

Soil erosion modeling for two recently burnt eucalypt slopes: *comparing USLE, MMF and initial MEFIDIS results*

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1. Abstract

The work to be presented is being carried out in the framework of the EROSFIRE project (POCI/AGR/60354/2004), funded by the Portuguese Foundation for Science and Technology (FCT). Ultimately, the project aims at assessing the performance of the Universal Soil Loss Equation (USLE), in comparison to that of other current soil erosion models, for predicting soil erosion in recently burnt forest stands in Portugal. Formulated in a somewhat different way, the project wants to evaluate the application of USLE that underlies the “Soil losses after the forest fires of the summer of 2003”-map produced in 2003 by the Portuguese Water Institute (INAG). Model comparison will include, besides other USLE variants, the “Morgan, Morgan & Flinley”-model and MEFIDIS.

For logistic reasons, the project has concentrated its efforts on the commercial Bluegum plantations that currently dominate the hills and mountains of north-central Portugal. Four slopes covered with eucalypt trees were selected immediately following a wildfire in early July 2005, and two more following a wildfire in late August 2006. At each site, four unbounded, slope-scale plots were installed as soon as possible after the fire, and monitored at weekly intervals till July 2007 or, in the case of the 2006-sites, repeated disturbance. In addition to runoff measurement and sampling for laboratory analysis of sediment and organic matter concentrations, soil cover and topsoil characteristics like moisture content and water repellency were monitored at frequent intervals, using three to five sample points located along transects. More incidental ancillary data gathering included topography, fire-induced vegetation damage, soil profiles and soil properties like texture and organic matter content.

The proposed presentation will focus on two neighbouring Bluegum stands burnt in 2005 and on the first year following the wildfire. The main difference between the stands is their pre-fire land management, one site having been ploughed in down slope direction and the other lacking evidence of mechanical ground operations. Data analysis and especially modelling is still in progress but the results for the ploughed slope show low overall yearly runoff coefficients (1-2 % of about 1100 mm rainfall) and low overall soil losses ($< 0.1 \text{ t ha}^{-1} \text{ yr}^{-1}$). Whilst more or less standard USLE predictions far exceed these measured losses, those of INAG’s variant appear to be considerably closer but their exact computation still requires confirmation.

2. Introduction

The present study was carried out in the framework of a larger project (EROSFIRE), which aims at predicting soil erosion hazard at the slope scale following forest wildfires, in particular for recently burnt eucalypt stands in north-central Portugal. Whilst the EROSFIRE project builds upon a line of research dating back about two decades (e.g. Coelho et al. 1997; Ferreira et al. 2000; Shakesby et al. 1993), its direct motivation was a nation-wide soil erosion hazard map entitled “Soil losses after the forest fires of the summer of 2003” (INAG 2003) and, more specifically, the fact that the erosion model underpinning this map - USLE - (Wischmeier 1978) lacked any kind of field validation for comparable burnt areas. EROSFIRE’s main aim is then to assess the applicability of USLE compared to that of other erosion models and, in particular, one(s) based on physical processes instead of purely empirical relationships. As ultimate goal, the project hopes to lay the foundations for a tool that, using the most appropriate model, will allow identifying burnt areas that require erosion mitigation or control measures.

Field rainfall simulation experiments (RSE’s), on micro-plots using a portable simulator (Cerdà et al. 1997), are at the core of the approach being tested in the EROSFIRE project. Although the small size of the RSE plots (0.28 m²) undeniably casts doubts about the extrapolation of the obtained runoff and sediment yields to larger areas, it is precisely at the micro-plot scale that the comprehensive data collection typically implied in testing physically-based models becomes feasible. An important argument for the RSE-centred approach was also that it permits responding quickly to the rapid but difficult-to-forecast changes that are typical in commercial forest plantations following wildfire, especially also due to human interventions like cutting and

replanting. To validate the RSE-results, erosion plots were employed as well but only at a restricted number of so-called permanent study sites. Micro-plots of exactly the same dimensions as those used in the RSE's were used to assess whether runoff and erosion rates produced by simulated rainfall were comparable to those produced by natural events. Slope-scale plots, in turn, were used to assess whether runoff and erosion rates from small areas are directly transferable to larger spatial scales and, thereby, provide an adequate knowledge base for guiding post-fire land management. Whereas the comparison of micro-plot measurement and modeling results under simulated and natural rainfall conditions is being dealt with by another paper of these Conference Proceedings (Malvar et al. 2008), the present paper will focus on slope-scale sediment losses and their modeling with USLE as well as the "Morgan, Morgan & Flinley" model (MMF; Morgan 2005). Slope-scale runoff and erosion modeling with MEFIDIS (Nunes et al. 2005) - selected as EROSFIRE's primary process-based model - is still in its initial stages and will therefore only be addressed very briefly here.

3. Study area and study sites

This study was carried out in two adjacent commercial eucalypt (*Eucalyptus globulus Ait.*) plantations in the Açores locality of the Albergaria-a-Velha municipality of north-central Portugal. The two study sites are located at approximately 40° 42' North, 8° 29' West and 60-70 m elevation, and comprise steep (15-20 degrees) but short (25-40 m) slopes bounded by paths.

The study sites were burnt during early July 2005 by a wildfire that affected a total area of about 16 km². The complete consumption of the litter and herb cover, together with the partial consumption of the shrub layer and tree crowns, suggest that fire severity at both sites had been moderate (Shakesby and Doerr 2006). Judging by remaining tree stumps, the two sites had undergone at least two eucalypt (re)growth cycles prior to the fire. The two sites were selected for their contrasting land management practices. At Açores1, trees had been planted without heavy mechanical ground operations, resulting in a relatively undisturbed soil profile. At Açores2, a clear pattern of shallow ridges and furrows (up to 20 cm high) running down the slope is present. Rip-ploughing in preparation for planting was a common practice in this region and, judging by the stand age, would have taken place around 5 years prior to the fire. At both study sites, two soil profiles were excavated in the middle and at the bottom of the study slopes. The sites' soils correspond to Umbric or Dystric Leptosols (FAO 1988), depending on the depth of the A horizon. They are developed over schists and have sandy loam textures and high organic matter contents (8.8 - 10.4 %) (Lucena 2006).

The climate of the study area can be characterised as humid meso-thermal, with a prolonged dry and warm summer (Köppen Csb) (DRA-Centro 1998). At the nearest climate station (about 17.5 km distance), long-term mean annual temperature is 13.9 °C and mean monthly temperatures range from 8.8 °C in December to 19.1 °C in July. At the nearest rainfall station (circa 4 km distance), annual rainfall is, on average, 1229 mm and varies between 750 and 2022 mm.

4. Material and Methods

Some 11 weeks after the wildfire, on September 19 2005, four unbounded plots were installed at the bottom of the central part of each of the two study slopes. The four approximately 50cm wide plots of the unploughed (Açores1) site were contiguous, whereas the four approximately 100 cm wide plots of the Açores2 site each corresponded to a ploughing line. The outlet of each plot was identical to that used for the micro-plots, and connected to one or two 60-liter tanks. In general, the water volume in the tanks was measured on a weekly basis and accompanied by the collection of one runoff sample of up to 1.5 l per tank, of which sediment and organic matter concentrations were obtained using standard laboratory methods. In addition, plot outlets were frequently checked for clogging up and, whenever needed, cleared from freshly deposited sediments, whose dry weight and organic matter concentration were determined using standard laboratory methods.

On September 24 2005, a tipping-bucket rainfall gauge (Pronamic Professional Rain Gauge) linked to an ONSET Hobo Event Logger was installed at the foot of the Açores1 site. For verification purposes, two totaliser rainfall gauges at the foot of the two sites were installed simultaneously and then measured concurrently with the runoff tanks. Rainfall data prior to September 24 were obtained with the same instrumentation at another study site at less than 1 km distance.

At one of the lateral parts of the study slopes, various soil characteristics like ash and stone cover, moisture content and water repellency were monitored at intervals of typically two weeks, and occasionally one, three or four weeks. For logistic reasons, this involved mostly alternating dates at the two sites. Sampling at the different dates concerned three to five points at fixed distances along transects laid out across the full length of the slopes. Further methodological aspects as well as spatio-temporal patterns in topsoil water repellency and water content are described in Keizer et al. (2008).

5. Results and Discussion

During the first study year, total rainfall amounted to almost 1160 mm and was thus very similar to the long-term mean annual value of the nearest rainfall station. Maximum 30-min rainfall intensities were below 20 mm h^{-1} , except for one occasion by mid October 2005 when it attained of 37.6 mm h^{-1} (Figure1). In the region, maximum 30-min rainfall intensities of 20-23 and 35-42 mm h^{-1} correspond to return periods of 10 and 1000 years, respectively (Brandão et al. 2001). It is therefore somewhat surprising that the measured R factor value over the study period was much lower than the value predicted on the basis of the work by Brandão and Rodrigues (2006), i.e. roughly 2500 instead of 6000 MJ ha^{-1} .

Figure 1 also shows a typical example of the pronouncedly seasonal patterns of overland flow generation and corresponding sediment losses. The absence of any significant overland flow from November 2005 to June 2006 is a main contributing factor to the low annual runoff coefficients as well as sediment loss rates. For the individual plots, the former vary between 0.6 and 1.8 % and the latter between 0.04 and 0.45 t ha^{-1} . Worth noting is that organic matter, largely composed of ashes, is a main component of the transported sediments, ranging between 45 and 55% and, thus, far in excess of its content in the topsoil.

Slope-wise annual runoff amounts are practically identical (*circa* 14 mm) for the ploughed (Açores2) and the unploughed (Açores1) study site. The corresponding soil and organic matter losses, however, are not but, somewhat surprisingly, values are higher for the unploughed than the ploughed site (0.09 and 0.10 vs. 0.04 and 0.03 t ha^{-1} , respectively). This is due to one Açores1 plot in particular, where losses amount to 0.20 and 0.25 t ha^{-1} , respectively, compared to 0.03-0.10 and 0.02-0.08 t ha^{-1} for all other individual plots.

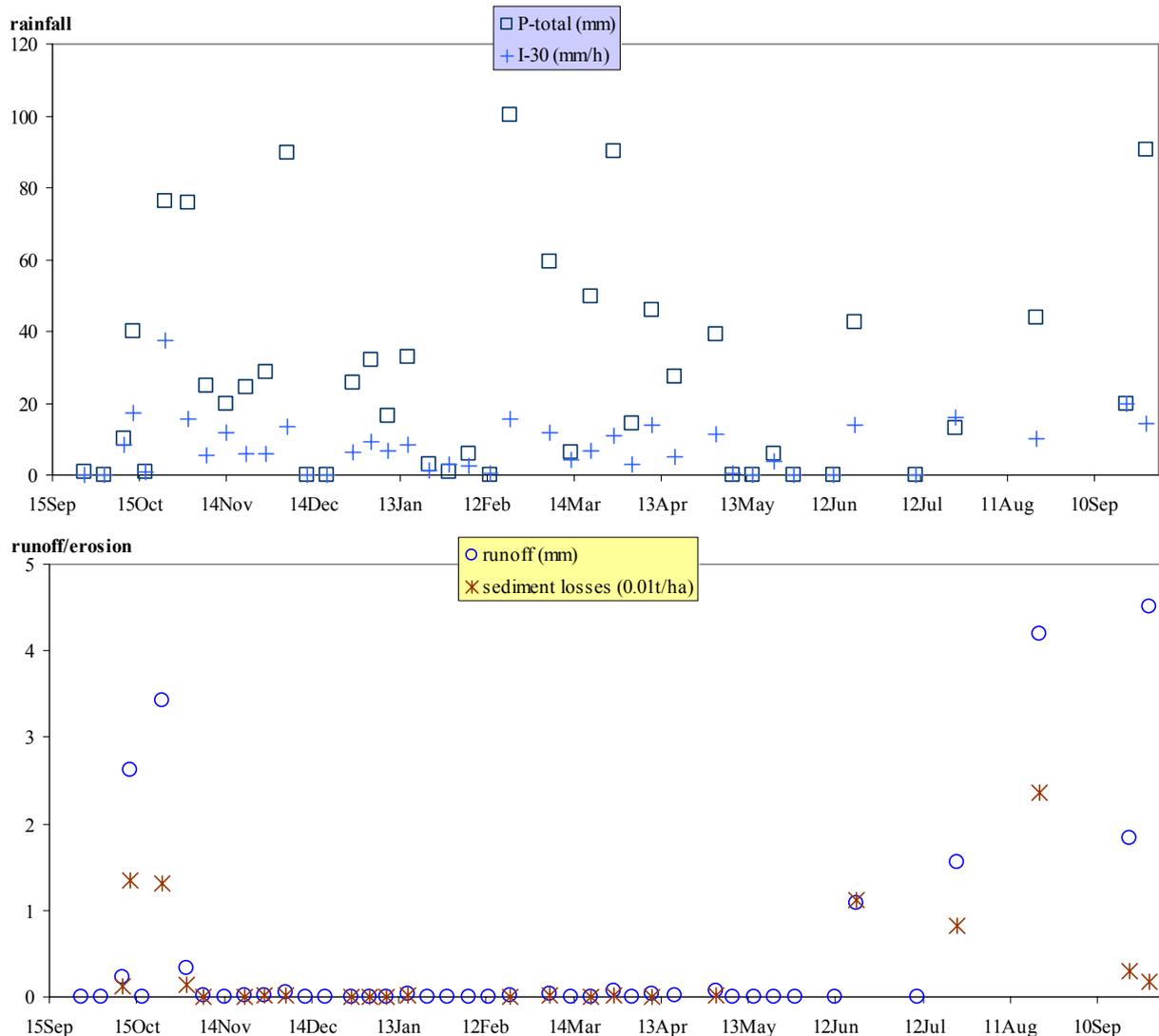


Figure 1 Weekly rainfall totals and intensities for the period September 19 2005 and September 28 2006, and typical temporal pattern of overland flow and sediment losses (note the scale of the latter)

USLE and MMF were applied for the four plots of each site together. Depending on the exact parameterisation chosen, USLE predicts somewhat higher annual soil loss rates for the unploughed (Açores1) than the ploughed (Açores2) study site, reflecting the site's steeper slope, on the one hand, and, the other, the fact that no specific P-factor value for down slope ploughing was applied. Much more importantly, however, is that even the lower bounds of these USLE predictions (45 and 30 t ha⁻¹) are notoriously too high. The above-mentioned soil erosion map by the INAG (2003) gives a better estimate (8-16 t ha⁻¹), especially if one takes into account that, as mentioned earlier, the map's underlying R-factor value is twice that of the observed value, but the exact reasons could not yet been established. This could be due to the spatial resolution of the DTM used.

MMF erosion predictions are much closer to the measured values than the USLE predictions, amounting to 0.67 and 0.20 t ha⁻¹ for the unploughed (Açores1) and ploughed (Açores2) site, respectively. Although these MMF values are encouraging, especially in the sense of being at least of the right order of magnitude, the underlying runoff predictions do not match very well the seasonal pattern as shown in Figure 1.

Initial work on transferring MEFIDIS results at the micro-plot scale (see Malvar et al. 2008) directly to slope-scale plots has revealed the marked decrease in runoff coefficient that was also observed in the field. Priority, however, is now being given to a thorough revision of the application of MEFIDIS at the micro-plot scale, especially with respect to soil losses.

6. Acknowledgements

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