Agropecuária Científica no Semiárido
Centro de Saúde e Tecnologia Rural
http://revistas.ufcg.edu.br/acsa/index.php/ACSA/index
ISSN: 1808-6845
DOI: http://dx.doi.org/10.30969/acsa.v21i1.1356

Fire Intensity of Fuel Materials in Different Phytophysionomies of Paraíba State, Brazil

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ABSTRACT: Fire is considered one of the greatest agents of environmental transformation and its study covers several areas of science. In natural sciences, is considered an essential natural element in the formation and preservation of various ecosystems, though, in areas altered by man, forest fires have caused serious ecological, social and economic damage. In this context, we aimed to evaluate the flammability of combustible material produced in different phytophysionomies in the Paraíba state. Where collected leaves, branches and leaf litter in an area of Caatinga, Atlantic Forest and pine plantings. The flammability was evaluated through rate of spread and intensity of the fire in the burning experimental plots with 1.0 m^2. We tested seven combustible materials the treatments: T1 – *Aristida adscensionis*; T2 – *Tabebuia aurea*; T3 – *Ziziphus joazeiro*; T4 – *Croton blanchetianus*; T5 – *Licania rigida*; T6 – Litter, and T7 – *Pinus* (control). The results revealed that the intensity of the fire in the treatment with grass panasco differed from the others, with 127.48 kW m^{-1}, a value higher than the control treatment, where, where there were pines (41%). The speed of propagation and intensity of the fire was higher in the treatment with grass panasco grass (*Aristida adscensionis*) and its presence in areas of the Caatinga creates a mosaic of high flammability.
Keywords: forest fuel; flammability; forest fires; fire behavior, fires in the Caatinga biome.

Intensidade do fogo em materiais combustíveis de diferentes fitofisionomias no estado da Paraíba, Brasil

RESUMO: Os incêndios florestais se propagam através da queima do material combustível que se distribui no piso florestal, principalmente as folhas. O estudo objetivou avaliar a inflamabilidade do material combustível produzido em diferentes fitofisionomias na Paraíba. Para isso foram coletadas folhas, ramos e serapilheira em área de caatinga, Mata Atlântica e plantio de Pinus localizados em diferentes regiões da Paraíba. A inflamabilidade foi avaliada através de observações das variáveis velocidade de propagação e intensidade do fogo em queimas experimentais de parcelas de 1 m2. Para isso foram testados sete diferentes materiais combustíveis que constituíram os tratamentos: : T1 – *Aristida adscensionis*; T2 – *Tabebuia aurea*; T3 – *Ziziphus joazeiro*; T4 – *Croton blanchetianus*; T5 – *Licania rigida*; T6 – Litter, and T7 – *Pinus* (controle). Os resultados revelaram que a intensidade do fogo no tratamento com capim panasco diferiu dos demais, com 127,48 kW m-1, valor cerca de 41% a mais que o tratamento com Pinus. Conclui-se que a velocidade de propagação e intensidade do fogo foi maior no tratamento com capim panasco e sua presença em áreas de caatinga cria um mosaico de alta inflamabilidade.
Palavras-chave: combustível florestal, inflamabilidade, incêndios Florestais, comportamento do fogo, incêndios no bioma Caatinga.

INTRODUÇÃO

Fire is considered one of the largest transforming agents of the environment and its study transversalizes several sciences, from history to engineering. In natural sciences, fire is an essential natural element in the formation and preservation of various ecosystems, however, in areas altered by man, forest fires have caused serious ecological, social and economic damage (SOARES, 2000; TEBALDI et al., 2013)

The forest fire, different from the burning, is an uncontrolled fire in an area of forest that spreads by conditions provided by the fuel material, climatic conditions, topography and the type of vegetation (SOARES, BATISTA 2007). Currently, the risks of fires have grown in different countries due to the accumulation of combustible material, the population increase and its activities (TETTO et al. 2009).

Combustible material is all organic matter, alive or dead, present in the forest capable of combustion and burning. The type of the material influences the intensity of heat, the ease of ignition and the speed of propagation of the fire (WHITE et al., 2014). According to Batista and Biondi (2009), in native vegetation, we can find non-flammable (or low

Recebido em 06/11/2024; Aceito para publicação em 05/02/2024
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flammability) species that, due to their characteristics, offer resistance to the propagation of the fire.

The fire behavior indicates the measures and techniques that can be used to prevent and mitigate fires, as they encompass several characteristics, such as the intensity of the fire, the velocity of propagation, the length of the flames, the direction of the fire, the Area consumed by fire, among other variables (CAMARGOS et al., 2015)

Knowing the characteristics of combustible materials present in the different phytophysiognomies of the medium such as moisture content, leaf type, thicknesses of branches, chemical composition and its form of distribution in the soil will allow the proper management of this material at different times of the year, thus contributing to better waste management and adequacy in the planning of prevention and fire fighting activities.

Climatic conditions are strongly associated with fire propagation factors: The air temperature influences the ignition temperature of the combustible material ranging from 260 to 400°c; the relative humidity controls the flammability of the materials by determining whether the material will be available for burning. Generally, when the relative humidity of the air drops to 30%, it becomes difficult to fight the fire; the wind by being very unpredictable; and precipitation (SOARES E BATISTA 2007; SORIANO, DANIEL e SANTOS, 2015).

In this context, we aimed to evaluate the flammability of the combustible material produced in different phytophysiognomies in Paraíba. Considering the following questions: (a) do different phytophysiognomies native or planted plant produce combustible material that, when burned, exhibit the same behavior of fire? (b) Will the knowledge of fire behaviour in different combustible materials facilitate combat in the event of a forest fire?

MATERIAL AND METHODS

The research was developed at the Rural Health and Technology Center/Federal University of Campina Grande, Patos campus. Combustible materials were collected on the soil surface in different phytophysiognomies occurring in the state of Paraíba, namely: Atlantic Forest biome (Mata do Pau Ferro Ecological Reserve), the municipality of Areia, and also in a plantings of *Pinus*. In addition, were collected Combustible material in an area of preserved Caatinga, in the RPPN for Fazenda Tamanduá, municipality of Santa Terezinha and of species occurring in the Caatinga in the microregion of Patos.

The species of the Caatinga chosen for the collection of the combustible material were Panasco grass (*Aristida adscensionis* L.), Craibeira (*Tabebuia aurea* (Silva Manso) Benth. & Hook. F. ex S. Moore), Juazeiro (*Ziziphus joazeiro* Martius), Marmeleiro (*Croton blanchetianus* Muell. Arg.), Oiticica (*Licania rigida* Benth). Collected materials were packed in bags of 60 kg, in the quantity to supply the flammability test for each species.

The fuel material of each sample, except for Panasco grass, consisted of fine branches up to 0.7 cm, collected with the leaves, in which it was spread in an environment with air circulation for natural drying, separating carefully each species. The experimental design was completely randomized, with seven treatments and three replications. The treatments consisted of the use of combustible material from: 1) Panasco grass; 2) *Tabebuia aurea*; 3) *Ziziphus joazeiro;* 4) *Croton blanchetianus*; 5) *Licania rigida*; 6) litter and 7) *Pinus* (Control).

The genus *Pinus* it's used as a control since it has high flammability, and has been extensively studied. Before burnin, the moisture content of combustible materials was determined in subsamples of 50 grams of each material that were packaged in paper bags and placed for drying in a greenhouse with forced air circulation at a temperature of 70 º C for 48 hours. In possession of the data, the water content of the combustible materials was estimated using the following equation:

$$H(\%) = \frac{FM - DS}{MS} * 100 \qquad \text{(Equation 1)}$$

Where: H =Humidity; MF = Fresh mass; MS = Dry Mass.

The burning of combustible materials was carried out in a flat area of the forest Nursery/Federal University of Campina Grande, in exposed soil, to perform the measurements of the effect on the soil, simulating the fire. Then, on a digital scale, 1kg of fuel material was weighed for each treatment and repetitions. After, the help of a jig, the plots of 1.0 m x 1.0 m were assembled, containing a load of 1.0 kg m^{-2} for each treatment.

After the plots were organized, the thickness of each stake was measured with the aid of a graduated ruler. At the time before burning, temperature and relative humidity were measured realized by digital thermo-hygrometer and wind speed with digital anemometer.

Afterwards, the burning was performed, and the propagation and height of the flames were observed, and the measurements of relative humidity and wind speed were repeated.

The burning intensity was calculated by in according equation of Byram (1959), and second

Fiedler et al. (2015), that variable is an important to understand the behavior of the fire and is directly associated with the reaction of combustion. Because it is directly related to the speed of fire propagation, it is observed that the faster the fire advances, the greater the amount of energy released into the environment and the more quickly the combustion of the material occurs. The determination of this variable obtained by the following equation:

$$I = H.w.r \quad \text{(Equação 2)}$$

Where: I = Burning intensity (kcal $m.s^{-1}$); H = Calorific power of the combustible material (reference value of 4.000 kcal); w = load of available combustible material (kg m^{-2}); r = fire spread speed (m s^{-1}).

The combustion index was also evaluated, which, according to Neves (2016), is an average based on the analysis of the images of the videos of each sample that went into ignition, and the maximum height that the flame reached was recorded.

The measurement of the flames in each plot was performed with a graduated ruler in order to measure the maximum height reached during burning. The entire firing process was recorded and photographed in order to allow, subsequently, to record the measurements.

To determine the velocity of fire propagation was measured the average time spent by the front of fire (in m s^{-1}) to travel pre-established distances during the burns [3, 12]. For this, chronometers were used, initially measuring the time for the fire to go through 1.0 linear M and, the duration of the combustion time of the combustible material in each plot, until the extinction of the flame.

To classify the velocity of fire propagation was based on the classification of Botelho and Ventura (1990).

Table 1. Classification of fire propagation velocity

Propagation velocity in ($m.s^{-1}$)	**Classification**
< 0,033	Slow
0,033 – 0,166	Average
0,166 – 1,166	High
>1,166	Extreme

In all plots, the soil temperature was measured before burning and after flame extinction, digital thermometer utilized. The burning of the materials was performed in the morning between 08:30am to 11h15min, with average ambient temperature of 26.6 ºC, relative humidity of 42% and wind velocity between 0.9 to 1.2 km h^{-1}.

The data obtained were organized in a spreadsheet and subjected followed by analysis of variance.

When the F value was significant, the means of the treatments were subjected to comparison using the Student-Newman-Keuls test with confidence interval at 5% and 10% of significance, using SISVAR statistical software v. 5.3 (FERREIRA, 2014).

RESULTS AND DISCUSSION

The values recorded for relative air humidity and ambient temperature are within the safety margin and the wind velocity was classified as calm (below km h-1), according to the Beauforte scale.

Table 2 shows the water content values of the different combustible materials. There is a variation in the water content of the materials studied where *Pinus*, considered the control treatment, presented the highest moisture content with 24.67%.

Table 2. Water content values of the different combustible materials.

Combustible material	**PIMC**	**PMSE after 48h**	**Humidity (%)**
Panasco grass	52,202	43,082	21,17
Craibeira	52,520	49,097	6,97
Juazeiro	42,112	39,639	6,24
Marmeleiro	32,739	30,775	6,38
Oiticica	52,250	52,218	0,06
Litter	62,690	58,157	7,79
Pinus (control)	32,196	25,825	24,67

The water content of Panasco grass presented a value close to that of *Pinus* with 21.17%. The fuel material from the *Licania rigida* recorded the smallest content of water (0.06%), value about 35 times lower than the treatments with *Pinus* and panasco grass and, about 6 times lower than the other materials.

The mean increase in soil temperature after burning the different materials are shown in Figure 1, where it shows the highest elevation occurred in the treatment with *Pinus* with 36.7 º C in the first centimeters of the soil, differing statistically only from the treatments with *Tabebuia aurea* and *Ziziphus joazeiro*.

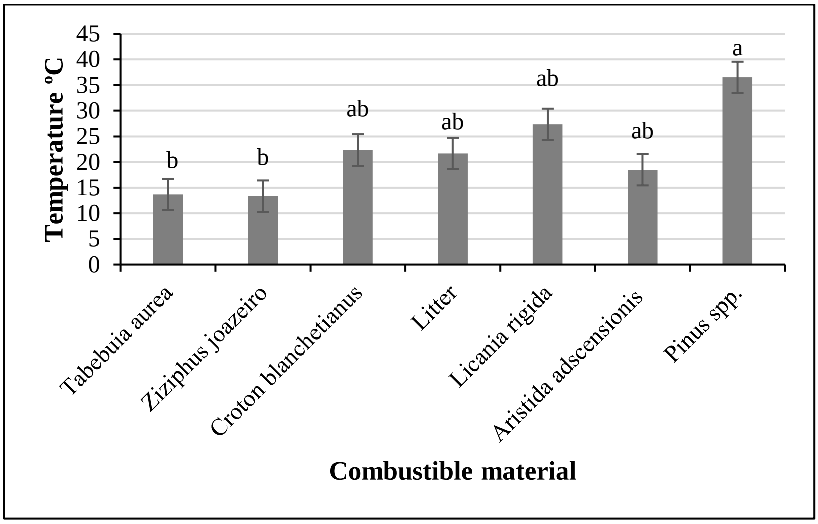

Figura 1 - Mean values ($p < 0.05$) of the increase in soil temperature. Bars represent standard error.

At table 3, of the fire behavior, it is observed, the treatments showed significant differences for the variables propagation velocity and intensity of the fire. The highest propagation velocity occurred in Panasco grass, which surpassed the treatment with *Pinus*, a species considered as "fire tree," due to its high flammability that is attributed to the presence of many essential oils and high content of volatile materials.

Table 3. Averages for the variables of Fire behavior ($p < 0.05$), during the burning of combustible materials.

combustible material	Propagation velocity ($m\ s^{-1}$)	Intensity ($k\ W\ m^{-1}$)	Propagation velocity Classification
Panasco grass	0,03187 a	127,48 a	Slow
Craibeira	0,00359 c	14,39 c	Slow
Juazeiro	0,00589 c	23,58 c	Slow
Marmeleiro	0,00434 c	17,35 c	Slow
Oiticica	0,00502 c	20,05 c	Slow
Litter	0,00230 c	9,21 c	Slow
Pinus	0,01879 b	75,16 b	Slow
CV (%)	34,23	34,24	

Regarding the thickness of the cells, measured before the burning, there was a significant difference between the treatments (Figure 2). The highest mean thickness was recorded in the treatment with *Pinus* with 5.7 cm and the lowest in the treatment with Oiticica specie with an average of 3.0 cm.

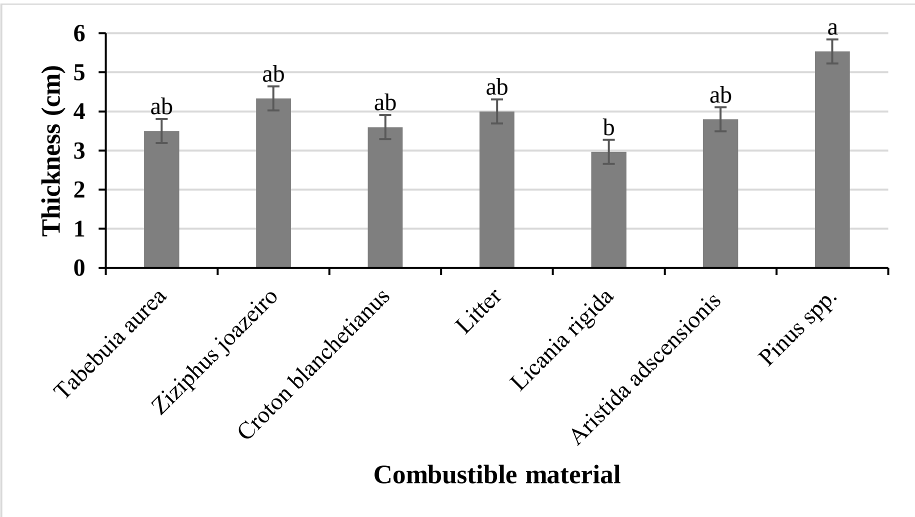

Figure 1 - Mean values ($p < 0.05$) of the sample thickness of the combustible material in the experimental plot (CV% = 23.15). Bars represent standard error

The portion constituted by leaves of Oiticica form a compacted layer, with greater contact with the soil. Moreover, it was observed that the flames consumed the leaves, but they remained in the same way, being disintegrated by the action of the wind, as can be seen in figure 5.

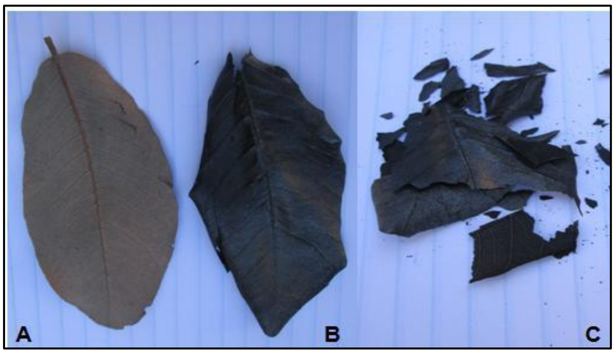

Figure 2- Leaf of the Oiticica (*Licania rigida* Benth): (A) before Burning; (B) carbonized and (C) fragmented.

The treatment with panasco grass was the one that registered the height of the flame above 0.5 m and those that approached this mark were quince and *Pinus*.

The average thickness of the pile ranged from 3.0 cm to 5.7 cm, being the treatment with *Pinus* the one with the thickest pile and the one with the lowest thickness.

The plots with Panasco grass had a mean thickness of 3.6 cm and the height of the flame was the highest in comparison with the other treatments, exceeding the control treatment which is considered in several studies as the high fuel material flammability.

The height of the very low flame was observed in the treatment with litter and in the other treatments was above 12.0 cm and, following the criterion adopted by Neves (2016), the combustion was considered high. Thus, in the variable height of the flame, the treatment with panasco grass presented combustion higher than the *Pinus* (control), revealing the high flammability in areas of Caatinga that has predominance of this species.

In relation to total combustion, the combustible material that took longer to be fully consumed by fire was the Craibeira (Figure 4), having the treatment with Panasco grass registered the shortest average time to be transformed into ashes.

In the figure 4 observed absence also of litter. This is due to the fact that, even though the ignition of the combustible material originated from the Atlantic Forest, the flame was quickly erased and the samples of this treatment were considered negative, that is, the ignition did not last for 30 seconds.

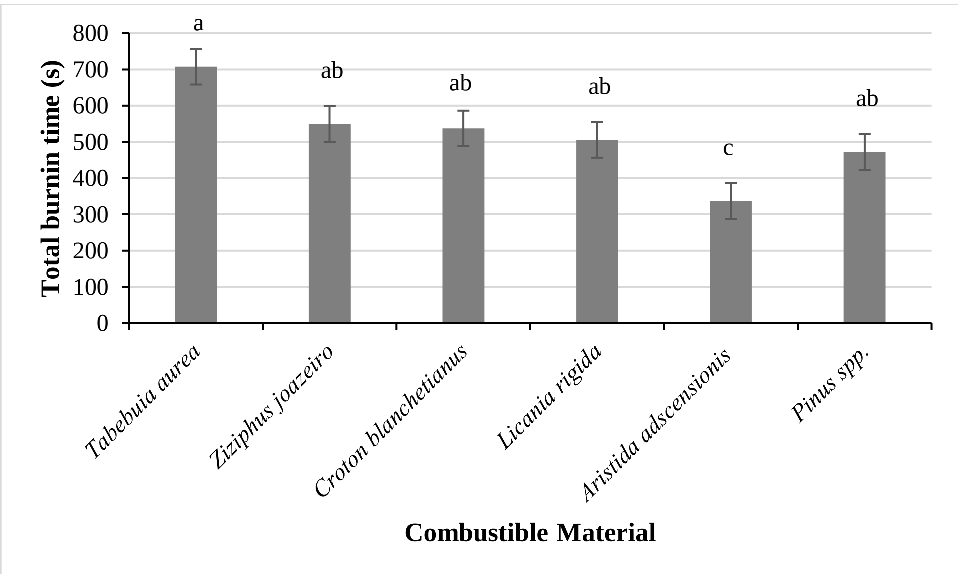

Fig. 3. Mean time ($P < 0.10$) for the total extinction of the flame in the experimental plots (CV% = 23.39). Bars represent standard error.

The knowledge of the water content of the combustible material allows relating with some variables of the fire behavior, such as the ignition time and the initial length of the flame. For Batista et al. (2012), the water content of the living vegetation is variable according to the development of it. The characteristics of leaves and branches have an influence on the water content of the species and this represents one of the properties that control the flammability of the living and dead combustible materials.

Soil temperature data measured in each plot, before and after burning, presented in table 3, indicate the increase of the soil temperature in all treatments with emphasis on *Pinus* (control) that recorded an increase of more than 100% in two replications, evidencing that the heat transfer in the burning of this material to the soil is high, which can cause irreversible damage to the biota that lives in the superficial layers of the soil.

The heat generated by the fire does not penetrate immediately into the soil, but the surface is sensitive to temperature changes, altering the community of organisms, the organic matter content and, sometimes, its colloidal structure (SOARES, BATISTA, 2007). Therefore, anthropic actions such as the use of fire in an unregulated manner over time promotes alterations that tend to reduce the bioindicator capacity of these areas, increasing the level of degradation of the environment.

The flammability of species on the soil surface, depending on the intensity and time that the plant material remains in combustion, this can lead to considerable losses to the environment. (VASCONCELOS et al., 2020)

The study revealed that the highest propagation velocity occurred in Panasco grass, which surpassed the treatment with *Pinus spp*, a species considered as "fire tree" due to its high flammability that is attributed to the presence of many essential oils and high content of Volatile materials.

As Panasco grass falls within the category of fine combustible material, it can be considered a material of high consumibility, i.e., faster is consumption, favoring the propagation after dehydration. An observation made during the firing of the plots with Panasco grass was that the material after dehydration it rolled like a steel straw in flames, being easily carried by the wind, spreading the fire to other areas. Thus, the presence of panasco grass in areas of caatinga increases the probability of the combustible material entering the ignition process and the fire spreading rapidly, consuming the vegetation, with incalculable ecological damage.

This knowledge is important in the adoption of preventive measures such as the reduction of this stratum by animal consumption, installation of firebreaks to break the continuity of this combustible material. For combat, having information about the high combustibility of the material requires rapid and effective measures to prevent the spread of fire in other areas.

Comparing the values of the velocity of fire propagation in the combustible materials obtained in the present study with the classification of Botelho and Ventura (1990), it was found that all treatments recorded values below 0.033 $m.s^{-1}$ being, therefore, classified as slow.

Another important component to understand the fire behavior evaluated in the research was the intensity of the fire and it is also observed in table 3. that the treatment with panasco grass differed from the others, with 127.48 $kW. M^{-1}$, a value about 41% more than the treatment Control. Given the data, it can be affirmed that the presence of panasco grass in areas of Caatinga creates a mosaic of high flammability, and the presence of fire in these areas can trigger forest fires of great proportions.

For the characterization of the burning, the variable burning intensity directly associated with the combustion reaction is used. Because it is directly related to the speed of fire propagation, the faster the fire advances, the greater the amount of energy released into the environment and the faster the material combustion occurs (RIBEIRO, 1997).

The estimation of the intensity of the fire using the Byram equation constitutes a reliable parameter in the study of the fire behavior that allows to compare the energy rates released by different materials (SOARES; BATISTA; NUNES, 2009).

With regard to the burning of the Oiticica material (Figure 5), it is probable that the type of ribs and the presence of hairs in the leaf may have reduced to dehydration that, associated with chemical composition, contributed to the slower action of fire in this material. Since the leaves of Oiticica were in the same format after combustion, it is evident that for a better understanding of the behavior of fire in different combustible materials it is necessary to perform chemical analysis, calorific power, which will allow obtaining more accurate data.

The disposal of the combustible material on the soil surface varies between the materials. It is important to know how each material forms the layer in the soil and whether it will affect the combustion process and support the fire. It is also noteworthy that the type, size and chemical composition of leaves and twigs, fractions that contribute most to the formation of the layer of combustible material, vary seasonally in the native plant formations and/or forest plantations.

In practice, the organization of the combustible material in very thick layers may produce higher flames and, if the batteries are close to the canopy, the flames may come into contact with branches, causing canopy fire, which are of high intensity and very damaging to the environment.

The lack of studies on the behavior of fire with materials from the Caatinga, a dry forest characteristic of the Brazilian semiarid, makes it impossible to compare data in similar environments, revealing a gap that should be filled with Future research, since fire is a devastating agent constantly in this environment.

The greater thickness in the treatment with *Pinus spp*. can be attributed to the distribution and accommodation of the acules, thin branches and some fruits, which spaces free between the materials allowing the circulation of oxygen which, together with the gases of the fuels evolved during pyrolysis will produce the flames, characterizing this material as high flammability.

In a work developed by Batista and Biondi (2009), where they evaluated the behavior of fire in combustible material consisting of *Pinus taeda* (control treatment), they observed that in the portion constituted of the acules the propagation of the fire was intense and quick.

According to the results it is important to warn that the seasons of climatic conditions favorable to the occurrence of forest fires in the semiarid region of Brazil, such as low rainfall, high temperatures, higher radiation and low relative humidity of the air and Areas with Panasco grass that is a flammable species, facilitates the propagation of the fire by placing also at risk less flammable plants.

The low efficiency in ignition and burning of the treatment with litter from the Atlantic forest, being in the present study considered negative, has an explanation reported by White et al., (2014). Where they emphasize that the combustible materials present in Areas such as the Atlantic Forest, hardly enter the combustion process. For these authors, the combustible material in the areas of Matas presents moisture content higher than the extinction humidity, therefore, the probability of ignition of these fuels is lower.

Evaluations of the combustible material in other regions of natural vegetation according to White et al. (2014), .are important, however, scarce in Brazil. More common are studies conducted in areas of reforestation of monoculture as *Eucalyptus* and *Pinus* forest.

Studies evaluating the effect of fire involve several areas of knowledge and should be done together to minimize impacts, proposing safe alternatives and less degrading use over time. In the field, some aspects are clearly visible while others are difficult to detect (CAMARGOS et. al., 2005)

The development of research on the behavior of fire in species occurring in the Caatinga is important to target strategies to prevent and combat forest fires, reducing ecological damage in the environment, in addition to filling a gap on the flammability potential in species of different biomes in Brazil.

CONCLUSION

The presence of Panasco grass in caatinga areas signals a more pronounced risk for the occurrence of forest fires, can be considered the "fire species" of the herbaceous stratum in the caatinga.

Like this, necessary the implantation of firebreaks in areas of Caatinga, with predominance of panasco grass, in order to break the continuity of this material of high flammability avoiding propagation during burning.

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