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Quantitative study to identify the fuel properties that determine propagation success under conditions of nil slope and nil wind

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Introduction

The reduction of the fuel load represents certainly the best approach in order to reduce fire hazard in Mediterranean regions. For many reasons (low impacts on the ecosystems, low costs…), the prescribed burning constitutes a very good tool to achieve this objective. To be efficient and safe, prescribed burning must be conducted under windless and backing fire conditions. The generalization of this practice needs necessary the redaction of a guideline on which the optimal conditions, in terms of external conditions (weather, slope, design of the operation) and state of the vegetation (mainly the fuel moisture content), are defined. The aim of this work is to highlight that a closed simplified physical fire spread model can provide an accurate assessment of the rate of fire spread, but also realistic estimates of these optimal fuel properties. The present study is focused on moisture content and fuel depth.

Modelling Approach

The simplified physical surface fire spread model was developed at the University of Corsica until 2007 (Balbi *et al.*, 2007, 2010, 2018; Chatelon *et al.*, 2017). Under no-wind and no-slope conditions, the expression of the rate of spread (R_o) is given by the relationship below:

$$R_0 = \frac{1}{\beta \rho_v} \frac{\varepsilon_b B T^4}{C_p(\mathrm{T}_i - T_a) + m\Delta h}\left(1 - \left(\frac{S_e}{\beta s e}\right)^{\frac{1}{2}}\right) \qquad (1)$$

where, S_e is a universal constant, β the packing ratio, s the surface area-to-volume ratio, e the fuel bed depth, B the Stefan-Boltzmann constant, m the moisture content, σ the fuel load, C_p the specific heat of vegetative fuel, Δh the heat of latent evaporation, T the flame temperature, T_i and T_a respectively the temperature of ignition and the flame temperature, ε_b the emissivity of the inflamed stratum and m the fuel moisture content. A fuel moisture content extinction criterion was also published in 2014 (Balbi *et al.*, 2014) to determine the critical FMC value, based on the fuel bed proprieties.

$$m_e = \frac{\tau_0 B T^4}{4 \rho_v \Delta h}\left(1 - \left(\frac{S_e}{\beta s e}\right)^{\frac{1}{2}}\right) - \frac{c_p(\mathrm{T}_i - T_a)}{\Delta h} \qquad (2)$$

In order to validate the results of the influence of the fuel proprieties on fire spread given by the simplified physical model, a numerical study has been performed using a multiphase formulation, Firestar 2D, based on a physical model similar to the approach proposed by Grishin (1997) (Morvan & Dupuy, 2001; Morvan, 2013).

Results

Moisture content influence

Experimental data showed that R_o decreases with the moisture content (m) increase. The figure 1 shows the relative fire rate of spread R_o (m)/ R_o (0) as a function of moisture content. The fuel bed is composed of *Eucalyptus globulus Labill* leaves (Balbi *et al.*, 2014).
Figure 1 indicates that R_o decreases by a factor of 3 when m increases from 0 to 50% (zone 1) but this fire rate of spread decreases only by a factor 0.7 when the moisture content increases from 80 to 130% (zone 2). This damping moisture content effect quantified using a closed model can be easily used for selecting optimal prescribed fires conditions throughout the year.

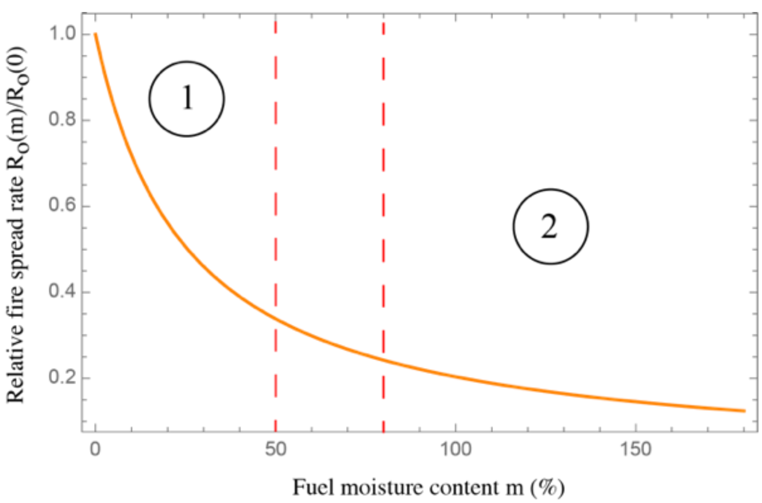

Figure 1: Theoretical relative fire spread rate (R_o (m)/ R_o (0)) as a function of moisture content (m). Fuel bed: Eucalyptus Globulus Labill leaves (e = 7.5 cm; S_e = 1.5)

A comparison was made between the formula of the simplified physical model and the numerical results conducted from Firestar simulations. The chosen fuel was the grassland used for the article (Morvan, 2013). Figure 2 shows the relative fire rate of spread R_o (m)/ R_o (0) as a function of moisture content for the two cases.

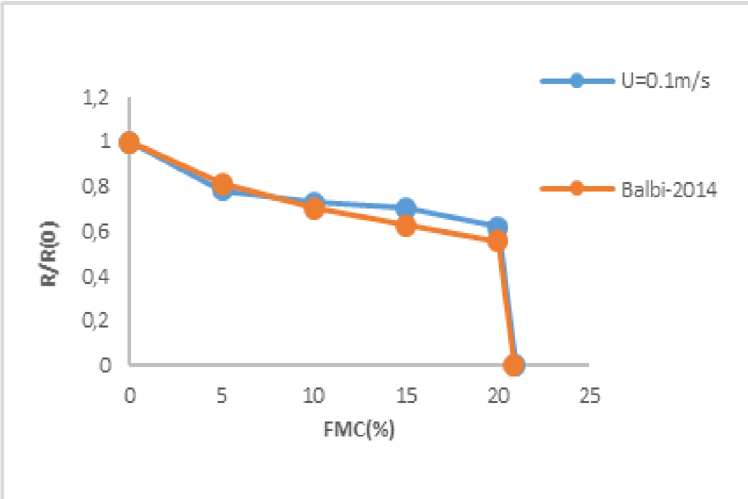

Figure 2: Numerical relative fire spread rate (R_o (m)/ R_o (0)) as a function of moisture content (m). Fuel bed: grassland (e = 70 cm)

The results of the numerical simulations agree with the results of the simplified physical model. Figure 2 shows the damping effect of the fuel moisture content on the rate of spread.

Combined influences of fuel bed depth and moisture content

Previous studies reported that the rate of spread R_o increases with the fuel bed depth (*e*) (Burrows 1999, Rossa 2017). The figure 2 shows an example of the combined influences of the fuel bed depth and moisture contents using the equation (1).

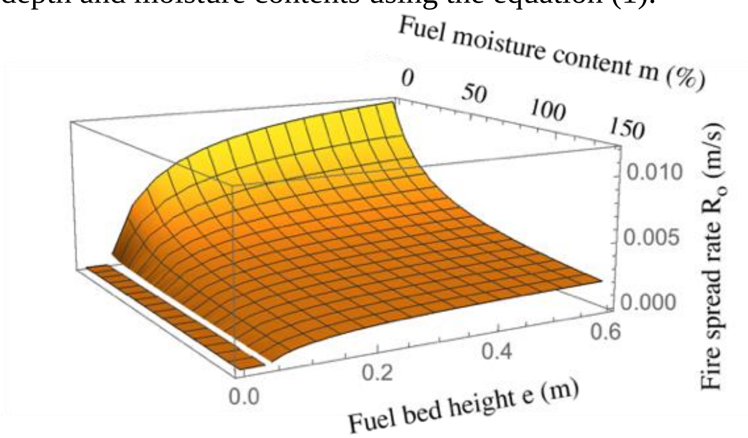

Figure 3: Theoretical rate of spread variation R_o as a function of fuel bed depth (e) and fuel moisture contents (m). Fuel bed: Eucalyptus Globulus (S_e = 1.5)

It is obvious that for a fixed moisture content, the results provided by the proposed model correctly describe that the fire rate of spread increases with the depth of the fuel bed as the experimental observations showed it. The figure 2 also shows that this increase is larger for low moisture content values and can be quantified.
Many simulations were conducted for the grassland fuel used in the article (Morvan, 2013). The

simulations were carried on for three different vegetation thickness (40cm, 70cm,150 cm) and for many fuel moisture content. The variation rate of spread for each thickness in function of FMC is represented in figure 4.

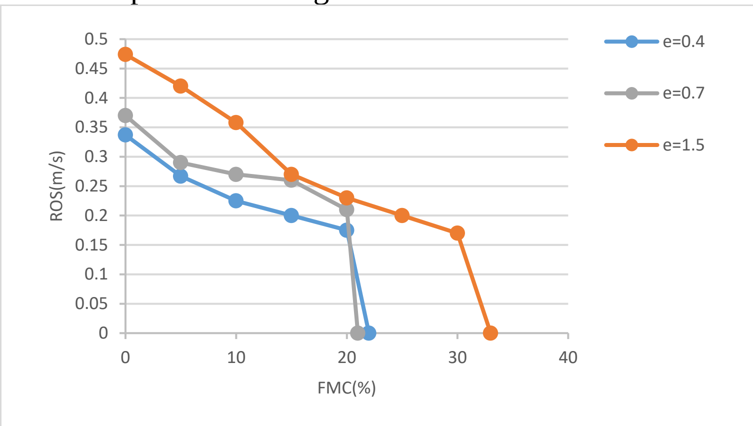

Figure 4: The rate of spread variation as a function of fuel moisture contents (m) for three different fuel bed depth (40cm ,70cm, 150cm) Fuel bed: grassland

Figure 4 shows that the rate of spread decreases with the fuel bed thickness and with the moisture content.

Moisture content of extinction

Many simulations were carried out for the fuel vegetation used in the article (Morvan, 2013) in order to determine the extinction value of the fuel moisture content, for no wind, no slope conditions. The simulations show that the fire cannot propagate for FMC above 22%. The critical value given by the formula (2) is 31%. Other studies show similar extinction values of FMC. Marsden-Smeldey and Catchpole (Marsden-Smedley, Catchpole and Pyrke, 2001) studied fire behavior in Tasmanian buttongrass moorlands and found that at low to medium wind speed (<5 Km/h) many fires failed to sustain when dead fuel moisture content was below 20%. Also (Leonard, 2009) indicated a critical value of 24,21% for Tasmanian grassland for weak wind speed.

Conclusion

The importance of this study reveals in the import of new data that may helps land managers to know the optimal conditions for a successful prescribed fire. This work gives an idea on the influence of fuel moisture content and fuel thickness on fire propagation. The simplified physical model and the multiphase formulation, validated by experimental data, affirm that the fire propagation decreases with the increase of FMC and increases with the fuel thickness.

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BIO

Carmen Awad is a second-year researcher at the University of Corsica, France. Prior to entering the field of wildland fire, she worked in the industrial field, as a design mechanical engineer. The purpose of her thesis is to study the criterions of no propagation of a fire. The motivation of her current work is to ameliorate the fundamental knowledge of wildfire, in order to decrease fire risk, and provide new information for fire management tools.