is 1.940 mm and average monthly air temperature ranges from 22.0 to 25.0 ° C (SOUZA et al., 2013).

The experiment was carried out in the center of stands (minimizing edge effect) of hybrid clones of *Eucalyptus grandis* x *Eucalyptus urophylla* cl. H13, 6 years old and with 3.0 x 3.0 m spacing (line x interplant). The trees were subjected to pruning, had an average total height of 26.0 m and a percentage of crown occupation of 62.0%. To the east of the experimental area was a fragment of native riparian forest and to the west farmland with successive soybean, corn and cotton crops (ALVES et al., 2017).

The experimental design was a three-level factorial: 6 x 3 x 2 (concentrations x spray volumes x time after application), with three repetitions (subplots) per treatment. In the random distribution (drawing) of the experimental units (subplots), interactions between concentrations and spray volumes were considered at the first level, and at the second level the post-application time (1.0 and 2.0 h) of the retardant over combustible material (Figure 1).

Plots of 25.0 x 3.0 m (length x width) were installed, composed of subplots of 3.0 x 3.0 m, interspersed “without” and “with” the application of the fire retardant (water-retaining polymer). The subplots were divided into three repetitions of 1.0 x 3.0 m (length x width), where points of observation of the behavior of the fire were fixed

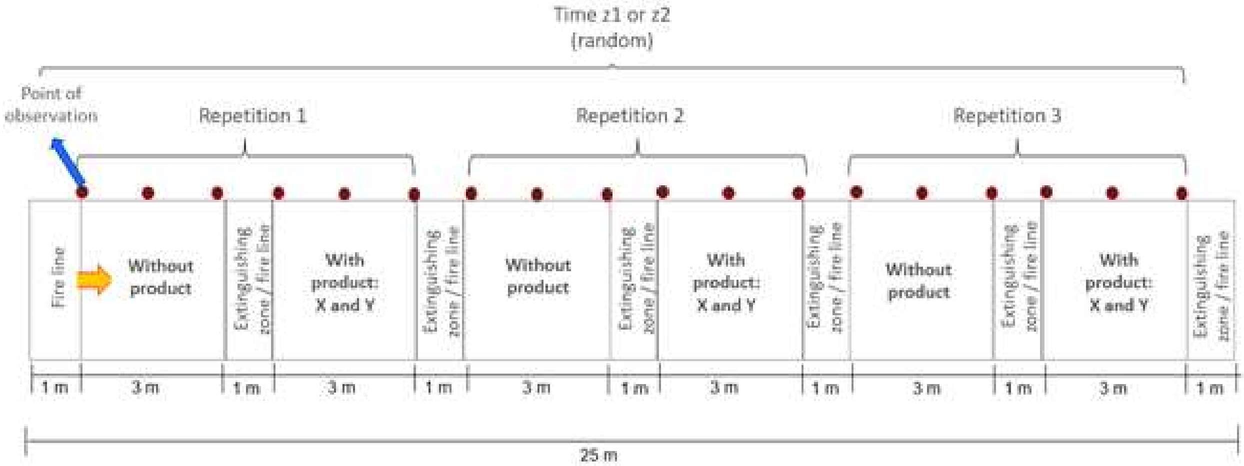

Figure 1 – Experimental sketch of the controlled fire plots with fire retardant application (water-retaining polymer), considering different concentrations (X), spray volumes (Y) and post-application times (z1 = 1.0 h; z2 = 2.0 h) in *Eucalyptus urophylla* x *Eucalyptus grandis* cl. H13.

Figura 1 *– Croqui experimental das parcelas de queimas controladas com aplicação do retardante de fogo (polímero hidroretentor), considerando diferentes concentrações (X), volumes de calda (Y) e tempos pós-aplicação (z1=1,0 h; z2= 2,0 h) em plantio de* ***Eucalyptus urophylla*** *x* ***Eucalyptus grandis*** *cl. H13.*

(ALVES et al., 2017). Between the subplots, transitions were installed (zones of fire extinguishing / fire line) of 1.0 x 3.0 m (length x width) to eliminate residues from the application of the retardant and start of another line of fire (another subplot).

The effectiveness of water-retaining polymer (commercial Nutrigel®) as a fire retardant was evaluated. It is composed of methylcellulose and 27.80; 49.70; 8.70 and 18.10% of CaO, $CaCO_3$, MgO and $MgCO_3$, respectively, with a neutralization power of 67.50% (classification similar to dolomitic limestone).

Six concentrations of the water-retaining polymer diluted in water (0 - water; 0.0010; 0.0025; 0.0050; 0.0075 and 0.0100%) in three spray volumes (0.5; 1.0 and 2.0 L m^{-2}) were evaluated. The concentrations were determined (between 0.1 and 1.0 g L^{-1}) in tests that aimed to avoid clogging of the fan-type nozzles used in fireproof backpack sprayers. Subplots without retardant / water were considered controls.

The available fuel material was characterized by random collection of samples of 1.0 m², at most 3.0 m from the subplots, on the same planting line and on the same day as the controlled burning, with one sample per subplot. The average thickness of the combustible material layer (litter) was obtained, with subsequent separation of the plant partitions in the classes: i) dead (dry) combustible material: leaves, barks, thin branches with diameter (d) <0.7 cm and branches mean 0.7 ≤ d ≤ 2.5 cm; and ii) live (moist) combustible material composed of herbaceous and grassy plants (ALVES et al., 2017; ALVES et al., 2018). The classes of the combustible material were weighed in the field to obtain the fresh wet mass. Subsequently, they were subjected to drying in an oven with forced air circulation at a temperature of 65 ° C (± 2 ° C), until reaching constant mass, to determine the moisture content of the combustible material.

Micrometeorological variables (air temperature, relative air humidity, wind speed and direction) were monitored every minute during burns controlled with a portable automatic weather station (Instrutemp Weather Station, model ITH1080), suspended at a height of 2.0 m in the center of the planting. Controlled burns occurred downwind between 10 am and 2 pm (local solar time), times with greater fire intensity and few variations in zenith angles (LIMA et al., 2017).

Fire behavior was assessed using the following variables: i) fire propagation speed (PS: m min^{-1}), timing the fire line travel time between two consecutive observation points; ii) length of the flames (L: cm), given by the visual estimate with a ruler attached to the observation point at the time of the fire. Subsequently, the rates of reduction in fire propagation speed (RRPS) and flame length (RRL) were defined, considering as reference the subplots that did not receive retardant (hydrogel) or water.

The remaining post-burn fuel material was collected by means of a random sample of 1.0 m² in the subplots of the controlled burns. After collection, the samples were dried in a forced air oven at a temperature of 65.0 ° C (± 2 ° C), until reaching constant mass, to estimate the percentage of total dry mass of fuel material remaining and consumed during burning.

The normality of the data (residues) was assessed by Shapiro-Wilk test, with subsequent analysis of variance (ANOVA) for the variables of the available fuel material and the factorial (concentrations x spray volumes x times after application of the retardant). Significant differences between means were compared by the Scott-Knott test at 5.0% significance. The determination of the ideal concentration of water-retaining polymer was obtained by means of regression analyses ($p \leq 0.05$), between the fire behavior variables (dependent variable) and the retardant concentrations (independent variable) with a spray volume of 2.0 L m^{-2} at post-application times of 1.0 and 2.0 hours.

3.RESULTS

3.1. Available fuel material and weather elements

The available fuel material was homogeneous between the treatments, since no significant differences ($p > 0.05$) were observed between layer thickness, percentage distribution, total dry mass and moisture content in the plots used in the evaluation of the different concentrations of the water-retaining polymer and its interactions with the spray volumes and post-application times (Table 1).

Regarding variations in air temperature, relative humidity and wind speed (Figure 2), monitored instantaneously during controlled fires, the fires occurred under similar weather conditions, when comparing the average values obtained for the different spray volumes applied and presence / absence of the water-retaining polymer. The average values of air temperature, relative humidity and wind speed ranged from 29.1 to 34.8 ° C; 18.5 to 33.0% and 0 to 2.7 m s^{-1}, respectively.

3.2. Fire behavior

The fire behavior described by the fire line propagation speed (PS) and the length of the flames (L), as well as their reduction rates, showed differences between the treatments in the unfolding of the triple factorial (concentrations, spray volumes and post-application times) of the water-retaining polymer (Table 2), indicating together that the preparation and application influence the product's effectiveness as a retardant.

Table 1 – Characterization of available fuel material in plantations of hybrid clones of *Eucalyptus urophylla* x *Eucalyptus grandis* cl. H13, subjected to controlled burns to assess the effect of water-retaining polymer as a fire retardant.
Tabela 1 – *Caracterização do material combustível disponível em plantio de clones híbridos de* ***Eucalyptus urophylla*** *x* ***Eucalyptus grandis*** *cl. H13, submetidos a queimas controladas para avaliação do efeito do polímero hidroretentor como retardante de fogo.*

Classes of combustible material	Concentration of retardant (%)					
	0	0.0010	0.0025	0.0050	0.0075	0.0100
	Fuel material layer thickness (cm)					
	8.67	8.83	9.00	11.33	9.00	9.67
	Classes of combustible material (%)					
Leaf	41.61	42.18	46.90	34.51	40.86	41.40
Bark	10.97	9.39	7.11	7.30	7.34	7.76
Thin branch	15.15	21.53	18.05	13.16	17.61	13.84
Medium branch	30.36	26.91	27.93	41.37	31.38	32.08
Herbaceous material	1.88	-	-	3.65	2.82	4.92
	Dry mass of combustible material (t ha^{-1})					
Leaf	11.30	11.23	11.87	10.40	12.06	10.67
Bark	2.93	2.50	1.80	2.20	2.17	2.20
Thin branch	4.17	5.73	4.57	3.97	5.20	3.57
Medium branch	7.94	7.17	7.07	12.47	9.27	8.27
Herbaceous material	0.43	-	-	1.10	0.83	1.27
Total dry mass	26.76	26.63	25.27	30.10	29.53	25.80
	Moisture content (%)					
Leaf	11.70	11.95	11.89	11.74	14.60	11.95
Bark	11.50	12.82	12.05	12.48	13.05	12.82
Thin branch	11.20	11.12	10.21	10.43	12.20	10.56
Medium branch	10.33	10.88	10.85	10.75	12.68	9.42
Herbaceous material	21.23	-	-	25.31	43.08	20.68

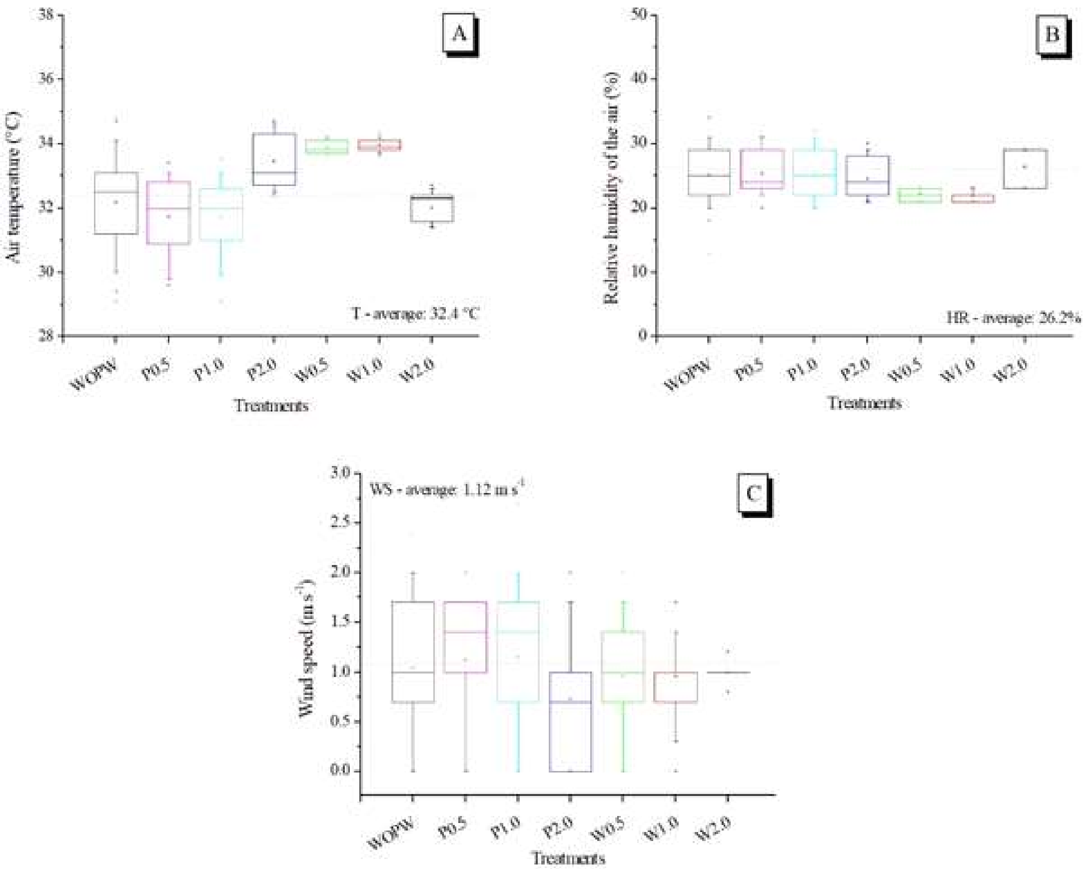

Figure 2 – Behavior of air temperature (A), relative humidity (B) and wind speed (C) during controlled fires with different treatments. WOPW: without water-retaining polymer and water; P0.5, P1.0 and P2.0: with application of water-retaining polymer at 0.5; 1.0 and 2.0 L m^{-2}, respectively; W0.5, W1.0 and W2.0: water-only application at 0.5, 1.0 and 2.0 L m^{-2}, respectively.

Figura 2 – *Comportamento da temperatura do ar (A), umidade relativa do ar (B) e velocidade do vento (C) durante queimas controladas com diferentes tratamentos. WOPW: sem polímero hidrorretentor e água; P0.5, P1.0 e P2.0: com aplicação de polímero hidrorretentor a 0,5; 1,0 e 2,0 L m^{-2}, respectivamente; W0.5, W1.0 e W2.0: apenas aplicação de água a 0,5; 1,0 e 2,0 L m^{-2}, respectivamente.*

Given the higher efficacy of the water-retaining polymer in the spray volume of 2.0 L m^{-2}, the ideal product concentration for this spray (based on the pre-determined concentrations of the polymer) was determined through adjustments of quadratic polynomial models with correlations greater than 80.0% in the two post-application times (Figure 3).

3.3.Survey of remaining and consumed fuel material

In the survey of the post-burn combustible material, the control (without application of retardant and water) showed a higher percentage of combustible material consumed by fire (above 90.0%) (Figure 3). As expected, at the most effective concentrations of the water-retaining polymer (0.0050 and 0.0075%, in the spray volume of 2.0 L m^{-2}, after 1.0 h of application), the combustible material consumed (23.0 %) was lower than the remaining fuel material (77.0%) (Figure 3I). However, after 2.0 h of application of the water-retaining polymer, an inversion of this relationship occurred (fuel material consumed and remaining 80.0 and 20.0%, respectively) (Figure 3J).

4.DISCUSSION

4.1. Available fuel material and weather elements

In all treatments, the percentage distribution of the classes of available fuel material showed a higher leaf composition, followed by medium branches, thin branches, barks and herbaceous material. The average

Table 2 – Fire behavior and rate of reduction in interactions of water-retaining polymer concentrations with spray volumes and post-application times.
Tabela 2 – *Comportamento do fogo e taxas de reduções nas interações das concentrações do polímero hidroretentor com os volumes de calda e tempos pós-aplicação.*

Concentration (%)	Spray Volume (L m^{-2}) 0.5		1.0		2.0	
	Time after application of retardant (hours)					
	1.0	2.0	1.0	2.0	1.0	2.0
	PS (m min-1)					
Control	0.73 Ca	0.73 Ba	0.73 Ba	0.73 Ba	0.73 Ba	0.73 Ba
0*	0.52 Ba	0.65 Ba	0.39 Aa	0.55 Ba	0.20 Aa	0.30 Aa
0.0010	0.38 Aa	0.60 Bb	0.24 Aa	0.46 Ab	0.17 Aa	0.23 Aa
0.0025	0.35 Aa	0.52 Ba	0.21 Aa	0.41 Aa	0.13 Aa	0.17 Aa
0.0050	0.22 Aa	0.36 Aa	0.18 Aa	0.27 Aa	0.00 Aa	0.13 Aa
0.0075	0.29 Aa	0.31 Aa	0.16 Aa	0.28 Aa	0.00 Aa	0.08 Aa
0.0100	0.25 Aa	0.54 Bb	0.22 Aa	0.32 Aa	0.13 Aa	0.26 Aa
	L (cm)					
Control	86.76 Da	86.76 Ca	86.76 Da	86.76 Ca	86.76 Ca	86.76 Ba
0*	86.66 Da	87.00 Ca	70.00 Ca	70.00 Ba	32.50 Ba	40.00 Aa
0.0010	80.00 Da	85.00 Ca	51.67 Ba	63.33 Ba	30.00 Ba	33.33 Aa
0.0025	70.00 Ca	70.00 Ba	50.00 Ba	55.00 Aa	15.00 Ba	30.00 Aa
0.0050	40.00 Aa	45.00 Aa	30.00 Aa	43.00 Aa	0.00 Aa	30.00 Ab
0.0075	58.33 Ba	62.00 Ba	30.00 Aa	50.00 Ab	0.00 Aa	20.00 Ab
0.0100	70.00 Ca	90.00 Cb	35.33 Aa	53.00 Aa	23.33 Ba	23.33 Aa
	RRPS (%)					
0*	28.36 Aa	11.88 Ba	47.12 Aa	25.07 Ba	72.90 Aa	58.82 Aa
0.0010	47.45 Aa	18.70 Bb	66.84 Aa	37.67 Bb	76.16 Aa	67.66 Aa
0.0025	51.94 Aa	29.30 Ba	71.39 Aa	44.49 Ba	81.55 Aa	76.93 Aa
0.0050	69.03 Aa	50.29 Aa	75.52 Aa	62.70 Aa	100.00 Aa	81.71 Aa
0.0075	59.75 Aa	57.89 Aa	77.21 Aa	61.42 Aa	100.00 Aa	89.08 Aa
0.0100	66.02 Aa	26.62 Bb	69.79 Aa	56.41 Aa	81.21 Aa	64.81 Aa
	RRL (%)					
0*	0.38 Ca	0.38 Ca	19.54 Ca	19.54 Ba	62.54 Ba	54.02 Aa
0.0010	19.54 Ca	230 Ca	40.61 Ba	27.20 Ba	65.42 Ba	61.59 Aa
0.0025	8.05 Ca	19.54 Ba	42.53 Ba	36.78 Aa	82.71 Ba	65.52 Aa
0.0050	54.02 Aa	48.28 Aa	65.52 Aa	51.15 Aa	100.00 Aa	65.52 Ab
0.0075	32.95 Ba	29.12 Ba	65.52 Aa	42.53 Ab	100.00 Aa	77.01 Ab
0.0100	19.54 Ca	-3.45 Cb	59.77 Aa	50.19 Aa	73.11 Ba	73.18 Aa

* Concentration of 0% considers only the application of water, while the other concentrations consider the water-retaining polymer dissolved in water; averages with the same lowercase letter in each row and uppercase in each column do not differ by Scott-Knott test (p> 0.05). PS: speed of fire spread; L: length of the flames; RRPS: rates of reduction of PS; RRL: rates of reduction in L; Control: portion without application of retardant / water ".
** A concentração de 0% considera apenas a aplicação de água, enquanto as demais concentrações consideram o polímero retentor de água dissolvido em água; médias com a mesma letra minúscula em cada linha e maiúscula em cada coluna não diferem pelo teste de Scott-Knott (p> 0,05). PS: velocidade de propagação do fogo; L: comprimento das chamas; RRPS: taxas de redução do PS; RRL: taxas de redução em L; Controle: porção sem aplicação de retardante / água ".*

total dry mass of the fuel material was 27.4 t ha^{-1}, composed of 11.2; 4.5; 8.6; 2.3 and 0.9 t ha^{-1} for leaves, thin branches, medium branches, bark and herbaceous material, respectively.

These values corroborate other studies of *Eucalyptus* aged between 5 and 7 years during the dry season (CORRÊA et al., 2013; CARMO et al., 2018). The combustible material available in the experimental area had a high ignition hazard due to the number of leaves, which are of a class with less timelag (time required for the loss of moisture from the fuel to the environment) (ALVES et al., 2018).

In the same area of cultivation, when the plants were 4.5 years old, Alves et al. (2017) obtained an average total dry mass of 14.0 t ha^{-1}, while Carmo et al. (2018) evaluating the same genetic material in this region, in areas aged 7 years, observed an average total dry mass of 31.0 t ha^{-1} in the composition of the litter (combustible material), both in the month of August. The increase in total dry mass observed in the experiment is common

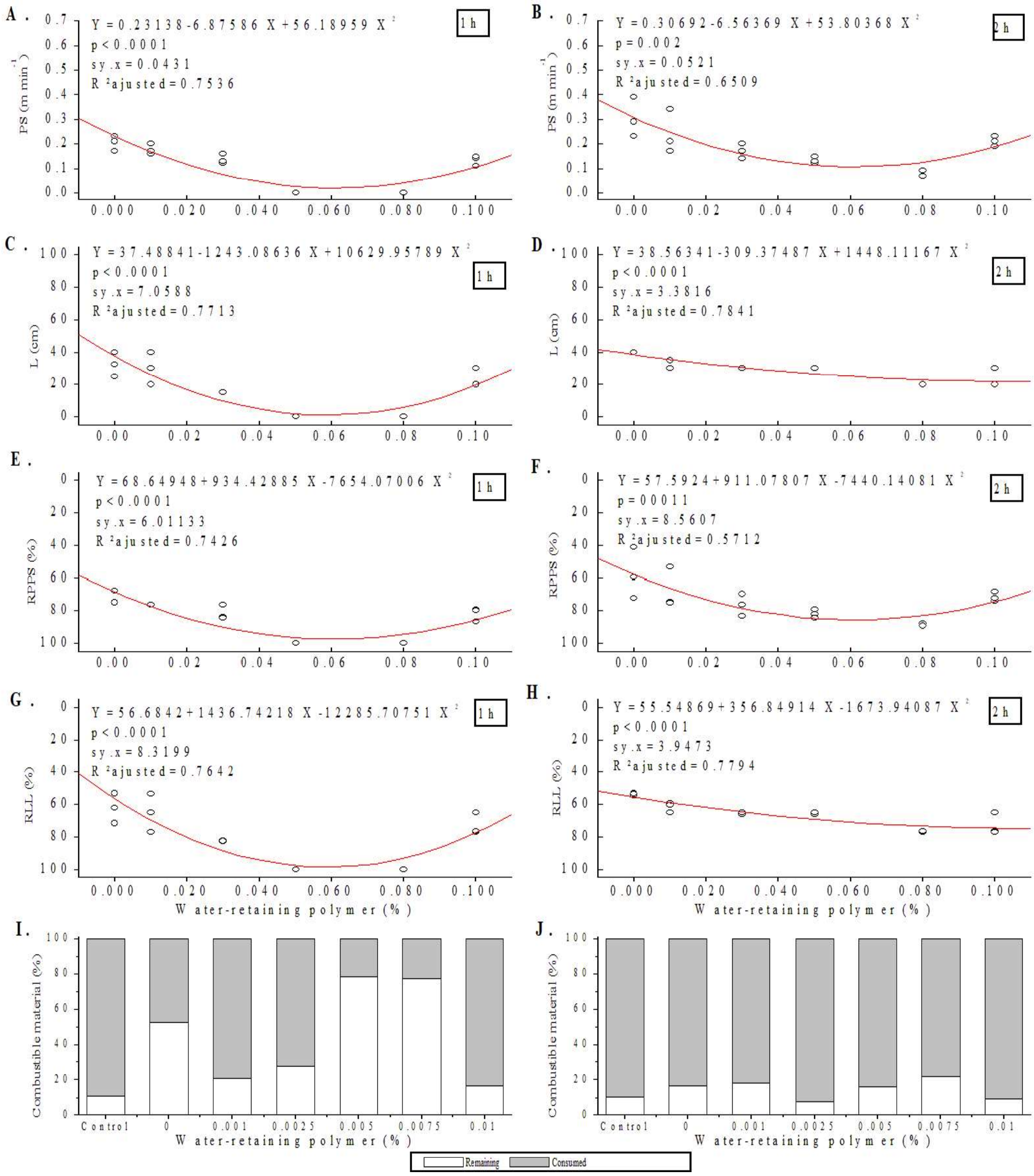

Figure 3 – Regressions between concentrations of the water-retaining polymer and fire behavior variables at the 2.0 L m^{-2} spray volume in controlled burns (A at H) and post-burn combustible material 1.0 h (I) and 2.0 h (J) after application of retardant in controlled burns. PS: fire propagation speed; L: length of the flames; RRPS: rate of reduction of fire propagation speed; RLL: rate of reduction of length of flames; Syx: standard error of the estimate.

Figura 3 – *Regressões entre concentrações do polímero hidroretentor e variáveis do comportamento do fogo no volume de calda de 2,0 L m^{-2} em queimas controladas (A até H) e material combustível pós-queimas com 1,0 h (I) e 2,0h (J) após aplicação de retardante em queimas controladas. PS: velocidade de propagação do fogo; L: comprimento das chamas; TRVP: taxa de redução do VP; TRL: taxa de redução do L; Syx: erro padrão da estimativa.*

in cultures of hybrid clones of *Eucalyptus grandis* x *Eucalyptus urophylla* cl. H13, aged 5 to 7 years, in the dry season (CARMO et al., 2018), in response to the high deposition of combustible material with the growth of the trees.

The moisture content of the fuel material was less than 15.0%, except for herbaceous materials (ranged from 20.7 to 43.1%). These values are considered lower than fire extinguishing moisture (25.0 to 30.0%), indicating a high risk of fire occurring in the area during the experimental period (SOARES and BATISTA, 2007). The observed values were higher than those found by Alves et al. (2017) for the same area, at an age of 4.5 years, in the month of August (around 8.0% in the same fuel material partitions).

The increase in moisture content with the age of the forest stand may result from lower rates of evaporation of water from the soil with the deposition of combustible material (MATEUS et al., 2013; SLIJEPCEVIC et al., 2018), since the litter of eucalyptus presents low decomposition rates (CARMO et al., 2018). The evaporation process depends on the transfer of water from the topsoil to the plant fragments in the combustible material. The movement of water from the soil occurs by capillary action, and is interrupted with the increase of the porous space in the fragments of the combustible material (SHARPLES and McRAE, 2011). Therefore, changes in energy balances occur in the fuel-atmosphere limit layer, causing surface fragments to dry faster compared to fragments close to the ground (HOFFMANN et al., 2012), altering the behavior of fire in controlled burns.

Micrometeorological conditions (Figure 2) associated with the characteristics of the combustible material in the study area indicate that the environment presented a high risk of forest fire (HOFFMANN et al., 2012; ALVES et al., 2017). The environmental scenario reinforces the importance of fire behavior forecasting models and indirect fighting methods, such as the use of retardants.

4.2. Fire behavior

The descriptive variables of the fire behavior showed higher values in the control (without application of retardant or water) in function of the real humidity conditions of the combustible material. Similar values were observed by Alves et al. (2017) in the same planting of hybrid clones of *Eucalyptus grandis* x *Eucalyptus urophylla* cl. H13, 4.5 years old in the month of August, with PS of 0.74 m min^{-1} and L of 100 cm.

The application of water only (concentration of 0%) reduced the behavior of fire when compared to the control, however, it was less effective when compared with the applications of the concentrations of the water-retaining polymer, regardless of the volume of spray solution applied. In this case, the post-application time may have influenced the water evaporation process (faster) in the microclimate conditions of the area (BOURNE et al., 2015; PLUCINSKI et al., 2017).

Regarding the post-application time of 1.0 h of the water-retaining polymer on the combustible material, the most effective concentrations were 0.0050 and 0.0075%, with maximum reduction of PS and L in the spray volumes of 0.5 and 1.0 L m^{-2}, with extinction of fire at 2.0 L m^{-2}. However, after 2.0 h of the application there was a tendency to increase PS and L in all concentrations and spray volumes. The rates of reduction of PS and L obtained in comparison with the control, were 100% in these concentrations and spray volume.

In this case, the water-retaining polymer penetrated evenly among the plant partitions, leading to increased conservation of moisture in the fuel due to the greater adherence between the water present in the water-retaining polymer molecules and the forest fuel. This characteristic makes the water-retaining polymer effective as a fire retardant, since it hinders the water evaporation process and reduces the behavior of fire (GIMÉNEZ et al., 2004; RIBEIRO et al., 2006; PLUCINSKI and PASTOR, 2013).

The concentration of 0.0100% in all spray volumes was less effective than the concentrations of 0.0050 and 0.0075%; in this case, this higher concentration allowed the formation of a gelatinous layer (lumps of gel), (BALENA, 1998) after 1.0 h of application of the product, which in turn, maintained the moisture only in the surface layer of the combustible material. This behavior differed from other studies with retardants, in which increasing product concentrations generated greater efficacy (RIBEIRO et al., 2006; FIEDLER et al., 2015; CANZIAN et al., 2016).

Among the factors evaluated, the spray volume was determinant for the maximum effectiveness of the water-retaining polymer as a retardant in hybrid clones of *Eucalyptus urophylla* x *Eucalyptus grandis* cl. H13. Similar results were observed by Batista et al. (2008)

in controlled fires of *Pinus taeda* L., where application of 0.5 L m^{-2} retardant spray (Phos-chek®) caused a reduction in fire behavior, whereas increasing the spray to 1.5 L m^{-2} led to extinction of the fire in the plots. In this scenario, when applying larger spray volumes, one should consider the availability of water resources for the capture of water in the affected areas (FIEDLER et al., 2015; CANZIAN et al., 2018).

The interaction between the largest spray volumes and the most effective concentrations of the water-retaining polymer generated greater conservation of moisture in the combustible material. In this case, the applied product inhibited the evaporation of water from the fuel for a prolonged period in response to the slow release of water present in the water-retaining polymer molecules (BALENA, 1998; SOUZA et al., 2012; FIEDLER et al., 2015). By differentiating the polynomials, 0.0060% is defined as the ideal concentration of water-retaining polymer for application without waste in chemical firebreaks for indirect firefighting within 2.0 h after its application on the combustible material of hybrid clones of *Eucalyptus urophylla* x *Eucalyptus grandis* cl. H13.

The post-application time of the water-retaining polymer on the combustible material, in general, did not impact the effectiveness of the retardant, however fire extinction was observed after 1.0 h of application of the product. Similar behavior was observed by Souza et al. (2012) applying water-retaining polymer spray of 2.0 L m^{-2} at a concentration of 0.0010% on *Melinis minutiflora* P. Beauv., observing the conservation of moisture up to 24 h after application of the product on the fuel. In this case, the type of combustible material can determine the conservation of moisture for a prolonged period in the forest fuel.

4.3. Survey of the remaining and consumed fuel material

In general, after 1.0 h of application of the product at concentrations of 0.0050 and 0.0075%, the fire was extinguished, thus justifying higher values of the fuel material remaining post-burn. However, in the plots with burns carried out after 2.0 h of application of the product, the fire continued to spread slowly, leading to an increase in the consumption of fuel material available in the plots.

Similar results were obtained by Ribeiro et al. (2006) in controlled burns of *Brachiaria decumbens* Stapf. with application of retardant (Phos-chek®) at a concentration of 13.4% in the spray volume of 1.2 L m^{-2}, where they obtained fuel material consumed below 2.0% due to the extinction of the fire in the plots. However, in the application of smaller spray volumes, there was a reduction in the behavior of fire and a higher percentage of combustible material consumed, as also evidenced by Canzian et al. (2016).

5.CONCLUSIONS

Water-retaining polymer was effective and can be used as a fire retardant for indirect use, including in controlled burning in plantations of hybrid clones of *Eucalyptus urophylla* x *Eucalyptus grandis* cl. H13, when applied at a spray volume of 2.0 L m^{-2} and a concentration of 0.0060% (diluted in water) within 2.0 h after application on the combustible material.

The increase in spray volume increases the effectiveness of the fire retardant; however, it is emphasized that the availability of water can be a limiting factor in the fight against forest fires.

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