Incendios Forestales: amenazas y oportunidades ante los desafíos de un entorno cambiante

Comunicaciones científico-profesionales

X SIMPOSIO NACIONAL SOBRE INCENDIOS FORESTALES

ESPAÑA

Incendios Forestales:
Amenazas y oportunidades ante los desafíos de un entorno cambiante

COMUNICACIONES CIENTÍFICO-PROFESIONALES

SINIF2019

Colección

SINIF-Incendios Forestales

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Incendios Forestales: amenazas y oportunidades ante los desafíos de un entorno cambiante

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Más de 300 personas participan en SINIF2019 en La Nucía.

Nota de Prensa:

El X Simposio Nacional de Incendios Forestales (SINIF2019) se celebró durante dos intensas jornadas en l'Auditori de la Mediterrània de La Nucía (Alicante), con el tema central, "Incendios forestales: amenazas y oportunidades ante los desafíos de un entorno cambiante", actividad científico-profesional con una carga horaria de 20 horas. Esta décima edición ha contado con la participación de más de 300 personas inscritas procedentes de España y Portugal.
La Nucía se ha convertido, un año más, en referente a nivel nacional en materia de incendios forestales, con prestigiosos ponentes nacionales e internacionales que han presentado un total de 33 trabajos.
El Cabildo de Gran Canaria, el Departamento de Física Aplicada de la Universidad de Vigo, el Departamento de Ingeniería Mecánica, ADAI, LAETA y el CEIF de la Universidad de Coimbra (Portugal), el Departamento de Biología Aplicada de la Universidad Miguel Hernández, el CEIS de la Región de Murcia, la Escuela de Ingeniería Forestal y del Medio Natural de Plasencia (Universidad de Extremadura), la Escuela Técnica Superior de Ingenieros Agrónomos y de Montes (Universidad de Castilla-La Mancha), el Grupo VALFIS del Departamento de Educación Física y Deportiva de la Universidad de León, el CERTEC de la Universidad Politécnica de Cataluña, la Fundación CIVIO, la Asociación "La Dula", PYRO FIRE EXTINCTION S.L.U., WILDFIRE SECURITY S.L., el Área de Geología, Geomorfología y Cartografía Geológica del Instituto Geológico y Minero de España, el Instituto Interuniversitario de Geografía y el Departamento de Análisis Geográfico Regional y Geografía Física de la Universidad de Alicante, el Instituto de Investigación en Biocomputación y Física de Sistemas Complejos y el Departamento de Física Teórica de la Universidad de Zaragoza, Parque Nacionales del Ministerio para la Transición Ecológica, la Asociación Profesional de Agentes Medioambientales de Castilla-La Mancha, el Ayuntamiento de Altea, Lokimica AEROLOCK, VALLFIREST Tecnologías Forestales S.L., la Unidad Militar de Emergencias (UME) y el Grupo de Investigación en Clima y Ordenación del Territorio de la Universidad de Alicante.

Los objetivos del simposio son mejorar el nivel de protección del patrimonio forestal y de los ciudadanos y buscar las respuestas más adecuadas a cada situación.

En la inauguración del SINIF2019 han intervenido Pedro Lloret, primer teniente de alcalde de La Nucía y Jaime Senabre, director del SINIF. "La Nucía ha sido la sede de seis de las diez ediciones del Simposio Nacional sobre Incendios Forestales. La Nucía se convirtió por unos días en referente en la materia a nivel internacional con prestigiosos ponentes hispano-lusos.

Por su temática monográfica, la prevención, investigación y extinción de incendios forestales, esta décima edición fue convocada para miembros de los cuerpos de bomberos, bomberos forestales, bomberos voluntarios, brigadas forestales, agentes medioambientales, agentes rurales, voluntariado ambiental, protección civil, policía local, policía autonómica, guardia civil- Seprona, Unidad Militar de Emergencia (UME), estudiantes de Ingeniería Forestal, postgraduados y de ciclos superiores de formación profesional, así como Técnicos de las Administraciones Públicas y, Empresarios del Sector Forestal y gestores de distintos Servicios de Emergencias.

Ponentes

El Auditori de la Mediterránia ha acogido un total de 33 trabajos, dos conferencias magistrales (una nacional y otra internacional), un taller sobre investigación de incendios forestales, una mesa debate sobre el cambio climático y la presentación de un libro temático han configurado un denso programa que se ha estructurado en 7 Mesas Temáticas y el denominado "Espacio Autor de SINIF", una sección del evento que pretende servir de lanzadera de las últimas publicaciones realizadas en materia de incendios forestales.

Entre los ponentes de gran nivel internacional destacan: Dr. Miguel Almeida, Dr. Carlos Viegas y Dra. Daniela Alves, investigadores procedentes del ADAI-LAETA y el Centro de Estudios sobre Incendios Forestales de la Universidad de Coimbra en Portugal, que trataron sobre los incendios en la interfaz-urbano industrial (IUI), la gestión del combustible en la IUF (interfaz urbano-forestal), barreras de protección contra incendios y el uso de drones con agua; el Dr. José Luis Legido, Catedrático del Departamento de Física Aplicada de la Universidad de Vigo, que expuso un "Análisis del número de incendios en Galicia en el periodo 1968-2018"; Sergi Pareja, director comercial de Vallfirest Tecnologías Forestales S.L., que presentó las últimas tecnologías en materia de "protección respiratoria en incendios forestales", o Federico Grillo, Ingeniero forestal, director técnico de emergencias del Cabildo de Gran Canaria, que nos habló sobre los grandes incendios forestales en Canarias y sobre el manejo del fuego técnico.

Los temas centrales de esta décima edición del SINIF han sido: "Grandes Incendios Forestales: estudio de casos", "Investigación aplicada a incendios forestales", "Prevención de incendios forestales: gestión forestal", "Innovación y desarrollo tecnológico: seguridad y autoprotección", "Medios aéreos: herramientas para la prevención y extinción del incendio forestal", "Salud laboral y prevención de riesgos laborales", "La interfaz urbano-forestal" y los "Horizontes en la gestión del fuego forestal: Ecología, Operatividad y Educación (ECOPED).

Espacio Autor de SINIF

Dentro de las actividades del X SINIF ha destacado la presentación del libro: "Salvemos los montes: protección y prevención de incendios" de Joaquín Araújo y José Ramón González Pan. La obra fue presentada por González Pan. Ingeniero, escritor y periodista, y Jefe de Servicio de Publicaciones del Organismo Autónomo de Parque Nacionales del Ministerio para la Transición Ecológica.

Premios SINIF2019

El Comité Organizador convocó los PREMIOS SINIF2019, con el objetivo de incentivar la realización de proyectos y trabajos de investigación en materia de prevención y extinción de incendios forestales. En esta 7ª edición de los Premios SINIF, dichos galardones se entregarán en base a tres categorías: Innovación y Desarrollo Tecnológico, Investigación y, Gestión y Prevención:

El Jurado de los PREMIOS SINIF2019 otorgó los galardones de su séptima edición a las siguientes personas, empresas o instituciones: en la categoría de "Innovación y Desarrollo Tecnológico" a "**WILDFIRE SECURITY S.L.**" por su "*SISTEMA SAVAIF*"; en la categoría de "Investigación" al trabajo "*Vulnerabilidad y resiliencia de la interfaz suelo en ecosistemas: simulación de quemas controlas en ECOTRON forestal mediterráneo*", realizado por el **Grupo de Investigación en Ecología Forestal** de la ETSIAM (Universidad de Castilla-La Mancha); y en categoría de "Gestión y Prevención", el trabajo premiado fue "*Una nueva herramienta para el diseño de los tratamientos de combustible en la interfaz urbano-forestal*", llevado a cabo por el **Centro de Estudios del Riesgo Tecnológico (CERTEC)**, de la Universidad Politécnica de Cataluña".
En la entrega de los PREMIOS SINIF2019 y clausura del X SINIF han participado: Pedro Lloret (primer teniente de alcalde de La Nucía) y Jaime Senabre (director del SINIF).

Colaboradores

El SINIF2019 ha contado con la colaboración de un Comité Científico-Profesional internacional, como órgano asesor, compuesto por investigadores y técnicos de Canadá, Estados Unidos, Chile, Grecia, Alemania, Eslovaquia, Portugal y España. También, con moderadores de mesa expertos en la materia que han servido de gestores de los intensos debates generados.
Especial mención a la Universidad de Vigo (a través del Grupo de Investigación del Física Aplicada FA2), Universidad de Coimbra (a través de ADAI-LAETA y CEIF), Universidad de Alicante (a través del Laboratorio de Climatología), APAM-CLM, VALLFIREST Forestal Tecnologies S.L., y a PREVINFO Soluciones S.L.

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(Téngase en cuenta a la hora de citar: T = Tema de libro; C = Capítulo de Tema de libro)

T3. Capítulo 3.

"Gestión de combustibles forestales en las áreas de interfaz urbana forestales"

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Resumen:

Todos los años, en todo el mundo, grandes incendios forestales devastan grandes áreas de bosques y crean múltiples impactos socioeconómicos, especialmente en regiones propensas a incendios. En países como Portugal, España, Francia, Italia o Grecia, cada año el área quemada y el número de igniciones son aproximadamente entre 24k ha a 164k ha y 1.5k ha a 18k has, respectivamente. En Portugal, el problema de los incendios forestales en las últimas décadas ha ido aumentando, con graves impactos en la sociedad. Los incendios forestales más grandes ocurridos en Portugal, en los últimos años además de las víctimas mortales que producirán, causaron la destrucción de varias construcciones (por ejemplo, casas e instalaciones industriales, etc.). Los incendios forestales de junio y octubre de 2017 destruyeron más de 500 edificios en las regiones del norte y centro de Portugal. La mayoría de esos edificios destruidos podrían haberse salvado si las construcciones tuvieran un diseño adecuado y si se hubiera realizado la gestión del combustible forestal en los alrededores de las construcciones. En el 90% de las construcciones dañadas, el encendido aumentó debido a las manchas, y las brasas se depositaron en elementos vulnerables (por ejemplo, techos, ventanas y otras partes de aberturas) y en el combustible forestal cerca de las construcciones. Este trabajo pretende explorar diferentes patrones de gestión de combustible en interfaz urbano forestal *(Wildland Urban Interface (WUI)),* con el objetivo de maximizar la relación costo / eficiencia, así como su eficiencia.

Presentamos una metodología novedosa con respecto al manejo de combustible alrededor de construcciones aisladas en áreas forestales y rurales. La atención se centra en la historia del incendio forestal y las características topográficas en torno a la ubicación de las construcciones que necesitan protección.

Con esta metodología se espera que aumente la seguridad de las construcciones y disminuya el costo de la gestión de los combustibles cercanos.

Para apoyar esta metodología, se llevó a cabo una serie de estudios experimentales en el Laboratorio de Investigación de Incendios Forestales de la Universidad de Coimbra en Lousã (Portugal) en una tabla de combustión específica, llamada tabla diedro.

Palabras clave:
Interfaz urbano-forestal, prevención de riesgos de incendio, paradas de combustible, infraestructuras, mejores prácticas.

FOREST FUEL MANAGEMENT IN WILDLAND URBAN INTERFACE AREAS

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Abstract:

Every year, all around the World, wildfires devastate large areas of wildland and create multiple socioeconomic impacts, especially in fire prone regions. In countries such as Portugal, Spain, France, Italy or Greece, every year the average burned area and the number of the fires is approximately between 24k to 164k and 1.5k to 18k, respectively. In Portugal, the problem of wildfires in the last decades has been increasing over the years, with severe impacts on society. The largest forest fires occurred in Portugal, in recent years, caused the destruction of several constructions (e.g. houses and manufacturing facilities, etc). More than 500 constructions were destroyed by the wildfires of June and October 2017, at north and centre regions of Portugal. The majority of those destroyed buildings could have been saved if the constructions had a proper design and if forest fuel management in the surroundings of the constructions had been performed. In 90% of the damaged constructions, the ignition resulted from spotting, with embers being deposited in vulnerable elements (e.g. roofs, windows and other openings parts) and in forest fuel near the constructions. This work intends to explore different patterns of fuel management in Wildland Urban Interface (WUI), aiming at maximizing the cost/efficiency relation as well as their efficiency.

We present a novel methodology regarding fuel management around isolated constructions in forested and rural areas. The focus is on the wildfire's history and the topographic features around the location of constructions that need protection.
With this methodology it is expected that the safety of the constructions is increased and the cost for the management of the fuels close to them decreases.

In order to support this methodology, a set of experimental study tests was carried out in the Forest Fire Research Laboratory of the University of Coimbra in Lousã (Portugal) in a specific combustion table, called dihedral table.

Keywords:
Wildland-urban interface, fire risk prevention, fuel breaks, infrastructures, best practices.

Introduction.

Wildfires cause in society a considerable socio-economic impact and high negative impacts in Mediterranean areas or in wildfire prone zones (Alcasena *et al.* 2019). According Alcasena *et al.* 2019 and Moreira *et al.* 2011, in southern Europe the yearly average of the burned areas is approximately 500k hectares and the number of the fires is approximately 50k. The main risks and the worst problems caused by large and devastating fires are the human lives losses (Costa *et al.* 2011; Cardil *et al.* 2017). The climate change during the last decades and the increasing availability of fuel load in wildland areas is one of the main causes for those types of "Large-Fires" (Barrera-Escoda 2011; Moreira *et al.* 2011; Cardil *et al.* 2014).

The largest forest fires occurred in Portugal, in recent years, caused the destruction of several buildings (e.g. houses and manufacturing facilities, etc). More than 500 constructions were destroyed by the wildfires of June and October 2017, in the north and centre regions of Portugal. The majority of those destroyed buildings could have been saved if the constructions had a proper design and if forest fuel management in the surroundings of the constructions had been performed correctly (Manzello et al. 2012; Viegas et al. 2017).

Regardless of prevention efforts at landscape level, wildfires will continue to impact on people and their assets, and they tend to be increasingly destructive, costly and socially threatening (Abrams *et al.* 2014; Valente *et al.* 2015). The number of destroyed constructions is also increasing and the future tendency is to remain growing, either due to climate change or to urban growth in Wildland Urban Interface (WUI) areas. Fuel management is very important to decrease the probability of damage to infrastructures caused by wildfires.

Objectives.

The purpose of this work is to present a novel methodology regarding fuel management around constructions in forested and rural areas. The main focus is on the wildfire's history and the topographic features surrounding the location of constructions that need protection. In the present study only the topographic variable will be analysed. All the presented tests were performed at ADAI's Forest Fire Research Laboratory, in a Dihedral table with two independent test beds or surfaces that allow different combinations of slope, as shown in **Figure 1**. The tests were performed without wind and spotting is not considered.

Materials and method.

Physical problem.

The slope angles considered are described schematically in **Figure 1**. An absolute reference frame $O_oX_oY_oZ_o$ in which the horizontal datum plane was considered and is defined by the axis O_oX_o and O_oY_o. A second reference frame is defined by OXYZ and the axis OY is parallel to O_oY_o and OZ is rotated by an angle α in relation to O_oY_o. This angle (α) will be designated as slope angle.

The surfaces of the ridge table are two square planar slopes and the angles can be inclined independently. It was considered *ACDH* and an angle α_1 in face F_1 and *DEGH* and an angle α_2 in face F_2, as shown in **Figure 1**. Let us consider, in **Figure 1** a) – Case 1 – angle α_1 was 30º and the angle α_2 was 0º and in **Figure 1** b) – Case 2 –angle α_1 was 0º and the angle α_2 was 30º. These two scenarios represent fire spreading upslope or downslope in relation to the structure and a different distance of the fuel management for each condition, as shown in **Figure 2**. A linear fire front *AC* or *EG* was ignited for the upslope and downslope fire spread, respectively, (**Figure 1**). Henceforth, this is designated as Line l_i and is represented as a red line in **Figure 1**.

At the top of the ridge a wooden house was placed, built with a scale factor of 1/16 (presented in the Methods section) compared with the common rural houses in Portugal, as shown **Figure 1**. Henceforth, the wooden house will be designated as infrastructure. The external faces of the infrastructure were defined as f_1, f_2, f_3 and f_4 and the left and right faces of the roof were defined as f_5 and f_6, respectively. The external face f_1 and f_3 are parallel to the OY axis and to the fire front. The face f_1 is totally exposed to fire front when the fire spreads upslope and the face f_3 is totally exposed when the fire spreads downslope. The temperature of each outside face, roof and inside of the infrastructure were monitored with K type thermocouples in contact with the wall surface. The temperature was recorded with a frequency of 1Hz by the array of thermocouples.

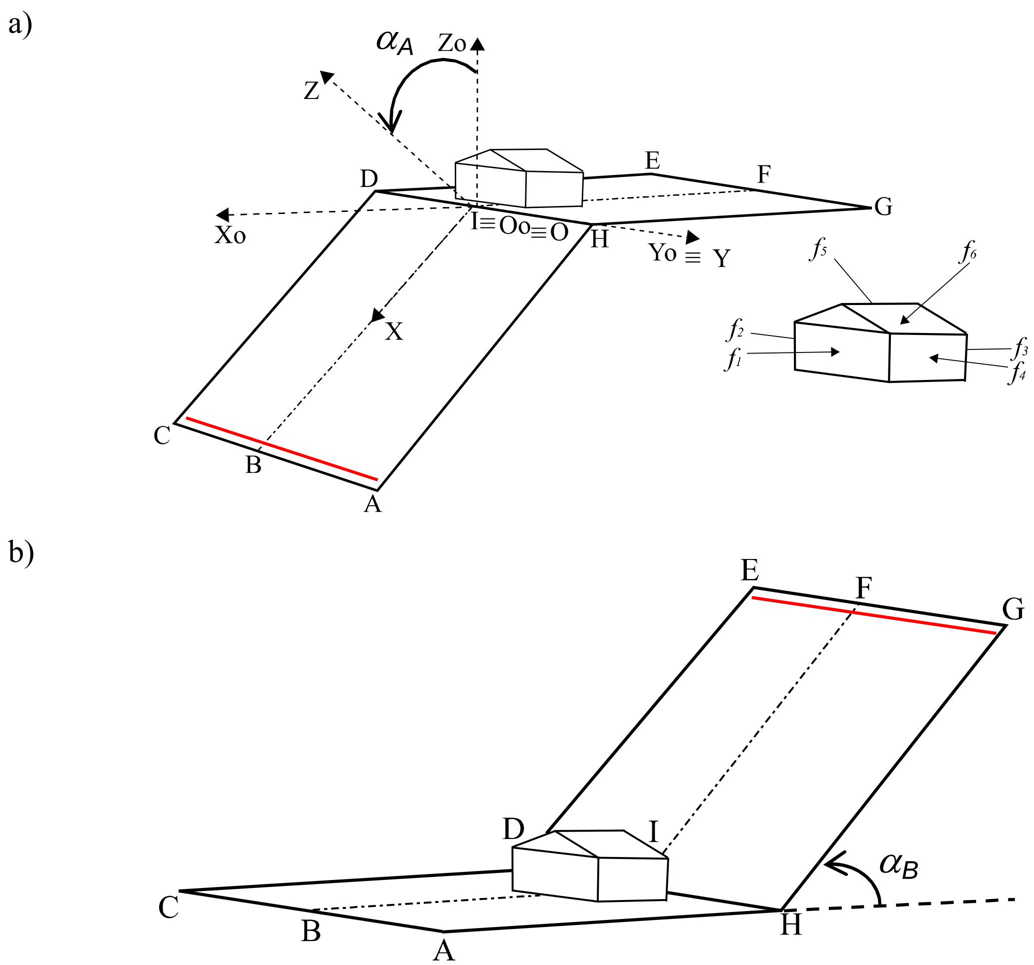


Figure 1. Schematic view of the test preformed: a) Case 1 - fire spreading upslope; b) Case 2 - fire spreading downslope.

The fuel management options surrounding the infrastructure are schematized in **Figure 2**. The dash line represents the top of the ridge. The infrastructure area (***A_h***) is represented by the white rectangle with external red line and defined by:

$$A_h = g \times h. \quad (1)$$

Near to the external faces of the structure (grey rectangle) we considered the absence of fuel (load is equal to ***0 $kg.m^{-2}$***), as shown in **Figure 2**. This area without fuel is important because, in this way, we ensure that there is no fuel in contact with the infrastructure. In the present study, this area (***A_{ef}***) is obtained by:

$$A_{ef} = (g + b_2 + b_3) \times (h + a_2 + a_3) - A_h. \quad (2)$$

The distance around all faces of the infrastructure is constant in all directions and we considered that variables ***b_2***, ***b_3***, ***a_2***, ***a_3*** haves the same dimension.
The fuel management area around the infrastructure is defined by the equation:

$$A_{fm} = a \times b - (A_{ef} + A_h), \quad (3)$$

where

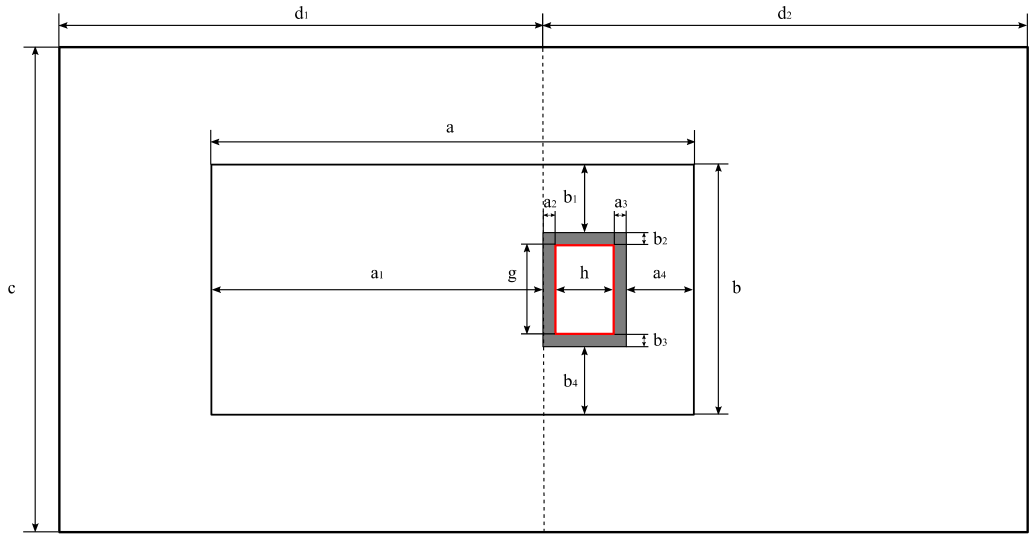
$$a = \sum_{i=1}^{4} a_i + h \quad (4)$$

and

$$b = \sum_{i=1}^{4} b_i + g. \quad (5)$$

The novel methodology presented here considers: a rectangular area for the fuel management; the house is not concentric with the fuel management area and a distance of the fuel management in the face exposed when the fire spreads upslope is larger compared with the face exposed when the fire spreads downslope or parallel with other faces.

a)



b)

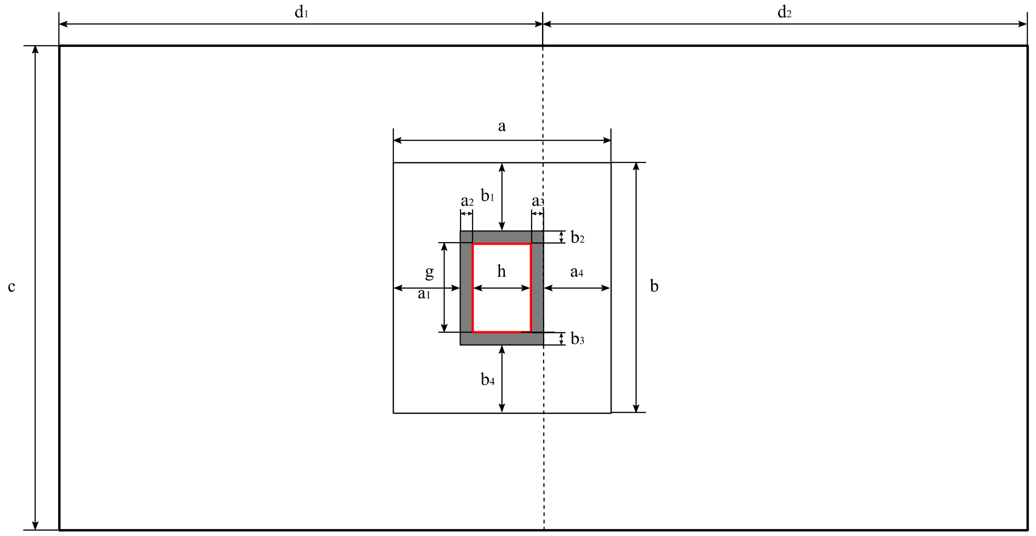


Figure 2. Schematic view of the fuel management around the infrastructure: a) Case 1 – test with fire spreading upslope; b) Case 2 – test with fire spreading downslope.

Methods.

The experimental research tests were carried out at the Forest Fire Research Laboratory of ADAI (University of Coimbra, Portugal) in Lousã on the Dihedral table. The Dihedral table has two square faces with a total test area ($\boldsymbol{A_b}$) defined by:

$$A_b = A_1 + A_2 \tag{6}$$

where

$$A_1 = c \times d_1, \tag{7}$$

$$A_2 = c \times d_2 \tag{8}$$

and $\boldsymbol{c}$, $\boldsymbol{d_1}$ and $\boldsymbol{d_2}$ measure ***4 m***. Therefore, the $\boldsymbol{A_1}$ and $\boldsymbol{A_2}$ is equal to $\boldsymbol{4x4m^2}$ and $\boldsymbol{A_b}$ results in $\boldsymbol{32\ m^2}$ test area. Each surface of the Dihedral table can be inclined independently between ***-45º*** and ***+45º*** in relation to the horizontal reference.

For the present study we considered a scale factor ***1/16*** that corresponds to the ratio of laboratory model to the real scale. So, in **Table 1** the corresponding values between laboratory and real scale values are presented.

	Real scale (*m*)		**Laboratory Dimension (*m*)**	
	Case 1	**Case 2**	**Case 1**	**Case 2**
$\mathbf{a_1}$	0 / 25 / 50	12.5	0 / 1.56 / 3.125	0.781
$\mathbf{a_2=a_3=b_2=b_3}$	3		0,186	
$\mathbf{a_4= b_1=b_4}$	12.5	0 / 12.5	0.781	0 / 0.781
c	64		4	
$\mathbf{d_1=d_2}$	64		4	
g	10		0.625	
h	7		0.438	

Table 1. Scale factor between real scale and laboratory dimensions.

The fuel bed was made with straw with a fuel load of ***0.6 kg.m***$^{-2}$ (dry basis) outside of the fuel management area (m_{co}) and ***0*** or ***0.2 kg.m***$^{-2}$ inside of the fuel management area (m_{ci}). The red line in **Figure 1** represents the fire Line l_i (as previously mentioned) and was ignited ***0.20m*** above the edge *AC* or *EG*. This distance considered for starting the ignition is related to ensuring that there is enough fuel bed to start burning and the combustion can be sustained.

During each test, the conditions of the fuel load and bulk density were controlled during the preparation, and air temperature (***ºC***), relative humidity (***%***) and fuel moisture (m_f) were monitored. The time between the preparation of the fuel bed and the beginning of the test did not exceed ten minutes. This was to ensure that there were no changes in the moisture content of the fuel in contact with ambient air. During the present tests the value of fuel moisture content was measured twice: during the preparation of the fuel bed and before the ignition of each test. According Byram 1959 and Pyne *et al.* 1996 the fuel moisture content determines if the forest fuels burn and what proportion of it is available for the combustion process. In **Table 2** the values of the moisture content immediately before each test are shown. Moisture content was measured with a moisture analyser (A&D ML50) was used.

The tests were monitored using an infrared camera (FLIR SC660) in continuous mode to record all test in the range ***0ºC*** to ***500ºC*** or ***300ºC*** to ***1500ºC***, with a rate of acquisition of ***15Hz***, a photographic camera (Canon EOS 550D) and two video cameras – one in the frontal plane (Sony AVCHD MPEG2 SD) and one in the lateral plane (Sony HD DCR-SR87). In order to reduce uncertainty three replications (T1, T2 and T3) were performed for each set of parameters, shown in **Table 2**. The videos recorded with the infrared camera were analysed to obtain frames of the fire front at pre-defined times. The time between frames was adjusted for each test and it was used to calculate the Rate of Spread (ROS) of the fire front. The ROS (***cm.s***$^{-1}$) is calculated by the equation:

$$R = \frac{x_2 - x_1}{t_2 - t_1} \tag{9}$$

in the present study we used the non-dimensional ROS calculated by:

$$R' = \frac{R}{R_o}, \tag{10}$$

where R_o represent the basic ROS (***cm.s***$^{-1}$). More details of this methodology can be consulted in Viegas 2005.

The fire front during the burning process produces heat energy. According to Byram (1959) the fire intensity (I) is the rate of heat energy release per unit time per unit of fire front (***kW.m***$^{-1}$) and can be calculated by

$$I = H_c\, M_c\, R, \tag{11}$$

where H_c is the fuel low heat of combustion (***kJ.kg***$^{-1}$), M_c is weight of fuel consumed per unit area (***kg.m***$^{-2}$) in the active flaming zone and R is the ROS of the fire front (***m.s***$^{-1}$). Let us consider the H_c value is ***20000 kJ.kg***$^{-1}$ and the M_c values are presented in **Table 2**. According to Rothermel and Deeming (1980) the fire intensity and the flame geometry of the fire are directly related and thus fire intensity results in

$$I = 259{,}833\, L^{2{,}174} \tag{12}$$

where $\boldsymbol{L}$ ($\boldsymbol{m}$) represents the flame length.

The thermocouples to register the temperature (*ºC*) in the wall of the infrastructures were connected to NI cDAQ-9174 with a TC module NI 9213 that allows synchronous data-logging. The temperature was registered during all the time of the test. Let us consider the next equation:

$$Q'A\, \partial t = C_e\, m\, \partial T \tag{13}$$

where ***Q'*** represents the flux of the heat energy ($\boldsymbol{W.m^{-2}}$) calculated by an heat flux sensor, ***A*** represents the face area exposed to the fire front, $\boldsymbol{\partial t}$ represents a differential time (***s***), $\boldsymbol{C_e}$ is the specific heat of the wood ($\boldsymbol{J.kg^{-1}.ºC^{-1}}$), ***m*** represents weight of the exposed wall to the fire front and $\boldsymbol{\partial T}$ represents a differential temperature of the exposed wall (*ºC*). The temperature gradient is the difference of the temperature per unit of time and can be calculated through the equation 11 and results in

$$\frac{\partial T}{\partial t} = \frac{Q'A}{C_e\, m}. \tag{14}$$

Ref.	α_A (º)	α_B (º)	b_1 and b_4 (m)	a_4 (m)	a_1 (m)	m_{co} (kg.m^{-2})	m_{ci} (kg.m^{-2})	Designation			m_f (%)			R_o (cm.s^{-1})		
								T1	T2	T3	T1	T2	T3	T1	T2	T3
1					50		0	FM01	FM04	FM07	10.9	10.13	11.73	0.78	0.80	0.73
2	30	0		12.5			0.2	FM02	FM05	FM08	10.9	10.13	11.73	0.77	0.80	0.73
3					25			FM03	FM06	FM09	10.6	10.01	10.13	0.77	0.80	0.67
4			12.5	0	0	0.6	0.6	FM10	FM11	-	10.13	11.98	-	0.83	0.83	-
5				12.5	12.5		0	FM14	-	-	10.13	-	-	0.83	-	-
6	0	30					0.2	FM15	-	-	10.13	-	-	0.83	-	-
7				0	0		0.6	FM16	-	-	10,13	-	-	0,83	-	-

Table 2. Data of the tests performed for different fuel loads and distances, inside and outside of the fuel management area. The values of $\mathbf{a_1}$, $\mathbf{a_4}$, $\mathbf{b_1}$ and $\mathbf{b_4}$ that appear in the table are presented in real scale dimensions (scale factor equal to 1/16).

Results.

As this is an ongoing work, we present here the preliminary results obtained in the described tests. The fire intensity of a fire front when the fire spread upslope and the temperature gradient in the face $\boldsymbol{f_1}$ of the infrastructure are presented. The ROS of the fire front is not presented because we consider the fire intensity is more relevant for problem. However, the fire intensity is directly related to the ROS, equation 11. The distances (***Dis***) presented in **Figure 3** are related to the real distances, and for a better understanding of the reader we assign the name to the real scale dimensions.

In **Figure 3** the fire intensity when the fire spreads upslope is shown as a function of the distance travelled by the fire front. The lines ***ref 2***, ***ref 3***, and ***ref 4*** represent the mean values for each configuration presented in **Table 2** and the points represent the results for each test preformed. The vertical dashed lines, ***Start FM 50 meters*** and ***Start FM 25 meters,*** correspond to the fuel load change from ***0.6*** to ***0.2 kg.m^{-2}***, that is the beginning of the fuel management. These lines are associated to the tests performed with configurations of ***ref 2*** and ***ref 3***. However, the line ***ref 4*** represent the configurations without fuel management surrounding the infrastructure. In the present analysis the fire intensity of tests with ***ref 1*** is not shown because those are equal to the tests ***ref 2*** but the fuel load inside of the fuel management is ***0 kg.m***$^{-2}$**.** For those tests (***ref 1***) the fire intensity near of the infrastructure is ***0 kW.m***$^{-1}$.

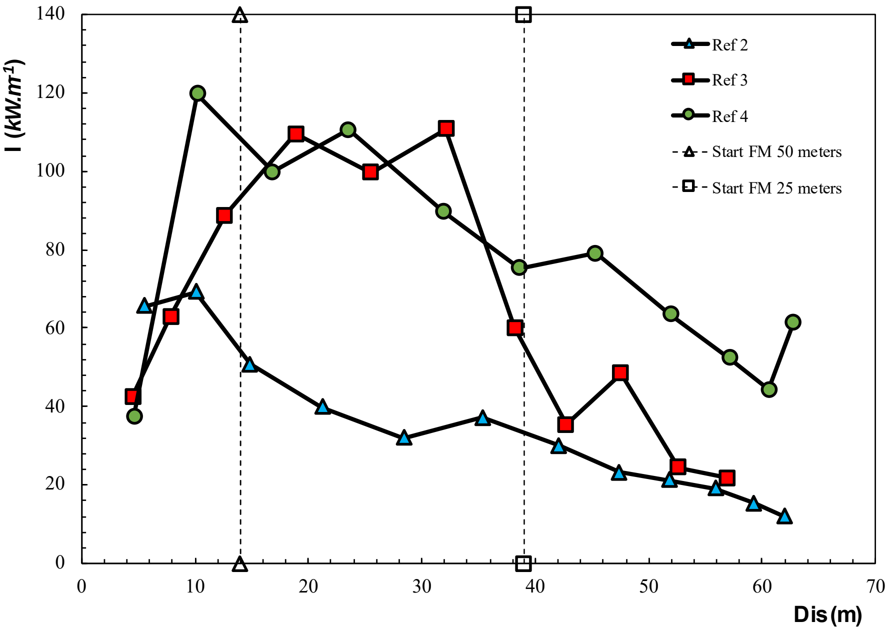


Figure 3. Fire intensity when the fire spreads upslope.

From these tests we may conclude that the fire intensity decreases significatively when the fuel load is reduced. Near the infrastructure, fire intensity obtained with tests ***ref 4*** showed values five times higher, compared to tests ***ref 2*** and ***ref 3***. As previously shown, fire intensity and flame length are directedly related. Flame length in areas without fuel management can be two times higher compared to where fuel management was made.

The fire intensity in tests ***ref 2*** increased normally but when the fire front reached the fuel management area the intensity of the fire decreased and, in these tests, the obtained results present lower intensity. The behaviour in tests ***ref 3*** is very identical to ***ref 2*** because during the beginning of the tests, when fuel load was ***0.6 kg.m***$^{-2}$, the fire intensity was equal to ***ref 4*** but during the approach and close to the infrastructure the intensity decreased to the same values of fire intensity in ***ref 2***.

The temperature gradient of face f_1 when the fire spread upslope is shown as a function of time, **Figure 4**. In this analysis the line ***ref 1***, ***ref 2***, ***ref 3*** and ***ref 4*** follows the same methodology of the previous results presented before (**Figure 3**) and represent the mean values for each test preformed. The maximum temperature gradient happen when the fire front reached the infrastructure on the top of the slope and the interval time is approximately the same.

From these tests we may conclude that in tests without fuel management (***Ref 4***) the temperature gradient is higher (***13.97 ºC.s***$^{-1}$) compared to the test that had fuel management around the infrastructure (***Ref 2 = 7.63 ºC.s***$^{-1}$ and ***Ref 3 = 9.79 ºC.s***$^{-1}$). When the fuel load around of the infrastructure is totally reduced (***Ref 1 – 0 kg.m***$^{-2}$) the values obtained are, during all the test time, approximately zero. It was also noticed that additional to the high values of temperature gradient, the duration time of this increment is more extended for the test ***Ref 4*** compared with the tests with fuel management ***Ref 2*** and ***Ref 3***. For the present study, we conclude that ***Ref 1*** corresponds to the best configuration because fire intensity in face f_1 and the temperature gradient are approximately zero.

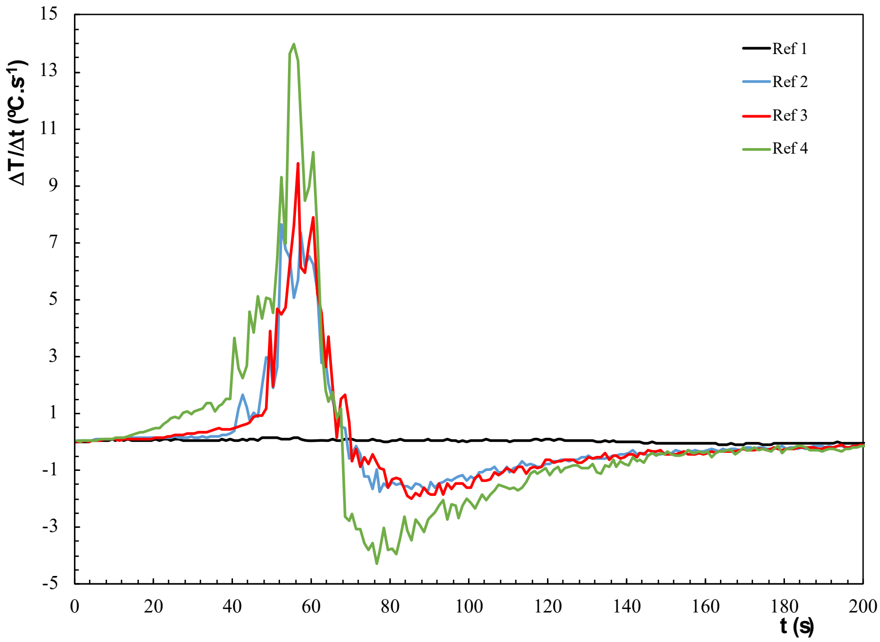


Figure 4. Temperature gradient in face f1 of infrastructure wall when the fire spread upslope.

When fuel management is done around the infrastructure and fuel load is reduced, the values of the temperature gradient in wall of the face f_1 reduce in same way. In tests ***Ref 3*** the temperature gradient obtained is higher than in test ***Ref 2***. This occurred in those tests not only because the fuel load is reduced (in both scenarios the fuel load is the same) but the distance of the fuel management in test ***Ref 2*** is higher than ***Ref 3***. In this case the values of the fire intensity and the temperature gradient are directly correlated.

Conclusions.

In the present study we tested a new methodology to assess the efficiency of fuel management surrounding isolated infrastructures, regarding fire impact. The tests were carried out at the Forest Fire Research Laboratory of University of Coimbra in Lousã on the Dihedral table. We preformed tests with the fire spreading upslope and downslope. However, in these preliminary tests we only presented the results for upslope tests because the position of the infrastructure related to the infrared camera did not allow us to record the fire front in fuel management area. The results shown are only to the critical exposed face f_1. Three parameters were considered in those tests: the slope angle α, the distance / area considered in the fuel management area and the variation of the fuel load outside and inside of the fuel management area.

The fuel management surrounding the infrastructures has a high importance in decreasing the risk or impact in infrastructures by a flaming front. The fire intensity when the fire spreads upslope without fuel management area is five times higher compared to when the tests were performed with fuel management area. Flame length is two times higher for the same conditions. This relation is independent of the distance of fuel management. In the tests with 50 linear meters of fuel management, fire intensity presents the lower values of all.

The temperature gradient in this study is higher when the fuel management around the infrastructure is not made. However, it was also noticed that additional to the high values of temperature gradient the duration time of this increment is more extended for the test without fuel management. For the present study, we conclude that tests ***Ref 1*** is the best configuration because the fire intensity in face f_1 and the temperature gradient are approximately zero.

The present work is the preliminary analysis of a new methodology to assess the efficiency of fuel management surrounding isolated infrastructures. We conclude that this methodology, in laboratory tests, presents the results expected for this configuration. However, for a better validation more research has to be carried to explore other experimental configurations in laboratory and in the field. In future work we intend to change the fuel type, the fuel load inside and outside of fuel management area and the slope angles when the fire spreads upslope or downslope.

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