The EROSFIRE project - a model-based, decision-support tool for soil erosion hazard assessment following forest wildfires

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Abstract

Since the late summer of 2005, the EROSFIRE project is investigating the hydrological and soil erosion response in recently burnt eucalypt plantations. The study areas are located in the municipalities of Águeda, Albergaria-a-Velha and Sever de Vouga, at reasonably close distances from the project's home base at the University of Aveiro, which has allowed carrying out intensive field campaigns and, thereby, the collection of a rather extensive data set. The present paper will, however, only present initial results that, first and foremost, serve to illustrate the approach that is being applied and tested by the project.

Field rainfall simulation experiments (RSE's) constitute the principal technique that is being employed by the EROSFIRE project for measuring soil erosion. Erosion plots are utilized as well but primarily to validate the results of the RSE's, in the sense of comparing erosion rates under artificial versus natural rainfall events as well as for micro-plots versus slope-scale plots. The various erosion measurements are ultimately intended to evaluate the suitability of a selection of erosion models for post-fire conditions.

Results are presented of 8 RSE's that were carried out two to three months after a forest wildfire. The amounts of simulated rain that do not infiltrate into the soil, are substantial. The resulting overland flow, however, does not produce as high sediment yields as to be expected on the basis the RSE results of earlier studies in recently burnt pine stands in the same region.

Introduction

The EROSFIRE project ("A model-based, decision-support tool for soil erosion hazard assessment following forest wildfires"; POCI/AGR/60354/2004; http://www2.dao.ua.pt/RECNATUR/EROSFIRE/index.htm) is financed by the Portuguese Foundation for Science and Technology (FCT), with co-funding by FEDER through the POCI2010 Programme. Whilst the project builds upon a line of research that dates back to the mid 1980s (e.g. Coelho et al. 1997, 2005; Ferreira et al. 2000, 2005; Shakesby et al. 1993; Walsh et al. 1998.), its direct motive was the

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"Soil losses after the forest fires of the summer of 2003"-map that elaborated by the Portuguese Water Institute (INAG) by applying a modified version of the Universal Soil Loss Equation (USLE; Wischmeier 1978). The EROSFIRE proposal then proposed to asses the applicability of USLE in recently burnt forest areas, in particular also in comparison with soil erosion models that are more recent and, especially, those that are based on physical processes rather than rely on empirical relationships. As final goal, the project envisages that the best model will be used in a computer application that allows mapping soil erosion hazard after forest fires, including for various post-fire intervention scenarios. By incorporating erosion mitigation and control measures, the software tool is hoped ultimately to contribute to a sustainable management of Portugal's widespread forest areas.

The approach that the EROSFIRE project is developing and testing, envisages the use of rainfall simulation experiments (RSE's) as principal method for gathering sufficient model input data to overcome the data constraints that are so commonly encountered in parameterization, calibration and assessment of soil erosion models. RSE's avoid the climatic uncertainties associated with erosion plots, on the one hand, and, on the other, permit responding quickly to the rapid changes, especially also by human intervention, that are typical in recently burnt forest areas.

The project, however, also employs erosion plots, first and foremost for the purpose of validating the RSE results. Micro-plots of exactly the same dimensions as those used in the RSE's, are used for assessing whether the erosion rates produced by simulated rainfall are comparable to those produced by natural events. Slope-scale plots, in turn, are employed to determine whether erosion rates at very local scales are representative for those at larger scales and, thereby, provide an adequate knowledge base for guiding post-fire land management, in particular the selection and implementation of specific erosion mitigation and control measures.

For soil erosion modeling, the EROSFIRE project selected, besides USLE as, so to say, the "model-to-beat", three other models. The models LISEM ("LImburg Soil Erosion Model"; e.g. De Roo et al. 1995) and MEFIDIS ("Modelo de Erosão FÍsico e DIStribuído"; e.g. Nunes et al., 2005) are both process-based, whereas PESERA ("Pan-European Soil Erosion Risk Assessment"; Gobin et al. 2004) is an empirical model like USLE but a much more recent one. LISEM and MEFIDIS will be applied and tested for the whole range of erosion data being gathered (i.e. from RSE to slope-scale data), whereas USLE and PESERA will only be evaluated at the slope scale.

The present paper wants, above all, to explicate the work that the EROFIRE team has been developing during the project's first one and a half year, and to illustrate some initial results from the RSE's as well as the erosion plots.

Study area and sites

Towards the end of the summer of 2005, four slope sections were selected as permanent study sites in the localities of Jafafe and Açores, on the borders of the Águeda and Albergaria-a-Velha municipalities, in an area that was burnt by a forest wildfire during early July 2005 (Figure 1). The four sites were all planted with eucalypt trees (*Eucalyptus globulus* Labill.) but differed in ground operation practices. From the two slopes in the Jafafe area – both publicly owned by the "Junta de Freguesia da Macinhata de Vouga" – one had been ploughed following the contour lines and the other had been converted into sloping terraces. From the two slopes in the Açores area – both privately owned – one had been ploughed in down slope direction and the other lacked any signs of mechanical ground operations.

In September 2006, two additional slope sections were selected in the locality of Soutelo, municipality of Sever de Vouga, in an area burnt by a forest wildfire during mid August 2006. These two slope sections were planted with eucalypt trees as well, and both evidenced mechanical soil mobilization but without a clear predominant direction. One of the slope section is publicly owned, by the "Junta de Freguesia da Talhadas", whilst the other is privately owned.

It is perhaps worth stressing that eucalypt plantations have now become the predominant land cover in the study region. Two other aspects that the six study sites have in common are their underlying geology, composed of Precambrian schists, and their short length, which is due to the intricate network of paths dissecting each of the three areas.

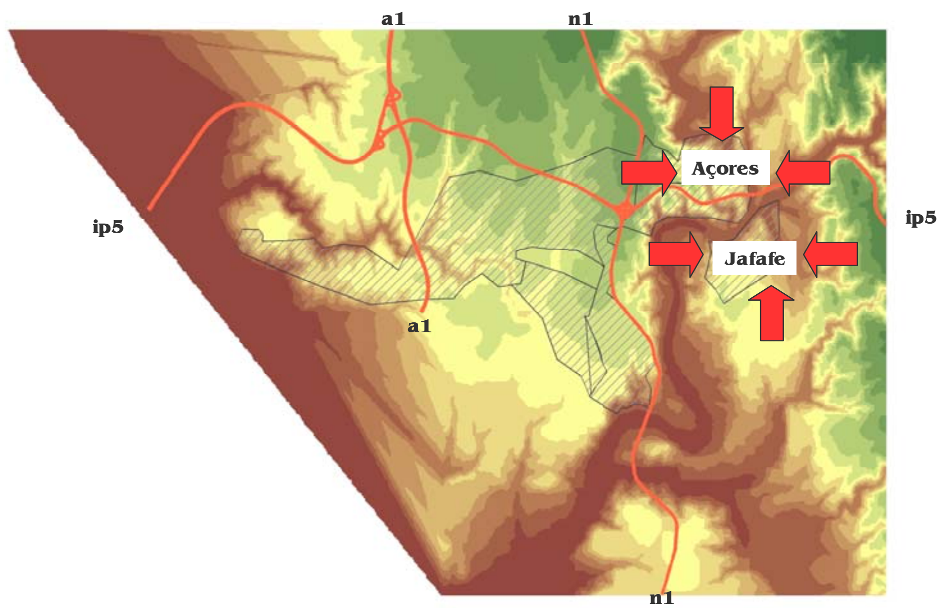

Figure 1— Digital Terrain Model of the Jafafe and Açores study areas, the area burnt in July 2005 and the principal (A1, IP5 and N1).

Material and methods

Rainfall simulation experiments

The rainfall simulation experiments (RSE's) were carried out using the portable simulator following the design by Cerdá et al. (1997) but with two modifications adopted previously by the EU-funded project MEDAFOR (ENV4-CT98-0686): an automatic pressure (developed by S. de Alba) and an approximately square plot with an area of 0.28 m2 (specifications following S. de Alba). A third modification was developed in the framework of the EROSFIRE project, comprising the substitution of internal parts of the spraying head (or nozzle) to achieve a higher rainfall intensity than the 45 mm.h-1 that could be obtained with the original Cerdà et al. (1997) model. This modification did, in fact, permit an intensity in the order of 85 mm.h-1, which corresponds to the maximum amount of rainfall ever recorder in Portugal over a 1-hour period (Brandão et al. 2001).

In general, the field RSE's were done in a paired-plot experimental design, in which a "high-intensity" (40-45 mm.h-1) RSE and an "extreme-intensity" (80-85 mm.h-1) RSE were carried out simultaneously in adjacent plots. In between these two plots, a third was placed for sampling the initial conditions, in particular with respect to the variables involving destructive measurement/sampling techniques like e.g. soil water repellency, soil texture composition or gravimetric soil moisture content. Another aspect of the sampling strategy that perhaps deserves special mention, is that, whenever feasible, two set of RSE's were performed on each slope section. This involved laying out an transect, dividing it in two parts of equal length, and carrying out one set of RSE's in the middle of each transect part.

The actual RSE's were carried out using a fixed field protocol that was basically the same as the one used in the MEDAFOR project. It involves, amongst others, detailed plot descriptions before and after the RSE's, comprising 60 min of artificial rain, and the collection of five samples of the possible runoff for subsequent analysis, in the laboratory, of sediment and organic matter concentration.

Up till the end of 2006, around 150 RSE's were carried out. Over half of these RSE's took place at the above-mentioned six permanent study sites. In the case of the Jafafe and Açores sites, these repeated RSE's initially, in August and September 2005, involved distinct plots along different transects but, starting in November 2005, involved fixed plots. The remaining RSE's were done in different land-cover types, in particular pine stands (*Pinus pinaster* Ait.), and, mainly, in eucalypt plantations that, contrary to the permanent sites, had been intervened following the wildfire.

Erosion plots

Each of the above-mentioned, six permanent study sites was equipped with four bounded micro-plots and four, unbounded slope-scale plots. The three study areas Jafafe, Açores and Soutelo were furthermore instrumented with an automated rainfall gauge and one or more totaliser rainfall gauges. As stated before, the micro-plots are identical to the plots used in the RSE's. The slope-scale plots, in turn, have outlets identical to those of the micro-plots, with the intent of facilitating the comparison across spatial scales.

In 2005 as well as in 2006, the erosion plots could only be installed in the field one to two months after the fire, so that, unfortunately, the first rainfall events after the wildfire were missed in both instances. The plots' overland flow and the gauges' total rainfall were, in general, measured at weekly intervals. Whenever possible, one runoff sample was collected per plot for subsequent analysis, in the laboratory, of sediment and organic matter concentration.

Apart from the weekly read-outs of the plots and gauges, the six permanent sites were monitored at 2- to 4-weekly intervals with respect to soil (surface) conditions, in particular soil cover, soil water content and soil water repellency. For a more general characterization of the soil conditions, two soil profiles were described and classified at each site, and various soil samples were taken for analysis, in the Soil Laboratory of the Agrarian High School of Coimbra, of granulometric composition, bulk density and pF curves.

Results and discussion

Rainfall simulation experiments

Table 1 presents the principal data from the first rainfall simulation experiments (RSE's) that were carried out at the four permanent study sites in the Jafafe and Açores areas. Both the "high-intensity" and the "extreme-intensity" RSE's produce very appreciable amounts of overland flow. It is worth stressing that in all these RSE's the soil was initially rather dry and, at the same time, noticeably water repellent. Ferreira et al. (2005) – using the same type of simulator at an intensity of 50 mm.h-1 – obtained comparable overall runoff coefficients (40-80 percent) for recently burnt pine stand in central Portugal. For a pine stand in the same region two years after a wildfire, Walsh et al. (1998) found - using a different type of simulator at an intensity of 35 mm.h-1 –lower overall runoff coefficients (20-25 percent). Given the present-day extent of eucalypt plantations in Portugal, it is perhaps somewhat surprising that the EROSFIRE project appears to be the first study to carry out RSE's in recently burnt eucalypt stands in Portugal.

Notwithstanding the similarly high runoff coefficients, the sediment yield rates presented in Table 1 are relatively low in comparison those of Ferreira et al. (2005: 520-640 mg.m-2.mm-1). These latter figures, however, are not exceptional for recently burnt areas. The RSE's of Benavides-S. & MacDonald (2001), with intensities between 70 and 90 mm.h.1, produced sediment losses from 650 to 1930 and from 3510 to 6840 mg.m-2.mm-1 in pine stands in the U.S.A. after wildfires of medium and high intensity, respectively.

Table 1— *Summary of the initial rainfall simulation experiments (RSE's) carried out at the Jafafe and Açores permanent study sites after a wildfire in early July 2005*

study site	Jafafe1		Jafafe2		Açores1		Açores2	
ground mobilization practice	contour ploughing		terraces		none		down slope ploughing	
date of rainfall simulation experiment (RSE)	08-Sep-05		01-Sep-05		27-Sep-05		20-Sep-05	
slope (degrees)	6	7	24	12	16	19	13	12
rainfall intensity (mm/h)	46	83	46	83	46	83	46	83
rainfall duration (min)	60	60	63	60	60	58	60	60
start runff (min after start RSE)	3.6	2.4	1.7	1.5	1.4	0.8	4.4	1.6
overall runoff coefficient (pct)	62	52	92	71	93	82	73	83
sediment yield rate (g/m2.mm)	146	217	303	216	289	190	205	170
soil loss rate (g/m2.mm)	115	116	222	151	214	123	121	100
initial soil moisture content (0-5 cm; pct gravim.)	2.7		2.7		1.8		3.4	
initial soil water repellency (0-5 cm; pct ethanol)	24		24		24		18	

Erosion plots

Figure 2 intends first and foremost to illustrate that also natural rainfall events can produce considerable runoff coefficients, in some cases even exceeding 50 percent. It should be stressed that the figure concerns micro-plots. Even so, the differences between the two plots give a first indication of the hydrological response at larger scales. The two events of about 80 mm shown in Figure 2 seem to correspond to two rather distinct situations in terms of slope-scale erosion hazard. In eucalypt stands in central Portugal less than two years after a wildfire, Walsh et al. (1994) found that the runoff coefficients of erosion plots of 8 by 2 m varied from 5 to 25 percent in most events but, in some events, they could attain values of 50 percent and even more. Soil water repellency supposedly is one of the key factors responsible for this highly variable hydrological response of recently burnt areas.

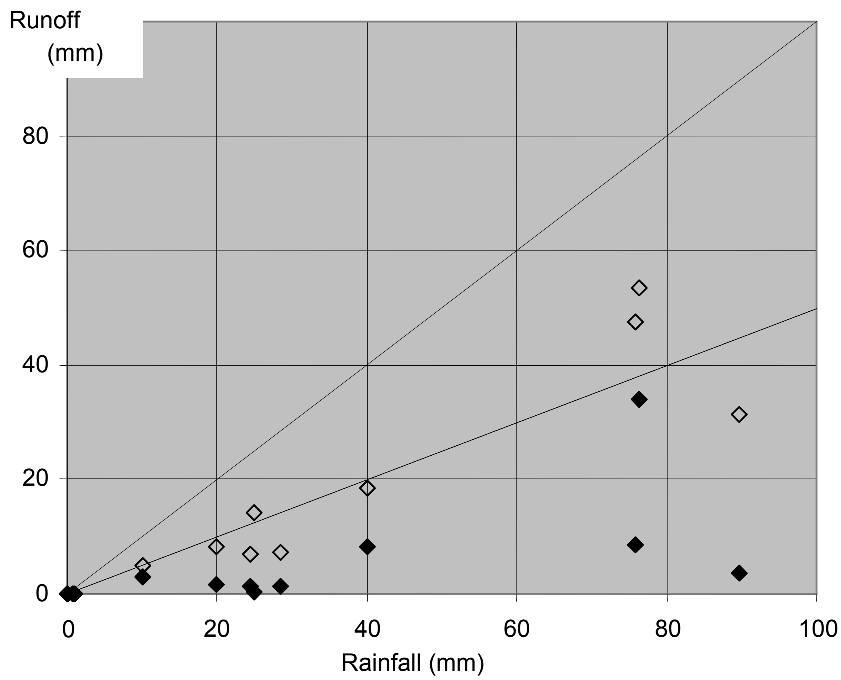

Figure 2— Rainfall-runoff relationship for weekly data from two of the four micro-plots at the Açores2 sites from 19 September to 19 December 2006, with the two lines corresponding to runoff coefficients of 100 and 50 percent.

Final consideration

Whilst the gathering of additional data continues to be an important task till at least the early summer of 2007, the EROSFIRE project is now directing much of its time and efforts to analyzing and trying to model the hydrological and soil erosion processes in recently burnt eucalypt plantations. Hopefully, the poster will be able show initial modeling results, in particular those obtained with MEFIDIS and USLE.

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