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PHYSICAL MODELLING OF WIND EROSION ON WILDFIRE ASH LOADS

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Abstract: Ash produced by wildland fires is subjected to aeolian erosion and transportation, which can directly affect human health if spread to populated areas. This work aimed to assess the relationship between the wind velocity and ash layer thicknesses in the post-fire ash detachment, considering different ash layer thickness that result from non-homogeneous deposition of ash during wildland fires. For that a set of experiments were conducted at the Laboratory of Atmospheric Aerodynamics of the Department of Environment and Planning of the University of Aveiro using a wind tunnel. The ash generated from forest fires from three sites with different predominant tree types (young maritime pine - YP, mature maritime pine - MP and eucalyptus – E3), and considering to two levels of crown consumption (low - LCC and high - HCC) was used. For each individual ash sample, five different layer thicknesses (1, 2, 5, 10 and 20 mm) were tested five times each to reduce the experimental error. Experimental results indicate that inter-patches with higher ash layer thickness are more propitious to be transported at lower wind velocities. Specie E3 has revealed to be more resistant to erosion, comparatively to YP and MP, for all ash layer thicknesses tested. Notwithstanding the difficulty to identify a clear trend of ashes detachment in relation to wind velocity per type of forest species, it was possible to quantify the wind velocity at which the biggest ash mass loss occurs. This work provides a set of data that will be particularly useful to calibrate CFD models to further assessments, namely to quantify the impacts of these wildfire ashes in public health, as well as to assess mitigation measures to reduce ash dispersion.

Key words: *wind erosion; ash layer thickness; wind tunnel measurements; post-wildfire*

INTRODUCTION

Wildfires are frequent phenomena in southern Europe and across the world with climate regimes propitious to fire ignition and spreading, as it is the case of Portugal. Forest fires transform biomass into materials with different chemical and physical properties. One of these materials is ash, which is a complex mixture composed of organic and inorganic particles with variable physical-chemical and morphological properties (Bodí et al., 2014; Pereira et al., 2015). The homogeneity and thickness of the ash layer resulting from a fire can vary substantially in space and time.

Depending on the burned area topography and meteorological conditions, post-fire ash may not remain on the soil surface for very long, since after its deposition, it may be incorporated into the soil profile, redistributed or removed from a burned site within days or weeks by wind and water (Pereira et al., 2012; Bodí et al., 2014). Transport and dispersion by wind could be particularly relevant when high combustion completeness results in small light particles of mineral ash (Bodí et al., 2014; Santín et al., 2015; Stavi, 2019). Burned soils are susceptible to particle entrainment by the wind through the removal of the protective vegetation and subsequent soil erosion (Varela et al., 2010).

There are several studies regarding post wildfires conditions focusing mainly on the effects of fires on vegetation recovery, soil erosion (Woods and Balfour, 2010; Zavala et al., 2014), soil water retention (Stoof et al., 2010) and mulch application rates to reduce post-fire erosion (Prats et al., 2012; Silva et al., 2016; Keizer et al., 2018). Wind erosion and aeolian sediment transport processes are understudied comparing to rainfall-induced soil erosion and fluvial sediment transport in post-wildfire environments (Prats et al., 2012). On the other hand, studies on wind erosion are scarcer.

In this context, the main goal of this paper is to assess the relationship between wind velocity and ash layer thickness in the post-wildfire ash detachment from the soil. For this, different wind velocities and ash layer thicknesses (derived from the non-homogeneous deposition of ash during wildfires) were tested in a wind tunnel, quantifying the ash particle mobilization by wind erosion.

DATA AND METHODS

Ash sampling

The two prevailing and, at the same time, most fire-prone forest types of Central Portugal targeted by this study - i.e. plantations of Maritime Pine (Pinus pinaster Ait.) and of eucalypt (Eucalyptus globulus Labill.) - were sampled in the "summer-autumn" 2018 burnt areas of Loriga and of Palmaz, in the municipalities of Seia and Oliveira de Azeméis, respectively. The Loriga wildfire (40°19′26.4″N, 7°41′27.6″W) occurred on 24 august 2018 and affected an area of 224 ha of mainly Maritime Pine stands (ICNF, 2018), whereas the Palmaz wildfire (40°47'43.06''N, 8°27'43.44''W) occurred on 3 October 2018 and affected an area of 161 ha of mostly eucalypt plantations (EFFIS, 2018a). According to the EFFIS classification, overall fire severity was predominantly high in the case of the Loriga burnt area (EFFIS, 2018b), and principally moderate in the case of the Palmaz burnt area (EFFIS, 2018c).

Within the Loriga burnt area, two Maritime Pine stands were selected for contrasting in height/age, on the one hand, and, on the other, for comprising two subareas with contrasting degrees of fire severity. The four pine sites are designated here as Young Pine (YP) vs. Mature Pine (MP) with low crown consumption (LCC) vs. high crown consumption (HCC). Within the Palmaz burnt area, an early-stage third-rotation eucalypt plantation (E3) was selected for comprising two subareas with contrasting degrees of crown consumption as well.

At each of the 6 study sites (YP-LCC, YP-HCC, MP-LCC, MP-HCC, E3-LCC, E3-HCC), wildfire ash was sampled along a transect comprising 5 points at approximately 5 m distances that was laid out in the direction of the main slope angle. At each transect point, wildfire ash was carefully collected, by hand, within a circular area of, on average, 966 cm^2 at three distinct microsites (the nearest tree, the nearest shrub, and the inter-patch in between) in order to determine ash load and selected physical-chemical properties. These selected properties included the two reported underneath: composition in terms of weight of 5 size classes, obtained by manual sieving ($\leq$ 1 mm; >1-$\leq$ 2 mm; >2-$\leq$ 5 mm; 5-$\leq$ 10 mm; >10 mm) and, for selected samples (1 per microsite per study site), real density of the $\leq$ 2 mm fraction.

Experimental setup

The experiments were performed in the wind tunnel located in the Laboratory of Atmospheric Aerodynamics at the Department of Environment and Planning of the University of Aveiro. These facilities consist of an in an open circuit, suction type wind tunnel, with a the test section of 6.5 meters in length, 1.5 meters in width and 1 meter in height (Sorte et al., 2018).

In order to weigh the ash mass along the experiments, a circular plate with a diameter of 60 mm was built and positioned in line with the bottom of the wind tunnel. The ashes were placed on top of this plate, connected to a balance with a readability of 0.01 grams and a linearity of 0.01 grams. The balance was then connected to a computer through an RS-232 connection, transmitting the mass measurement twice every second. In order to simulate the interaction between the ashes and the soil, sandpaper was added to the top of the circular plate. The mean weight diameter of soil aggregates is 1.716 mm (van Bavel, 1950). Considering that 50% of the soil aggregate is below the average soil level, thus not exposed to the wind or the ashes, an average height of 0.858 mm was considered, measured between the average soil level and the top of the soil aggregate. Sandpaper with Grit 24 was used to represent this soil roughness since the particle diameter of the sandpaper (minimum of 0.686 and maximum of 0.940), agreeing with the 50% mean weight diameter of the soil.

For each species and crown consumption samples, five different ash layer thicknesses (1, 2, 5, 10, 20 mm) were studied in the wind tunnel at wind velocities ranging from 0.9 to 9.5 $m \cdot s^{-1}$ at time steps of 0.8 $m \cdot s^{-1}$, keeping the wind velocity constant for 3 minutes at each time step. Each experiment was replicate five times, totalizing 150 experiments. During every experiment, the air temperature, atmospheric pressure and air relative humidity were monitored in order to assess variations. These variables remained relatively constant throughout the wind tunnel experiments.

RESULTS AND DISCUSSION

Ash characterization

Ash load at the inter-patches revealed a tendency to be lowest at the young pine stand, intermediate at the mature pine stand and highest at the eucalypt plantation (Figure 1). This was not only the case for the median loads but also for the minimum and maximum loads. By contrast, the two degrees of crown consumption did not play a consistent role in inter-patch ash loads across the three forest stands.

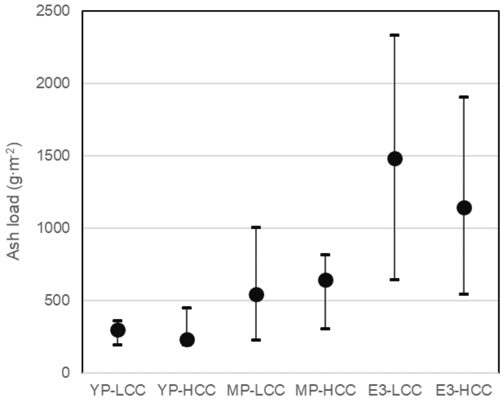

Figure 1. Minimum, median and maximum ash load of the 5 sampled inter-patches at each of the six study sites (forest type: young and mature Maritime Pine stands (YP and MP) eucalypt plantation (E3); fire severity: low and high crown consumption (LCC and HCC)

The inter-patch ash load was dominated by the >2 -≤5 mm fraction at five out of the six study sites, whilst the >10 mm fraction constituted the smallest fraction at all six sites. These two fractions also revealed contrasting differences between the two forest types. The >10 mm fraction was larger at the 2 eucalypt sites than at the 4 pine sites, while the >2-≤5 mm fraction was larger at the pine than eucalypt sites. The latter was also true for the >1-≤2 mm fraction. None of the fractions revealed consistent differences between the two degrees of crown consumption across the three forest stands

Wind tunnel analysis

The wind tunnel results were analysed based on two kind of approaches: i) assessment of the influence of wind flow velocity in the ash lifting, by categorizing the total percentage of mass loss, in respect to the initial mass, in five velocity groups (defined based on the free wind stream velocity range and using an average velocity-step of 2 $m \cdot s^{-1}$), which allow to compare behaviours between species; and ii) estimate the wind velocity at which the biggest ash mass loss occurs, which reflects the capacity of different ash layer thickness from different species and crown consumption levels, to resist against wind erosion.

Figure 2 shows the percentual distribution of mass loss (in relation to the initial mass) within the five different velocity groups, for all species and, as example, for the minimum (1mm) and maximum (20 mm) layer thickness. For all ash types and ash layer thicknesses, the ash mass loss for wind velocities lower than 2 $m \cdot s^{-1}$ is practically inexistent. The increasing ash layer thickness results in greater ash mass losses at lower wind velocities. E3 (LCC and HCC) results show increased resistance when compared to YP (LCC and HCC) or MP (LCC and HCC), since the majority of mass loss of E3 ashes occurs at higher wind velocities for all ash layer thicknesses. Furthermore, thinner ash layers are more resistant to wind erosion than thicker ash layers.

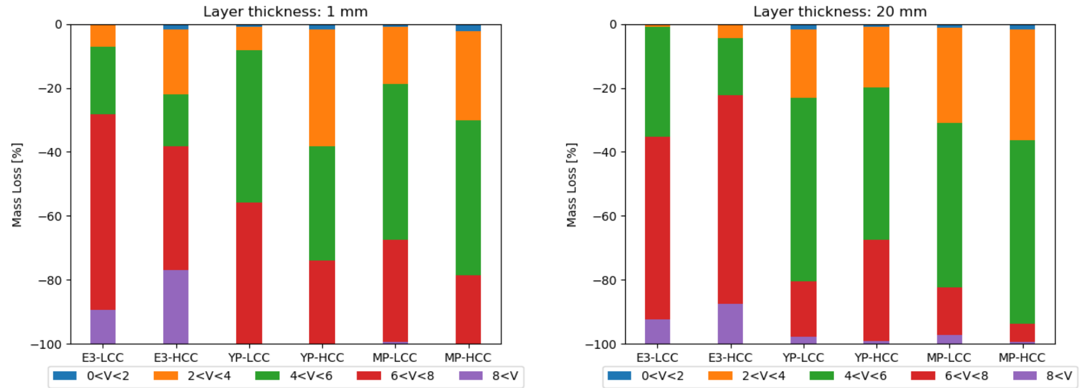

Figure 2. Distribution, in a percentage base, of the mass loss (in relation to the initial mass) within the five different velocity groups, for all species and for an ash layer thickness of 1mm and 20 mm

Figure 3 illustrates the wind velocities at which the biggest ash mass loss occurs for all the species and ash layer thickness. Differences between Eucalyptus and the Maritime Pine stands (YP and MP) are clearly visible, with the wind velocities at which the biggest ash mass loss occurs being higher for E3 than for YP and MP. Maritime Pine stands show a coherent behaviour for all layer thicknesses in mature pine and at layers above 5 mm for young pine; little differences are seen between age (young and mature) and fire severity (low and high crown consumption). The expected behaviour where thicker ash layers are less resistant to wind erosion was not found for E3-LCC, with the wind velocities at which the biggest ash mass loss occurs increasing for layers below 5 mm and decreasing for layers 10 and 20 mm thick.

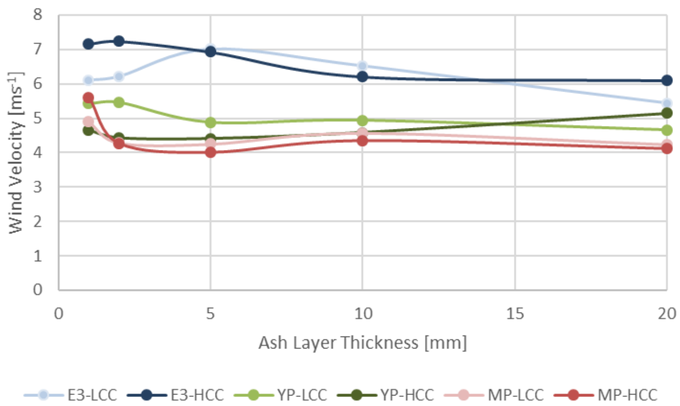

Figure 3. Wind velocities at which the biggest ash mass loss occurs for all the species and ash layer thickness

More details about the experimental setup and the obtained results can be found in Correia et al. (2021).

CONCLUSIONS

This work provides a first assessment of the wind erosion effect on wildfire ashes resulting from forest types of Central Portugal. For that wind tunnel experiments were conducted for predominant tree type (young maritime pine - YP, mature maritime pine - MP and eucalyptus – E3), subjected to two levels of crown consumption (low - LCC and high – HCC). For each individual ash sample, five different layer thicknesses (1, 2, 5, 10 and 20 mm) were tested five times each to reduce the experimental error.

The obtained results highlight the correlation between ash layer thickness and mobilization by wind erosion (both negative and positive correlation were obtained according to the tree type) and provide insights regarding the behaviour of ash detachment considering different species and crown consumption severity, which can greatly affect surrounding urban areas. Further studies are required in order to assess the influence of particle size and humidity in ash detachment and to quantify the impact of ash particles in public health.

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