



**ADVANCES IN  
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RESEARCH**

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## Relationship between the slope and some variables of fire behavior

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### Abstract

The topographic features influences fire regime and fire behavior jointly with the remaining environmental variables. The fire regime characteristics can vary due to fine scale topography and variation in stand history according to topographic features. The fire often influences severity with smaller areas of high severity on lower mesic slopes and larger areas on upper xeric slopes. Several researches confirm the severity of wildland fire. Topographic variables were relatively more important predictors of severe fire than either climate or weather variables. Predictability of severe fire was consistently lower during years with widespread fires, suggesting that local control exerted by topography may be overwhelmed by regional climatic controls when fires burn in dry conditions. This was an indoor study conducted at Forest Fire Laboratory, of Departamento de Engenharia Florestal, Universidade Federal de Viçosa (DEF/UFV), Minas Gerais State, Brazil. It was used a combustion table apparatus with a dispositive to simulate six slopes (0°, 5°, 15°, 25°, 35° and 45°). It was measured the flame length to correlate with the fire line intensity. Five replications were used for each slope, both in uphill as the downhill. The fuel bed was formed by a grass *Melinis minutiflora* Beauv. common in Brazilian grassland. The average values of dry fuel load for each slope were 0.561 kg, uniformly distributed on a platform area of 1.0 x 1.0 meter. The fire line intensity was calculated according to Byram (1969). The relative humidity mean in the downhill and uphill burn day was 48.8% and 57.8% respectively. The result showed that there was increases in the fire line intensity when compared downhill with the uphill slope from range 5 to 45 degrees. The increase was 2.7 times higher in the 45-degree slope compared with the lowest slope. This study will establish a factor for increasing the height of the flames and the fire intensity increased as the surface slope. In all replicates of downhill burning was observed a shorter length of the flames at the beginning and the end portion of plot while on uphill the flame length was shorter only on last plot portion. The flame length was a crescent relationship from 0 until 45 slope degree, represented by  $Y=1.1136+0.0675X-0.0012X^2$ , with a R<sup>2</sup> of 0.9362 for uphill and a polynomial representation of  $Y=1.0923X + 0.101X - 0.0046X^2 - 5E-05X^3$  with a R<sup>2</sup> of 0.8304 for downhill.

**Keywords:** *slope effect; flame length; fire spread; fire behavior*

### 1. Introduction

The great wildfires are occurring on all parts of the world, according to their regional climatic conditions. The relationships between mankind activities and the environment are heavily documented due to the influence of the climatic variations on the human welfare overtime. On the last years we are observing a great demand for food given the population growth requiring the expansion of agricultural areas and a necessary and periodical management of the soil which the fire has been an important tool (JUSTINO *et al.*, 2011). Although the fire has been used by man since the remote times, is now growing concern over its use due to the change in the structure of farms, climate and greenhouse gas emissions. These conditions are producing great changes on the landscape and resulting in large accumulations of fuel. In fact, in different parts of the world and by different reasons the amount of fuel has risen considerably and there has been a consequent increase in the number of fires and land burnt each year as reported by Miller *et al.* (2012), Pausas (2012), Pausas (2004), Soares and Batista (2007), Beautling (2009). Miller *et al.* (2012) further state that recent research has indicated an increasing in worldwide fire size, large fires are becoming more frequent, and in at least some locations



percentage of high-severity fire is also increasing. These changes in the contemporary fire regime are largely attributed to changing climate, land management practices, including suppression of fires and abandonment of rural areas.

The topographic features besides others parameters environmental influences the fire regime and fire behavior jointly with the remaining variables that characterize the environment. According Miler *et al.* (2011), the fire regime concept was developed to provide a framework for investigating differences in the way fire influences ecosystems. The fire regime characteristics can vary due to fine scale topography and variation in stand history. These researchers conclude that topographic features however, often influence severity with smaller areas of high severity on lower, mesic slopes and larger areas on upper, xeric slopes.

The environmental complexity leads to different situations and makes not all fire is equal; fire-caused change or fire severity can vary considerably and decisively influences the effects resulting like evolved species largely with low to moderate-severity fire, and those post-fire landscapes are characterized by survival of fire-tolerant and large-diameter individuals. Severe fires kill and consume large amounts of above and belowground biomass and affect soils, resulting in long-lasting consequences for vegetation, aquatic ecosystem productivity and diversity, and other ecosystem properties (DILLON *et al.*, 2011). However, in many respects, Dillon *et al.* (2011) confirm it is the severity of wildland fire, rather than whether or not a location burned that has greatest effect on ecological processes. Topographic variables were relatively more important predictors of severe fire occurrence than either climate or weather variables. Predictability of severe fire was consistently lower during years with widespread fires, suggesting that local control exerted by topography may be overwhelmed by regional climatic controls when fires burn in dry conditions.

Fire behavior probabilities are different from each other because they depend on spatial and temporal factors controlling fire growth. That is, the likelihood of fire burning a specific area is dependent on ignitions occurring off-site and the fuels, topography, weather, and relative fire direction allowing each fire to reach that location. The results shown by Mistry and Berardi (2005) indicated that there is a higher probability of fire entry from particular border regions as a result of the fuel characteristics. Wind speed greatly increased the spread and extent of fire. According to Miller *et al.* (2011), species compositions vary widely, influenced by precipitation, topography, and substrate, producing different severity degree.

Moreover, studies have shown that fire is part of several ecosystems on the world. It can be used as a tool land management like a prescribed or controlled burning (RIBEIRO, 2009) and can be used safely to achieve different objectives of land management. Biswell (1989) make several recommendations to describe an area to be burn and the mainly one are the topographic features. The combustion process and fire behavior are complex as well as being compounded by variations caused during the burning that are difficult to predict.

The fuel used in this work was the *Millinis minutiflora* Beauv. an 1 hr time lag fuel.

The aim of this study was to assess the influence of slope steepness in fire line intensity and flame length in an indoor condition using the *Melinis minutiflora* Beauv. as a fire bed with no wind flow, and known conditions of fuel moisture and fuel load.

## **2. Materials and methods**

This was an indoor study conducted at Forest Fire Laboratory, of Department of Forest Engineering, Federal University of Viçosa (DEF/UFV), Minas Gerais State, Brazil. It was used an apparatus named combustion table (Figure 1) with a dispositive to simulate the slope steepness in the desired angles and the flame length.

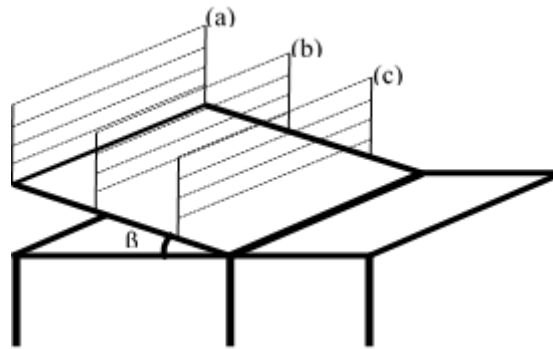


Figure 1. Schematic drawing of the combustion table

The angles  $\beta$  tested were  $0^\circ$ ,  $5^\circ$ ,  $15^\circ$ ,  $25^\circ$ ,  $35^\circ$  and  $45^\circ$  and the flame length was measured from three devices (a,b,c) through the cotton yarns vertically distant every 0.25 m. Five replications were used for each angle, both in uphill as the downhill which were burned on different days.

The fuel bed was formed by a grass *Melinis minutiflora* Beauv. Its power heat was determined in the Panels and Wood Energy Laboratory, Department of Forestry Engineering, DEF/UFV finding 4,186 kcal. The relative humidity of the testing room and the fuel humidity throughout the day 1 (uphill) and the day 2 (downhill) are shown in Tabel 1.

Table 1. Relative humidity and fuel humidity on day 1 (uphill) and day 2 (downhill) of burn.

Day time (h)	Uphill		Day time (h)	Downhill	
	Relative humidity (%)	Fuel humidity (%)		Relative humidity (%)	Fuel humidity (%)
9:00	43	10,20	9:00	76	20,28
11:00	52	9,20	11:00	75	16,47
13:00	51	10,34	13:00	52	18,58
15:00	52	6,05	15:00	43	19,69
17:00	43	7,65	17:00	42	18,64

The average values of dry fuel load for each angle tested are shown in Table 2. Before each burning the fuel load was uniformly distributed on an platform area of 1.0 x 1.0 meter (Figure 1).

Table 2. Dry fuel load (kg) for each slope.

Uphill		Downhill	
Slope (degree)	Fuel load (kg)	Slope (degree)	Fuel load (kg)
$0^\circ$	0.545	$0^\circ$	0.545
$5^\circ$	0.557	$5^\circ$	0.508
$15^\circ$	0.554	$15^\circ$	0.525
$25^\circ$	0.577	$25^\circ$	0.498
$35^\circ$	0.567	$35^\circ$	0.511
$45^\circ$	0.569	$45^\circ$	0.513

The fire line intensity was calculated by Byram (1969) equation:

$$I = H \cdot w \cdot r$$

where,

I = fire line intensity (kcal/m/s);

H = heat power (kcal);

w = fuel load (kg);

r = fire spread (m/s).

It was measured after each burning the flames length, the burning time, the rate of fire spread and burning intensity by Byram (1969). The analyzes were carried out with the StatGraphic statistical package to determine the correlation between the flames length and burn intensity, the gradient increase in intensity with slop increasing and to establish a propagation factor in accordance with the slope for the fuel type studied.

#### Results and discussions

The media and standard deviations values of fire line intensity (Figure 2 and 3) recorded small burning values for both slopes. This was expected because the burning was conducted indoor or without the influence of wind besides the controlled conditions of humidity and fuel load. However, they show a significant difference between the two types of burn. The uphill burning recorded higher and increasingly values between the flat condition (0°) and the largest slope (45°). The highest intensity of burning was recorded for the 45° uphill and was about three times higher than the intensity recorded for the 45°downhill. This confirms the expected scattering flames towards the uphill or the effect of topography behavior.

It is clear that the fire behavior has a strong influence of the fire speed in the absence of others variables. In this study both the heat value as fuel load did not vary. The highest fire speed attained was for the 45° uphill and it was 4.5 times higher than the highest speed reported for the downhill.

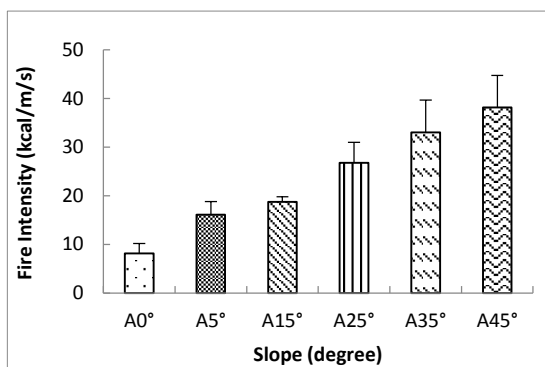


Figure 2. Uphill burning

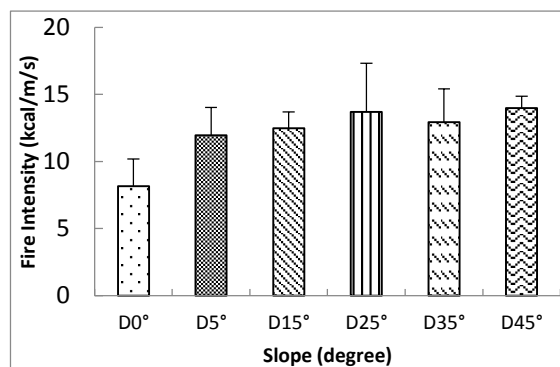


Figure 3. Downhill burning

The relationship between the different levels of slope and the fire line intensity (Figure 4 and 5) showed a better fit of the mathematical model for the firing in the uphill. This relationship was almost direct to which a rectilinear model was fitted.

This profile of fire behavior in uphill is well within the expected. However, in the downhill burning the fire behavior was not the same. The mathematical model fitted was a second degree polynomial equation. In addition, the adjusted model showed a lesser coefficient than the uphill model.

The Figure 5 shows a trend of reduced intensity as the line of fire approaches the lower portion of the burning area. This can be explained by the fact that the fuel load is practically in the end and a less heat flow is produced.

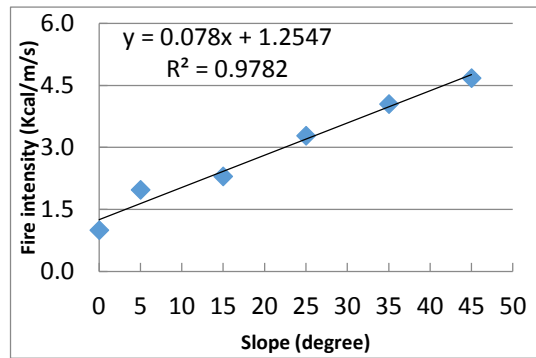


Figure 4. Uphill burning

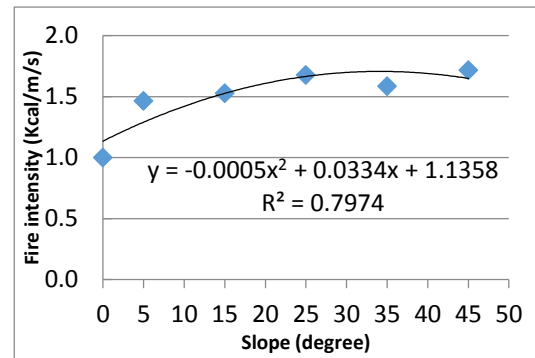


Figure 5. Downhill burning

As noted in other studies, there is a direct relationship between The fire line intensity and the flame length. However, this behavior varies according to other environmental variables and the direction of fire. Burning in the uphill (Figure 6) tends to have a direct relationship with exponential trend. The flames tend to have greater length in relation to the downhill fire and increase in length with increasing slope. However, when reaching the top portion of the flame length decreases by the fact reduce the fuel to be burned and the headwind on the opposite side of the burning surface.

Burning in the uphill shows a different behavior in relation to downhill. Upon reaching the end of the burning surface, the smaller slope, the flames become smaller, probably no more upward flow of warm air and there is no more fuel to be burned.

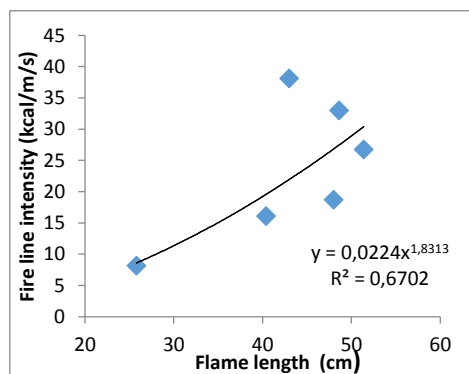


Figure 6. Uphill burning

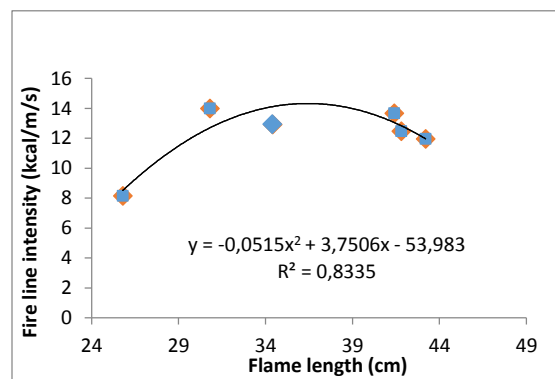


Figure 7. Downhill burning

### 3. Conclusion

It can be concluded that in the absence of any other variables such as fuel moisture, prevailing winds, different loads and fuel type the slope of the relief has a strong influence on fire behavior. In natural conditions this variables can have an exponential influence that is very difficult to predict because the reaction of combustion promotes local modifications in the combustion area that match the variables in humidity and air flow and are difficult to measure.

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