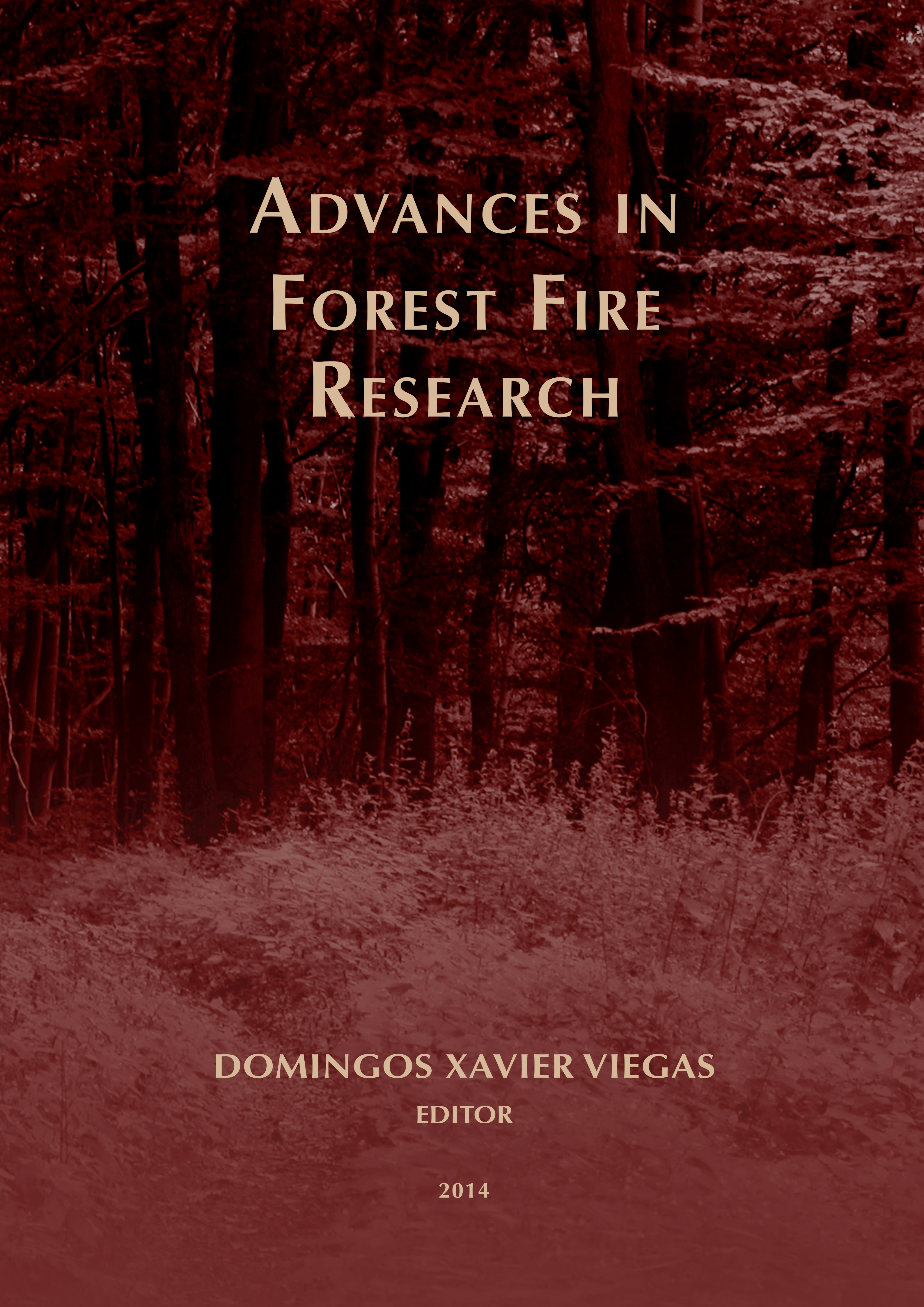

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Fire behavior of prescribed burns in grass - woody steppe on Paraná State, Brazil

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Abstract

Prescribed burns are widespread in many countries, becoming a management practice in different types of vegetation. In addition to practice pasture renewal and land clearing, prescribed burns also represent a means of preventing forest fires, because through this practice, the fuel load can be reduced significantly. To be used safely and effectively, it is crucial understand the aspects of the fire behavior from the vegetation to be burned. The Grass-Woody Steppe (Natural Fields) consists of the phytogeographic regions of the state of Paraná, covering an area of approximately 20,000 km^2 of east-central region of the state. The vegetation consists mainly of grasses and shrubs, with a large concentration of fine fuels (≤ 0.7 cm), representing a high danger of forest fires. For many years, the region of Grass-Woody of Paraná was used as pasture for the intensive rearing of cattle and sheep, activity that lost momentum in recent years due to the advancement of agriculture and forestry. Many farms, however, still keep areas of fields that are management by the fire. Although the burning of vegetation is still a common practice in the region, there are not however, information about the behavior of fire in this vegetation type. The objective of this research was to characterize the behavior of fire in steppe vegetation of the state of Paraná, through prescribed burns. The results aim to support studies of effects of fire on survival and regeneration of plant species in this environment, considering the hypothesis that controlled burning is a viable and safe activity for pasture management. The survey was conducted in the period preceding the winter in an area with more than eight years without human interference, located in Palmeira county, Paraná state. For the experiment, 10 plots of 3 x 20 m were prepared and burned by backfire and head fire techniques. On the day of burning, the weather conditions were: average wind speed of 2.20 $km.h^{-1}$, average relative humidity of air 60.31% and average temperature of 21.83 °C. The surface fuel load was estimated at 2.53 $kg.m^{-2}$, with an average moisture content of 79.77%. The results obtained in the backfire and headfire burnings were: rate of spread - 0.0536 and 0.0150 $m.s^{-1}$, height of flames - 1.39 and 0.68 m, fire intensity - 119, 11 and 51.96 $kcal.m^{-1}.s^{-1}$ and heat per unit area - 2218.84 and 4259.32 $kcal.m^{-2}$. It concluded with the achievement of the experiment, that the prescribed burns conducted at vegetation of Steppe within the established criteria and burning plans, are feasible and safe from the point of view of fire hazard.

***Keywords**: fuel loading; fire intensity; fire danger.*

1. Introduction

Fire is the result of the rapid combination of oxygen and a combustible substance, releasing large amounts of energy. Although it may cause serious environmental damage, the fire is not only a agent that can cause damage to nature, but can also bring benefits to certain ecosystems, when used in a controlled manner, ie, through burnings that provide management vegetation without compromising the processes of natural regeneration (Soares, 1985).

Prescribed burnings, widespread in many countries, are a practice of manegement of different types of vegetation (Soares, 1995). Basically, consists in using the fire confined to a selected area and in appropriate climatic conditions, so that the rate of spread, the intensity of the fire and the heat released, reach management objectives intended in any vegetation. The use of prescribed burning has, among other objectives, to reduce the surface fuel load that can generate the most destructive fires in most critical periods, manegement the vegetation of pastures, control of pests and diseases and to promote the clearing of land for agricultural crops and forest (Soares; Batista, 2007).

For conducting prescribed burns properly, it is essential, however, know how fire behaves in relation to vegetation that will be managed. The knowledge of fire behavior allows understanding the factors that have an important role in the onset and spread of fire. This knowledge is thus so important for the management, as being for planning to fight forest fires operations (Souza *et al*., 2003).

Basically, the variables that describe fire behavior are: rate of spread, fire intensity, heat per unit area and residence time (Soares; Batista, 2007). These variables serve to quantify and characterize the behavior of the fire, as well as, to control the difficulty of extinguishing any fire (Vega, 1996). Other variables such as the maximum temperatures reaching in the areas of combustion and the height of the flames, in addition to describing aspects of fire behavior, can establish associations about the effects produced on the various elements of the forest ecosystem (De Ronde *et al*., 1990).

In Brazil, the use of fire in many regions to vegetation management is still a common practice. Although all biomes are subject to burning a greater or lesser extent, the Savanna (Cerrado) and the Steppes (Southern Fields) are handled more frequently by fire (Pivello, 2011). This is the case of natural fields present in the state of Paraná, which are covered by grasses and shrubs and calling of “Estepe Gramineo-Lenhosa”. The “Estepe Gramineo-Lenhosa” of Paraná state covers approximately 20,000 km^2, composing a phytogeographic zone with vegetation of grasslands adapted to relatively dry environments (Maack, 1981).

Although the burning of vegetation in the region is still a common management practice, there is, however, information about the behavior of fire in this vegetation type. Therefore, the aim of this research was to characterize the behavior of fire in steppe vegetation of the state of Paraná through prescribed burning in order to generate knowledge related to the effects of fire on the survival and regeneration of vegetation.

2. Methods

2.1. Study area

The study was conducted in the Private Natural Heritage Reserve “Caminho das Tropas”. (Figure 1), coordinates 620334 E and 7196739 S, located in Palmeira county, state of Paraná. Created by decree nº 188/08 of the Environmental Institute of Paraná (Instituto Ambiental do Paraná, 2013), the Reserve with an area of 189.70 hectares, is one of the few private protected areas that conserves “Estepe Gramineo-Lenhosa” vegetation in the region.

The climate of the study area, according to the Köppen classification, is the Cfb, present in the higher portions of Paraná highlands. The summers, are usually fresh, with average temperature of 22 °C, while in the winters the average temperatures are below 18 °C. Severe frosts are frequent, occurring on average of 10 to 25 days annually. Rainfall is evenly distributed throughout the year, however, with higher intensity during the summer. The wind blows constantly, in the prevailing direction northeast (Instituto Agronômico do Paraná, 2013).

***Figure 1. Study area –** Private Natural Heritage Reserve "Caminho das Tropas".*

2.2. The experiment

For the realization of the experiment, 10 plots with dimensions of 3 m x 20 m (60 m^2) were bounded with the use of tractor, arranged in the predominant wind direction in the region (Figure 2). The burnings were held in the 5th July (autumn) between 02:00 pm and 6:30 pm, period of the day when weather conditions were more favourable to burn and with less risk of loss of control of the fire. To evaluate the fire behavior, two techniques (treatment) of burning were employed: backfire and headfire.

Figure 2. ***Delimitation of plots to the experiment***

The last rains before of the experiment ocurred on 29 and 30 June with 12.8 and 37.4 mm rainfall respectively (Fundação ABC, 2013). Thus, the burnings occurred 5 days after the last rainfall, covering a period considered relatively safe for burning (within 10 days since the last rain), when the degree of fire danger has not yet reached critical levels (Soares; Batista, 2007).

2.3. Fuel characterization

To characterize the fuel, informations about the type, quantity, moisture content and thickness formed by the deposition of material on the ground were obtained (Figure 3). To do so, it were allocated randomly in each plot three samples of 400 cm^2 (20 cm x 20 cm), where fuel was collected and separately in four categories: material with diameter between 0 and 0.7 cm, material with diameters between 0.71 and 2.5 cm and material whith diameter between 2.51 and 7.6 cm. This fuel was oven dried at 75 °C of constant temperature for determination of dry weight.

After drying, it was determined the fuel moisture using the formula U% = [(Mu - Ms) / Ms] .100 (Batista, 1990), where: **U**% is the fuel moisture content (%); **Mu** is the mass of the fuel during the collection (in grams) and **Ms** the mass of fuel after drying (in grams).

Figure 3. ***Collection and fuel characterization***

2.4. Monitoring of weather conditions

During the period in which the burns were done, the weather conditions were monitored. In all plots were recorded the variables: wind speed ($m.s^{-1}$), air temperature (°C) and air relative humidity (%). For the measurement of meteorological variables, an automatic station Kestrel 6000 Station was used, positioned a height of 1.20 meters above the ground.
Data regarding rainfall of days prior the burnings were obtained from de weather station of the locality of Rosario from the city of Ponta Grossa, whose results are available for viewing on the ABC Foundation website (Fundação ABC, 2013).

2.5. Fire behavior variables

While the burning was occurring in each plot, observations about the following fire behavior variables were made, according to standard procedures adopted internationally and recommended by several authors (Ribeiro *et al*., 2006; Garnica *et al*., 2006; Kuçuk *et al*., 2008; McDonald; McPherson, 2011):

- Rate of spread - obtained visually by determining the time required to the fire line cover distances of 2 m, previously demarcated in each plot, along its length (20 m);
- Flame height - visual estimate of the average height reached by the flames in each 2 m at the advancing of line fire, with the aid of comparators (scales) of known dimensions;
- Intensity of the fire - estimated by the equation proposed by Byram (1959):

$$I = H.\ w.\ r$$

Where:
I = intensity of fire in $kcal.m^{-2}.s^{-1}$
H = calorific value in $kcal.kg^{-1}$
w = weight of fuel available in $kg.m^{-2}$
r = rate of spread of fire in $m.s^{-1}$

For the calorific value was used 3875 kcal.kg^{-1}, proposed by Griffin and Friedel (1984) for the grasslands and savannas vegetation.

Figure 4 present the plots before, during and after the prescribed burning.

Figure 4. Sequence of operations in the burning plots

2.6. Processing and analyzing the data

From the collection and processing of data was possible to construct a matrix, composite of environmental (fuel and weather conditions) and fire behavior variables (Table 1). The data, relating to the environment (fuel and weather conditions) and fire behavior, were processed and analyzed with software STATGRAPHICS Centurion XV. The statistical test used for analysis and comparison of data was the "t" test.

Table 1. Environmental and fire behavior variables

Variable	Description	Unit
WCf	Fuel load (average of 3 samples per plot) before burning	kg.m^{-2}
WCc	Residual (average of 3 samples per plot) after burning	kg.m^{-2}
Hch	Flame height during burns (average of 10 observations per plot)	m
T	Air temperature at the beginning of the burning portion	°C
UR	Relative humidity at the beginning of the burning of plot	%
r	Rate of spread (average of 10 observations per plot)	m.s^{-1}
Vv	Wind speed at the beginning of the burning of plot	km.h^{-1}
I	Fire intensity (average of 10 observations per plot)	kcal.m^{-1}.s^{-1}
H_a	Heat per unit area	kcal.m^{-2}

3. Results

3.1. Weather conditions

The prescribed burnings must be conducted in accordance with established the previous requirements for the weather and fire behavior conditions (Fernandes *et al.*, 2002; Soares; Batista, 2007; Fernandes; Loureiro, 2010). For grasslands, the appropriate recommendations to carry out the burns and achieve the objectives with less risk of fire control losing are shown in table 2.

Table 2. Prescription for burning grassland vegetation

Weather conditions	Optimun	Minimum	Maximum
- Number of days without rain	3 - 7	1	10
- Air temperature (°C)	8 - 20	5	25
- Air Relative humidity (%)	30 - 70	20	85
- Wind speed ($km.h^{-1}$)	5 - 15	1	20
Fire behaviour			
- Rate of spread ($m.s^{-1}$)	0,03 - 0,08	< 0,03	0,13
- Flame height (m)	1 - 4	< 1	5,5

Note: adapted from Fernandes et al. (2002).

Weather conditions recorded at the day of the experiment are presented in table 3

Table 3. Weather conditions

Meteorological variables	Backing fire burning			Head fire burning		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Air temperature (°C)	$22,32_a$	20,00	24,00	$21,34_b$	18,50	23,50
Relative humidity (%)	$58,40_a$	54,00	63,00	$62,20_b$	55,50	69,00
Wind speed ($km.h^{-1}$)	$1,36_a$	1,00	1,80	$3,08_b$	2,20	4,00

Note: Results in the same line followed by different letters are statistically different, by "t" test (p < 0,01).

It is observed by table 3, as well as verified for the precipitation, that the experiment was accomplished within condition acceptable of weather and fire behaviour for the achievement of the prescribed burn safely, according to the parameters listed in table 2.

The results in table 3 indicate that there were differences in weather conditions for the burnings techniques utilized. These distinct weather conditions demonstrate the difficulties that are often encountered when performing burning experiments outdoors. Despite the variations in the weather, the values of weather variables remained very close to the limits recommended for safely performing burnings as shown in table 2.

3.2. Fuel caracteristics

The fuel, as one of the components of the fire triangle is basic and essential for the occurrence and spread of fire. The amount of fuel in an area and their characteristics define whether there will be ignition and how will be the spread of fire. Therefore, the characterization of the remaining fuel is a decisive factor in plans to prevent and fight fires, especially in prescribed burnings programs (Soares; Batista, 2007).

The characteristics of the fuel in the area of the two burn treatments are shown in table 4.

Table 4. Fuel characteristics

Fuel variables	Backing fire burning			Headfire burning		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Fuel load ($kg.m^{-2}$)	$2{,}72_a$	1,23	4,48	$2{,}35_a$	1,59	4,18
Fuel moisture (%)	$74{,}60_a$	52,00	92,19	$86{,}46_b$	60,61	115,83
Fuel consumed ($kg.m^{-2}$)	$2{,}09_a$	0,85	3,12	$1{,}19_b$	0,78	1,81
Fuel consumed (%)	$76{,}25_a$	69,11	90,98	$56{,}60_b$	30,12	77,19

Note: Means in the same line followed by different letters are different, by "t" test ($p < 0{,}01$).

There is not statistical difference in fuel load of the two areas of burns, reflecting the homogeneity of the surface fuels in this type of vegetation.

The fuel moisture was statistically different between the two burning techniques. This variable has great influence on the ignition and the efficiency of combustion, and can vary greatly depending on weather conditions observed on the day or pre-burn period, as well as the season of the year. The fuel moisture found for the 20 plots was approximately 80%, being 74.60% (with a range of 52.00 and 92.19%) in the backfire burning and 86.46% (variations of 60.61 and 115.83%) in headfire burning.The most of the fuel (approximately 70%) was dead and was composed primarily of fine material (≤ 0.7), sorted by Soares (1985) as a hazardous fuel. Although the most of the vegetation was dead, even so, the fuel moisture was high, probably due the amount of rainfall that occurred five days prior to the experiment and due to the overcast sky that prevailed in the following days. However, even with the high fuel moisture, the fire has spread normally, being influenced by the amount of dead fuel, its thickness and also because of the fuel arrangement. Experiments by other authors in grassland vegetation showed that the fuel moisture vary greatly depending on the season and the region. Fidelis *et al*. (2010) reported values between 37.80 and 44.49% for the fine fuels in an experiment conducted with burning of grassland near the Porto Alegre county, south region of Brazil. Miranda *et al*. (1996) found values between 8 and 23% of moisture in fine dead fuel (≤ 0.7 cm) and 113-163% in live fuels in the Savannas near Brasília city. Pivello and Coutinho (1992) reported content of 21-44% moisture of the vegetation of Savannas in the São Paulo State.

Regarding the "burning efficiency" variable that comes to the amount of fuel consumed (in percentage) in relation to fuel load, differences were also recorded. The results of 56.60% for the treatment of headfire burnings and 76.25% for the backfire burnings are significantly different. The burning efficiency of herbaceous vegetation in fields and grasslands may vary from 65 to 95%, according Levine (1996). For savannas of Brazil, Pivello and Coutinho (1992) found values of 63 and 77%, while Miranda *et al*. (1996) determined values between 81 and 94% for the same vegetation. In vegetation of Steppe, Fidelis *et al*. (2010) reported values of 93% in an area with about two years without burning and 95% in an area with six years without fire.

In general, two conditions acting directly for the efficiency of burning: the first related to vegetation type and its characteristics (thickness, arrangement, fuel moisture, etc.), and the second, the meteorological factors during burning (Soares; Batista, 2007).

The differences for the two techniques burning of the experiment can be explained mainly by the physiological state of the fuel load. The moisture checked for fuel from the plots of backfire burnings was greater than moisture of the burned plots of headfire burnings. Other factors, such as, the weather conditions shown in table 3 during the burning may also have influenced the results.

3.3. Fire behavior

It is understood by fire behavior, the result of the interaction between weather, fuel caracteristics, topography, burning technique and form of ignition. The results of the fire behavior variables are represented in table 5.

Table 5. Fire behavior variables of the burning treatments

Fire behavior	Backing fire burning			Headfire burning		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Rate of spread ($m.s^{-1}$)	$0,0150_a$	0,0100	0,0239	$0,0536_b$	0,0391	0,0841
Flame height (m)	$0,68_a$	0,47	0,86	$1,39_b$	1,20	1,75
Fire intensity ($kcal.m^{-1}.s^{-1}$)	$51,96_a$	35,83	73,95	$119,11_b$	65,40	205,08
Heat released ($kcal.m^{-2}$)	$4259,32_a$	1498,85	5754,20	$2218,84_b$	1167,64	2802,29

Note: Means in the same line followed by different letters are different, by "t" test (p < 0,01).

The table 5 shows that all variables that characterize the fire behavior are significantly different for the two treatments.

The mean rate of spread of the backing fire burning was 0.0150 $m.s^{-1}$, with a range of 0.0100 and 0.0239 $m.s^{-1}$, classified as slow according to Soares and Batista (2007). At the head fire burning, the rate of fire ranged between 0.0391 and 0.0841 $m.s^{-1}$, with mean of 0.0536 $m.s^{-1}$, classified as medium by the cited authors.

In a research on fire behavior in prescribed burning in grasslands in the Oklahoma State, United States, Bidwell and Engle (1991) obtained values of 0.20 and 0.02 $m.s^{-1}$ for the rate of spread in the headfire and backing fire burnings, respectively.

Fidelis *et al*. (2010) recorded average rate of spread of 0.015 $m.s^{-1}$ in burnings in an area with one year without burning, and 0.013 $m.s^{-1}$ in an area with six years without burning, in the both cases with headfire. Miranda *et al*. (1996) has found values of rate of spread of burnings in brazilian savannas of 0.13 to 0.64 $m.s^{-1}$ (mean of 0.385 $m.s^{-1}$). Brown and Davis (1973) observed in several experiments of burning in the United States of America, a rate of spread of backing fire burnings with variations of 0.009 to 0.018 $m.s^{-1}$, values very similar to those observed in this experiment.

Statistical analysis detected a significant difference between the mean flame height between the two burning techniques, which were of 0.68 and 1.39 m respectively. These values are within the recommended limits to conduce the fire safely (Fernandes *et al*., 2002).

The fire intensity also varied significantly between the two forms of burnings. In the backing fire burnings, the values were lower, mean of 51.96 $kcal.m^{-1}.s^{-1}$, ranging between 35.83 and 73.95 $kcal.m^{-1}.s^{-1}$. In the backing fire burnings performed in prairies by Engle and Bidwell (1991), the mean of intensity observed were 23.18 $kcal.m^{-1}.s^{-1}$, ranging from 7.41 to 34.89 $kcal.m^{-1}.s^{-1}$. In the headfire burnings, the variation was from 65.40 to 205.08 $kcal.m^{-1}.s^{-1}$ (mean of 119.11 $kcal.m^{-1}.s^{-1}$). In the literature very different values of the fire intensity of prescribed burning on grassland vegetation are found. Fidelis *et al*. (2010) determined a mean of 22.35 $kcal.m^{-1}.s^{-1}$for an area with frequent burning and 42.79 $kcal.m^{-1}.s^{-1}$ to an area with more than five years without burning, both headfire burnings. In the study by Miranda *et al*. (1996), values between 299.99 and 3405.95 $kcal.m^{-1}.s^{-1}$ were recorded and an average of 995.33 $kcal.m^{-1}.s^{-1}$. Fidelis *et al.* (2010) cited the following values obtained by various researchers: 6.68 to 4276.53 $kcal.m^{-1}.s^{-1}$ for the African savannah; 36.06 to 2200.72 $kcal.m^{-1}.s^{-1}$ for the Australian savannas; from 23.64 to 273.95 $kcal.m^{-1}.s^{-1}$ for the grasslands of Australia; 7.40 to 2813.12 $kcal.m^{-1}.s^{-1}$ for the prairies of the United States; from 10.27 to 265.59 $kcal.m^{-1}.s^{-1}$ for the heaths (wetlands) of Scotland; from 95.06 to 112.73 $kcal.m^{-1}.s^{-1}$ for the low savannas of Venezuela; from 46.09 to 538.11 $kcal.m^{-1}.s^{-1}$ for the high Venezuelan savannas and 678.80 to 3916.59 $kcal.m^{-1}.s^{-1}$for the Brazilian savannas.

The fire intensity, calculated by the equation of Byram (1959), has proven to be a very useful parameter in the description of fire behavior, and serve as a benchmark to visualize and compare the rates of energy released by different types of burnings or forest fires (Soares; Batista, 2007).

Regarding the heat released per unit area, values of 4259.32 $kcal.m^{-1}.s^{-1}$ at the backing fire burn (ranging from 1498.85 and 5754.20 $kcal.m^{-1}.s^{-1}$), and 2218.84 $kcal.m^{-1}.s^{-1}$ were obtained in the headfire burnings (range of 1167.64 and 2802.29 $kcal.m^{-1}.s^{-1}$). Miranda *et al.* (1996) found values from 1999.85 to 3405.94 $kcal.m^{-1}.s^{-1}$ in a experiment with headfire burnings in Brazilian savanna, considered very close to the values determined for the African savannas. This variable of fire behavior is an important parameter to evaluate the effects of fire on soil and on the emission of particles in the atmosphere. Generally, as higher is the rate of spread, the lower the amount of energy directed to the inner layers of the soil. In contrast, as slower is the spread of fire, the greater is the amount of energy concentrated there. The highest values of observed heat per unit area in backing fire burning when compared with the headfire burning, are due to the lower rate of spread in this kind of burning.

4. Conclusions

Considering that the controlled burns were conducted within the limits of environmental conditions recommended by the guidelines for fire management adopted internationally**,** it can be concluded that**:**

- The prescribed burns in vegetation of Steppe carried out within the criteria set out at burns plans are feasible and safe from the point of view of fire hazard;
- The parameters of fire intensity, the rate of spread, the heat released per unit area and flame height could be quantified easily and accurately, allowing adequate description of fire behavior;
- The values of fire behavior observed in this study are compatible with most results recorded in similar surveys conducted in other regions and are fundamental to evaluate the effects of fire on the dynamics of post-fire period in steppe vegetation of Paraná state.

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