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Fire intensity reduction in straw fuel beds treated with a long-term retardant

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ABSTRACT

The present paper reports fire intensity reduction factors in partially retardant-treated straw fuel beds. Propagation experiments were carried out in the laboratory with fuel beds with a bulk density of 7.5 kg m^{-3} under no-slope/no-wind, upslope/no-wind and no-slope/wind-aided conditions. Fire-Trol 931, a long-term retardant based on polyphosphates, was employed in these experiments and a single retardant concentration of 0.2 kg of dry retardant product per kg of fuel was tested. It has been statistically inferred that fire intensity reduction factors are constant, regardless of the fire intensity of the flame front at the untreated area of the fuel bed, and a mean fire intensity reduction factor of 0.80 has been computed under the experimental conditions tested.

1. Introduction

Different methods can be used to control and suppress wildland fires depending on the type of fuel, topography, fire behavior and firefighting resources available. Two fire extinction methods are normally distinguished: direct and indirect attack. Direct attack refers to any treatment applied directly to the burning fuel, such as smothering (with fire beaters) or wetting (with water or suppressants). Suppressants, such as foam surfactants and water enhancers (gels), are also known as short-term retardants and they are products that are effective as long as the water has not evaporated [1,2]. Indirect attack refers to any suppression tactic used a distance away from the oncoming fire. With regard to the use of chemical additives, a basic indirect attack method is the construction of chemical firebreaks. In this case, long-term retardants are mainly used; these are products that continue to be effective after their water content has evaporated [3]. Despite several advantages associated with the construction of chemical firebreaks, this technique has certain drawbacks, such as: suppressant drops can be burned through or burned around with an inadequate level of coverage or, as with any type of drop (direct or indirect), drops can be breached by spotting. In Ref. [4] a comprehensive overview of outstanding operational and scientific evaluations of suppression methods is presented.

The work presented here focuses only on long-term retardants (henceforth referred to as retardants). The need for evaluating and predicting the effects of these products on fire behavior has been longstanding [5]. Many interacting parameters associated with retardants (type of product, effective coverage level, etc.), fuels (type and arrangement) and fire spread (wind- or slope-aided) make it difficult to estimate the effectiveness of retardants. Most of the work done to date has actually been on retardant evaluation, i.e. on the development of procedures to compare one product with another and classify retardant effectiveness [6–8]. The effectiveness of fire retardant formulations has been studied using analytical laboratory tests and flame spread tests mainly in the laboratory, although some efforts on a field scale have also been made. Fewer attempts have been developed to assess the amount of retardant that would be needed with varying fuel or to quantify retardant effects in varying fire situations. Important efforts in this direction include the works of Rothermel and Philpot [9], Pastor [10] and Giménez et al. [11]. In the laboratory study of Rothermel and Philpot [9] a mathematical approach was followed to estimate the maximum retardant concentration that would be useful in preventing fire spread with a wide variety of fuel types. In Ref. [10] expressions were developed for the ratios of rate of spread to rate of weight loss for retardant-treated and untreated fuel beds under no-slope/no-wind conditions. The proposed expressions depended on the ratio of the amount of dry retardant to dry fuel and the ratio of the amount of water to that of dry fuel. Other no-slope/no-wind laboratory experiments were performed by Giménez et al. [11] who derived relationships between the ratio of rate of spread for retardant-treated and untreated fuels, and two variables—the ratio of the amount of dry retardant to that of dry fuel and a non-dimensional variable related to fuel bed characteristics, i.e. the total surface area per unit horizontal area of fuel bed.

Though some progress has been made in understanding fire behavior and in developing expressions that relate fire spread variables to retardant amounts, knowledge of fire behavior associated with slope- or wind-aided fires in retardant-treated fuels

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needs to be introduced. The present paper reports fire intensity reduction factors in partially retardant-treated straw fuel beds. The main results concerning fuel moisture content as well as slope and wind effects on fire behavior are also described.

2. Experimental method

Experiments consisted of igniting the total width of rectangular and partially retardant-treated fuel beds in order to observe the flame front spread under no-slope/no-wind (C), upslope/no-wind (S) and no-slope/wind-aided (W) conditions. Flame fronts propagated parallel to the slope or to the wind direction. A total of 36 C, 18 S and 18 W fires were conducted but, at the analysis phase, some tests were excluded either because some data were lacking or because the propagation at the retardant strip was not uniform.

2.1. Fuel beds

Porous fuel beds made up of wheat straw (*Triticum turgidum*) spread as evenly as possible, were tested in this study. They had a constant bulk density of 7.5 kg m^{-3}. Physical and chemical properties of the straw are given in Table 1. Tests performed on the combustion table had a fuel bed length of 3.15 m, while tests in the wind tunnel were 5.5 m long when the fans was switched on and 3 m long when they were switched off. Fuel beds were longer when there was an induced wind to allow some stabilization of the flame front, which means that, since fans were not gradually but suddenly switched on, it was considered necessary to allow some distance for the flame front (which was suddenly tilted) to adapt to the new environmental conditions. All fuel beds had a 0.50 m long strip of retardant-treated fuel, which was placed 0.50 m before the end of the fuel bed. The length of this strip was judged to be sufficient to allow a steady-state propagation of the flame front in this area.

Fuel beds were either 0.50, 1.00 or 1.25 m wide. Both fuel bed loading and depth varied depending on the fuel bed width. The main characteristics of the fuel bed configurations are indicated in Table 2 and the appearance of a 1.25 m wide fuel bed prepared on the combustion table is shown in Fig. 1.

Fuel bed configuration was established this way because the experiments described in this study were designed to also analyze how changing the experimental scale (in this case, the fuel bed width) might affect the characteristic parameters that describe the fire behavior prior to entering the retardant strip [12,13]. Since the aim of this work was to compare the fire behavior in the untreated area of the fuel bed with the fire behavior in the retardant-treated area, differences in fire behavior due to fuel bed configurations were not taken into consideration.

Table 1
Fuel properties (extracted from Ref. [10]).

Species	Triticum turgidum (straw)
Surface-area-to-volume ratio (m^{-1})	4734
Fuel particle density (kg m^{-3})	258
High heat of combustion HHC (kJ kg^{-1})	18,868

Table 2
Fuel bed configurations.

Width (m)	Fuel loading—dry basis (kg m^{-2})	Depth (m)
0.50	0.30	0.04
1.00	0.60	0.08
1.25	0.75	0.10

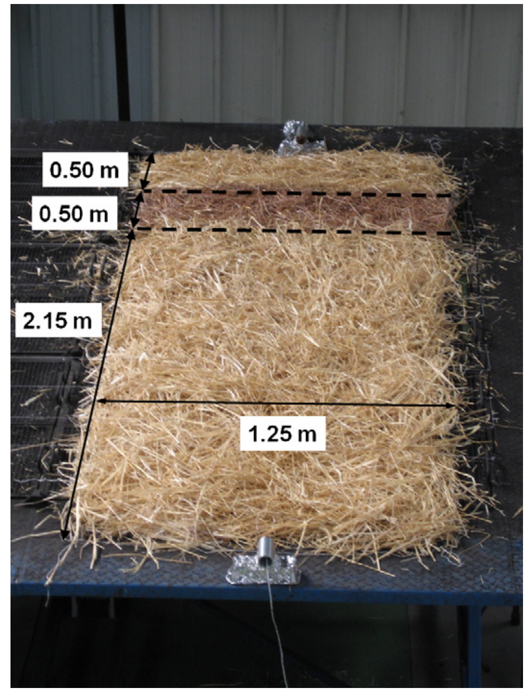

Fig. 1. Fuel bed 1.25 m wide prepared on combustion table. Retardant-treated strip (0.50 m long) is placed within the two dashed lines. The length of untreated areas is also displayed.

Table 3
Wind velocities tested.

Fuel bed width (m)	Wind velocity (m s^{-1})
0.50	0.7, 1.4, 2.1
1.00	1.0, 2.0, 3.0
1.25	1.1, 2.2, 3.3

2.2. Simulated slopes and wind velocities

Experiments were conducted on a combustion table and in a wind tunnel, both placed in the ADAI's large enclosed experimental building near Lousã (Portugal). Both devices are essentially composed of a platform of 4 m × 4 m and 2.6 m × 8 m. The combustion table can be inclined from 0° to 40° and has no lateral walls. The wind tunnel has two lateral glass walls of 2 m high and two axial fans allow the creation of a wind flow. The flow velocity can be varied (0.5–5 m s^{-1}) with a frequency converter, which controls the rotational speed of the fans. Before the tests wind velocities were measured at different positions inside the tunnel and no significant differences were observed along the length, width or height (data supporting this statement are available in Ref. [13]).

The combustion table was inclined at 10°, 20° or 30°, and flow velocities induced in the wind tunnel ranged from 0.7 to 3.3 m s^{-1}. Specific wind velocities tested in this study are indicated in Table 3; they were established to suit the requirements of the previously mentioned parallel study.

2.3. Fuel moisture content and environmental conditions

Immediately prior to ignition, two samples of straw were extracted for moisture analysis from the untreated and the retardant-treated areas of the fuel bed. Moisture content of untreated