Catena 169 (2018) 21–30

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

The effectiveness of two contrasting mulch application rates to reduce post-fire erosion in a Portuguese eucalypt plantation

J.J. Keizer[a,*], F.C. Silva[a], D.C.S. Vieira[a,b], O. González-Pelayo[a], I. Campos[a], A.M.D. Vieira[a], S. Valente[a], S.A. Prats[a]

[a] CESAM, Centre for Environmental and Marine Studies, Eco-Hydrology Laboratory & Earth Surface Processes Team, Department of Environment and Planning, University of Aveiro, 3810-193 Aveiro, Portugal
[b] MARETEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

ARTICLE INFO

Keywords:
Wildfire
Soil erosion
Erosion mitigation
Forest logging residue mulching
Eucalypt plantation

ABSTRACT

Wildfires are well-known to increase runoff and erosion during the initial stages of the window-of-disturbance, and mulching has been widely documented to effectively minimize this impact. However, the relationship between the rate of mulch application and erosion reduction is poorly studied, in spite of its potential importance for optimizing mulching costs and efforts per ha. Therefore, a field experiment was carried out in a recently burnt eucalypt plantation in Central Portugal that had been burnt by a moderate severity fire during August 2015, comparing sediment as well as organic matter losses from three untreated 2 m × 8 m erosion plots with losses from six plots mulched with eucalypt logging residues at two contrasting rates of either 2.6 or 8.0 Mg ha^{-1}. The two mulching treatments resulted in the targeted litter covers of 50 and 79%, and these covers hardly changed over the ensuing year. Over this first post-fire year, the mulched plots produced significantly less mineral soil as well as organic matter losses than the untreated plots. At the same time, the plots with the high mulching rate lost consistently less sediments and organic matter than the plots with the low mulching rate but the differences were not statistically significant over all measurement periods. Total sediment losses over the first post-fire year were, on average, 86 and 96% lower following mulching at 2.6 and 8.0 Mg ha^{-1}, respectively, than without mulching. In absolute values, total losses dropped from 8.0 to 1.1 and 0.3 Mg ha^{-1} y^{-1}, respectively, or, in other words, similar to and well-below the widely-accepted threshold of tolerable soil loss of 1 Mg ha^{-1} y^{-1}. If this threshold value is acceptable to land managers, they could treat a three times larger area with the same amount of mulch.

1. Introduction

The EU-FP7 project RECARE (www.recare-project.eu) had as one of its objectives to test and demonstrate prevention, mitigation and restoration measures against 11 soil threats in 17 case study sites across 15 countries in Europe, with stakeholders deciding on the selection of these measures through two dedicated workshops. In the Portuguese case study, addressing the threat of soil erosion by water, in particular following wildfire, mulching with forest logging residues was selected, from an initial set of traditional and novel post-fire land management practices established by post-fire soil erosion experts, as one of the measures to be tested under field conditions. The main reason for the stakeholders (which covered private and public forest owners and managers as well as representatives from local, regional and national governmental and non-governmental organizations with another stake in post-fire land management) to select mulching was that they were unfamiliar with this measure at the time of the workshops, in 2015. This lack of familiarity with mulching appears to be general phenomenon among forest stakeholders in Portugal (Ribeiro et al., 2015).

Wildfires are a common phenomenon in Portugal, as they are in many other countries in southern European and across the world with climate regimes propitious to fire ignition and spreading (Doerr and Santin, 2016; Moritz et al., 2014; San-Miguel and Camia, 2009). In Portugal, wildfires affect, on average, roughly 100.000 ha of rural lands each year (Cardoso Pereira et al., 2006) but much larger areas in extreme years such as 2003, 2005 and 2017 with c. 426.000, 339.000 and 496.000 ha (ICNF, 2017). The apparently unprecedented and possibly escalating fire regime in Portugal over the past decades is largely attributed to human activities, not only as cause of ignition (Veléz, 2009) but also through land-use changes such as land abandonment and widespread planting of fire-prone tree species (Moreira et al., 2009; Shakesby, 2011; Valente et al., 2015).

* Corresponding author.
E-mail address: jjkeizer@ua.pt (J.J. Keizer).

https://doi.org/10.1016/j.catena.2018.05.029
Received 25 January 2018; Received in revised form 13 April 2018; Accepted 21 May 2018

Wildfires have frequently been observed to produce strong and sometimes extreme hydrological and erosion responses in recently burnt areas, especially during the initial stages of the so-called window-of-disturbance and with a key role therein of soil burn severity (Moody et al., 2013; Shakesby, 2011; Vieira et al., 2015). Such fire-enhanced responses have also been reported for eucalypt and maritime pine plantations in Portugal, the country's two most widespread and fire-prone forest types (Hosseini et al., 2016; Shakesby et al., 1993; Vieira et al., 2016). Increased runoff and erosion rates following wildfires are generally attributed to (partial) consumption of the vegetation and litter layer as well as to heating-induced changes in soil properties determining soil's infiltration capacity and/or erodibility, including soil water repellency and aggregate stability (Cerdà and Doerr, 2005; Malvar et al., 2013; Mataix-Solera et al., 2011; Shakesby, 2011).

A range of measures has been tested for their effectiveness to mitigate post-fire runoff and erosion (Bautista et al., 1996; Fernández et al., 2011; Robichaud et al., 2008, 2013; Wagenbrenner et al., 2006). Robichaud et al. (2010) and Vega et al. (2013) made exhaustive reviews of the results of such tests, to inform post-fire land management in the USA and Galicia, respectively. Both reviews concluded that mulching, or the application of a layer of organic residues, is the most effective measure to reduce post-fire erosion, especially under intense rainfall events, typically using straw due to its wide availability, low costs and easy-of-handling. In Portugal, several field experiments have been carried out in recent years to test the effectiveness of mulching to reduce post-fire erosion (Hosseini et al., 2017a; Prats et al., 2012, 2016b). The two experiment in eucalypt plantations, however, opted for using eucalypt logging residues, firstly because of the limited availability of straw (Prats et al., 2012, 2014b, 2016b). These studies showed that mulching with eucalypt logging residues was highly effective, reducing post-fire erosion rates during the initial stages of the window-of-disturbance with 85% or more across a wide range of plot scales (0.25–100 m^2). However, the tested application rates were in the order of 10 Mg ha-1 or, in other words, considerably higher than the 2–3 Mg $ha^{-}1$ of straw mulch that are typically applied in operational post-fire land management in both the USA (Robichaud et al., 2010) and Galicia (Vega et al., 2013), casting doubt on the feasibility and economic viability of using eucalypt logging residues for large-scale mulching in operational post-fire land management settings.

The overarching aim of this study was therefore to provide further insights into the suitability of mulching with forest logging residues as a post-fire soil conservation measure, focusing on the role of mulch application rate. The first specific research questions was if two contrasting rates of applying eucalypt logging residues mulch immediately after wildfire would be effective measures to increase protective litter cover - i.e. the soil property that is directly targeted by mulching - over the fire-induced window-of-disturbance and, in this specific case, over the first post-fire year. These two rates were a “standard” rate of 8.0 Mg ha^{-1}, similar to that applied in prior field experiments in the study region, and a “reduced” rate of 2.6 Mg ha^{-1}.The second question was if these two mulching rates would impact other soil properties than litter cover that could potentially influence post-fire soil erosion by water and associated organic matter losses, in particular other ground cover categories and topsoil moisture content. The third question was if the “reduced” mulch application rate as effective to mitigate post-fire sediment losses as the “standard” rate, while the fourth question was if post-fire organic matter losses would be affected similarly by the two contrasting mulch application rates as sediment losses.

2. Case study area and monitoring site

This study was carried out in the Vale de Colmeias burnt area located in the Miranda do Corvo municipality of the Coimbra District in north-central Portugal. The wildfire started on 8 August 2015 and ended the next day, affecting a total area of 715 ha of mainly forest stands (96%) and, in particular, *Eucalyptus globulus* Labill. plantations (ICNF, 2017). According to EFFIS (2015), the study area as a whole was predominantly burnt at moderate or high severity. The climate of the area is Mediterranean with oceanic influence and can be classified as humid meso-thermal (Csb, according to the Köppen classification), with prolonged dry and warm summers (DRA-Centro, 1998). Long-term mean annual temperature and average annual rainfall at the nearest meteorological station (Carapinhal, located at approximately 12 km) were 12 °C and 851 mm (SNIRH, 2016).

Within the burnt area, a privately-owned *Eucalyptus globulus* Labill. plantation on a steep (27°), ENE facing slope was selected as study site. Two important reasons to select this particular plantation were that: (i) the trees were planted in regular lines running in downslope direction, thereby allowing to avoid the possibly confounding impacts of tree stems on overland flow retention and sediment deposition, especially at the lower parts of the erosion plots; (ii) the tree stems were still relatively thin as the plantation was 2–3 years into the second rotation cycle, thereby minimizing the chances that salvage logging would take place during the monitoring period and lead to disturbance of the plots (the impacts of salvage logging on erosion were studied in the same burnt area by Malvar et al. (2017). Fire severity at the actual study site was classified as high by EFFIS (2015) but field observations during early September 2015 suggested a moderate vegetation as well as soil burn severity. The former was indicated by partial combustion of the tree crowns and an average Twig Diameter Index of 0.4 (see Maia et al., 2012; based on measurements of 3–5 shrubs nearest to nine equi-distance points along a transect running from the bottom to the top of the plantation), while the latter was indicated by complete combustion of the litter layer and the predominantly black color of the ash layer (see Shakesby and Doerr, 2006). The terrain between the planting lines where the plots were installed was smooth, lacking any obvious micro-topographic features. The soil at the study site was described in the field through two full soil profiles that were cleared at the side of the trail at the bottom of the plantation and that were complemented by three validation profiles that were dug up some 10 m upslope. All five profiles were classified as epileptic Umbrisols (IUSS, 2014), comprising a thin (< 5 mm thick) layer of predominantly black ash and charred plant material, Ah1 and Ah2 horizons to a depth of 35–40 cm, and a C horizon of partly weathered pre-Ordovician schists of the Hesperic Massif (Pereira and Fitzpatrick, 1995). The two Ah layers had a dark brown color (7.5YR 3/4 in dry and 7.5YR 3/3 in wet), a loamy field texture, and a moderately fine blocky sub-angular to a fine granular structure. The samples collected from the two Ah layers of the full soil profiles had a pH (in 1:5 v/v Milli-Q water suspension, following ISO 10390:2005) ranging from 4.6 to 4.8, and an organic matter content varying from 15 to 18% (loss-on-ignition-method (Pribyl, 2010), using 2 g of soil without stones or recognizable plant parts in a muffle furnace at 550 °C for 4 h). These values agreed well with the results obtained for nine additional soil samples that were collected at 0–5 cm depth next to each of the plots in September 2015, with minimum–median–maximum values of 4.6–4.7–4.8 for pH and 15.3–16.1–18.2% for organic matter content.

3. Materials and methods

3.1. Experimental design and treatments

Almost one month after the fire (07 September 2015), a total of nine erosion plots were installed at the bottom part of the plantation (for reasons of easy access from the forest track immediately below), and, as referred earlier, in between the tree planting lines. The plots were divided over three blocks and, within each block, the three plots were randomly assigned one of the three treatments, i.e. mulching at the standard and reduced rates of 8.0 and 2.3 Mg ha-1 and doing nothing (control). Each plot was approximately 2 m wide and 8 m long, was bounded by geotextile held upright by wooden stakes and, at the bottom of the plot, by steel re-bars, and was protected against upslope