

Variability of the soil thermal properties after a prescribed fire

Carles M. Rubio^{a,b,*}, Luís Outeiro^c, Francesc Ferrer^b, Xavier Úbeda^c

^a Dpt. Agri-Food Engineering and Biotechnology, Technical University of Catalonia, 08860 Castelldefels (Spain);

^b LabFerrer. Environmental Biophysics and Soils Consulting Center, Ferran Catolic 3, 25200 Cervera (Spain);

^c Mediterranean Environmental Research Group (GRAM), Dept. of Physical Geography, Faculty of Geography, University of Barcelona, 08001 Barcelona (Spain).

* carles.rubio@upc.edu

Key-words: thermal properties, water content, dual needle sensor, heat pulse, prescribed fire.

Introduction

Prescribed fires are used in Catalonia since 1999 as a tool, among others, for managing forested areas with large amounts of fuel in order to prevent high intensity fires. The Montgrí prescribed fire main objective was reduced the scrubland in an ancient and abandoned pine plantation. On the whole of the literature, many researchers have studied the variations on the chemical and physical properties on or above burnt soils, but there are other physical properties as are thermal properties that govern the heat flow transport inside the soil, and affect the aspects mentioned above. Thus, when biomass on or above a soil surface burns, a heat pulse penetrates the soil. The resulting high soil temperatures can alter soil properties and kill roots and soil microbes (Campbell et al., 1994)

Objectives

The purpose of this research is to explore the variability in the soil thermal properties (thermal conductivity $-\lambda-$, thermal diffusivity $-\alpha-$ and volumetric specific heat $-C_v-$) after a prescribed fire for a natural and typical Mediterranean limestone soil.

Methodology

The study area is located in the north-western corner of the Iberian Peninsula in the coastal mountains of Catalonia, within the calcareous Montgrí massif. The vegetation of this area is typically Mediterranean, composed of Pinus plantation (*Pinus halepensis*) with shrubland of *Quercus coccifera*, *Cistus albidus*, *Rosmarinus officinalis* and *Pistacea lentiscus*. At the time of the fire, the temperature was 12.5°C with a air relative moisture about 60%. A set of 42 soil samples between surface and 5 cm depth was collected before and after the fire (UTM coordinates x: 514555 y: 4659552). The size of the plot is 18 x 4 meters, with a quadrangular structure (see Figure 1). Soil samples were taken, before, just after the fire and one year after the fire, from 42 points arranged in three transects and three crosses across the central transect.

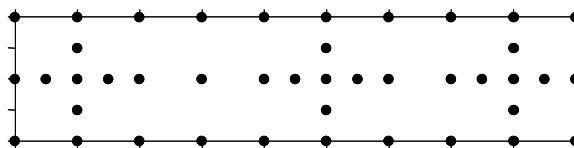


Figure 1. Sampling plot designed. Black points are sampling points.

The fire temperature was measured with a laser thermometer. To characterize the soil chemical and physical variables were analyzed. Particle-size distribution was determined using the wetting sieve method for 2000 to 50 μm and a device by dispersion laser beams (Malvern Mastersizer/E) for particles smaller than 50 μm . Bulk density and porosity were determined from undisturbed sample volume. Calcium carbonate was determined based on Bernard calcimeter (Skinner et al., 1959), whereas the hygroscopic water content was determined by weight differences after drying the samples at 105°C during 24h. The pH and conductivity was analysed following extraction with pure water (1:2.5), and measured with a pH-meter and conductimeter (MAPA, 1986). The organic matter was measured according to the sulfochromic oxidation method (Walkley and Black, 1934). To determine the variability on the soil λ , α and C_v a dry-out (relationship between thermal properties and water content) curve was calculated (Rubio et al., 2008; 2009) using a compound sample on the whole of the set samples per moisture scenario (before and after fire). Dry-out curves on soil columns device were determined. Water content was calculated by dried sample in the oven. To determine the λ , α and C_v a SH-1 small dual-needle sensor was employed. The method is based on ASTM D-5334-08, which it is made using the method and analysis described by Shiozawa and Campbell (1990). The SH-1 thermal sensor combined with KD2-Pro reader-logger to obtain reliable and accuracy soil thermal values, allowing obtaining a continuous large soil thermal data-set.

Results and conclusions

The soil from this plot in the Montgri massif was classified according to USDA as loam textural class (SSS, 1998). Mean bulk density was around 1.1 $\text{g}\cdot\text{cm}^{-3}$. The chemical and physical properties values before and after prescribed fire were, respectively: mean total organic carbon content were about 14.7% and 17.2%. The mean electric conductivity increased. On the other hand, the pH of the media did not show any change, and hygroscopic water content was similar, as well.

Table 1. Physical and chemical characteristics of the studied soil before and after fire. OM = organic matter content; CaCO_3 = calcium carbonate content; EC = electrical conductivity and Hw = hygroscopic water content.

<i>Variables</i>	<i>Before Fire</i>	<i>After Fire</i>
Sand (%)	39.3	41.7
Silt (%)	35.1	32.4
Clay (%)	25.6	25.9
E.C. ($\mu\text{s}\cdot\text{cm}^{-1}$)	330	520
pH	7.0	7.1
O.M (%)	11.2	10.9
CaCO_3 (%)	<3	<3
Hw (%)	1.8	1.9

Respect to soil thermal properties, all of them λ , α and C_v showed changes in their values. Indeed, in all cases the values of soil λ , α and C_v decreased after soil was burnt, especially the thermal conductivity values on the whole of the dry out curve. The critical point in the relationship $\theta(\lambda)$ always was stronger when soil samples were burnt than soil before prescribed fire, starting a critical reaction at 8% of water content for samples no fired, and 6% of water content for burnt samples. Probably, this situation could be explained by the incorporation of organic matter on the soil after of the prescribed fire, such that organic matter behaviour did not transmit well the heat pulse; among other

changes in the variables. Also, the mean temperature values for the soil samples before and after fire during the experiment were about 21.5°C and 18.5°C, respectively. The difference between both values did not affect the soil thermal properties measurements. Finally, a new experiment using the black and white ashes found out over the soil surface after fire was carried out. After the prescribed fire different quantity of ash patches were found out.

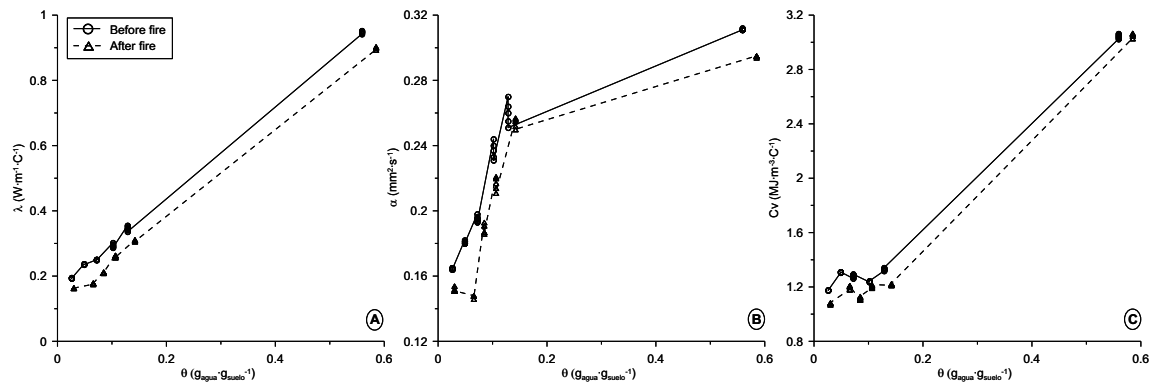


Figure 2. Dry-out curves of the relationship between **A:** thermal conductivity, **B:** thermal diffusivity, **C:** volumetric heat capacity and gravimetric water content.

Some of them were black ashes where the temperature of the fire was lower, and other patches were white ashes where the temperature of the fire was higher. The new test was used to find differences out between two types of ashes. The soil samples after fire was used to amend and to repack with different quantities of black ashes in volume percentage of soil (0, 10, 20, 30,..., 100 %), and maintaining a similar bulk density. The same test was performed with white ashes.

The relationship between bulk density and porosity using fired soil and different ashes (black and white) is showed in Figure 3. The linear relation between both variables means a well-compacted soil samples, and a decreasing pattern of the macro-porosity when bulk density increase, as well. In any case, two well-defined groups of samples were determined. The soil mixture with black ashes presented less bulk density values than soil with white ashes, which it presented a lower porosity.

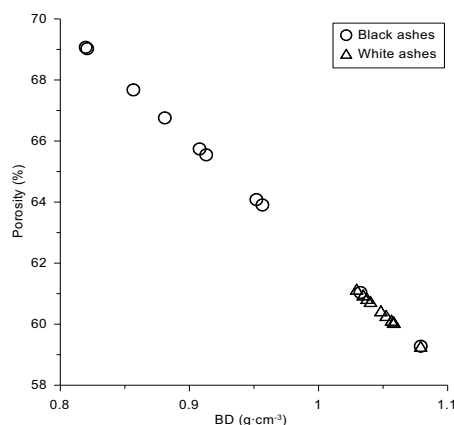


Figure 3. Relationship between bulk density and porosity for a burnt soil mixture with two different types of ashes.

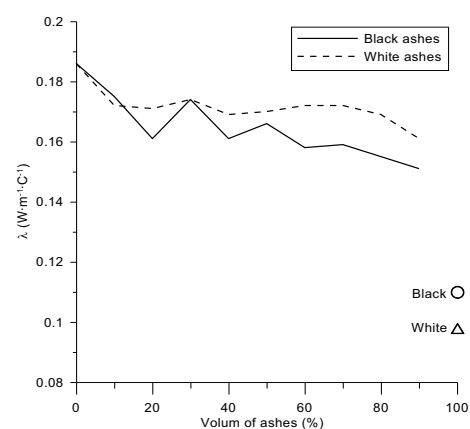


Figure 4. Effects of the different ashes on soil thermal conductivity for a burnt soil.

Figure 4, presents different volume percentages of two types of ashes mixture with soil after prescribed fire, where soil thermal conductivity was measured. The white ashes (dot line) always shown a higher thermal conductivity, meanwhile soil with black ashes was a lower λ . Probably, this fact would be attributed by the large organic matter content that was not burned during the prescribed fire (Abu-Hamdeh and Reeder, 2000), such that the organic matter content has a low thermal conductivity. Thus, when organic matter content increase exhibit a decrease of soil λ (Noborio and McInnes, 1993).

As a summary, we could say that thermal properties can present changes when the scenario changes, i.e. before and after a prescribed fire. Soil after fire always presented a less thermal conductivity, and therefore a less thermal diffusivity, and volumetric specific heat capacity. On the other hand, when the ashes provoked by the fire were incorporated to the soil, the white ashes, which are poorer in organic matter, provided a better heat flow transfer. Therefore, when soil is burned its thermal properties change, and a natural or antropic addition of ashes, especially black ashes, could make worse the conductance of the heat into the soil.

References

- Abu-Hamdeh, N.H.; Reeder, R.C. 2000. Soil thermal conductivity: *Effects of density, moisture, salt concentration and organic matter*. SSSA Jour., 64: 1285-1290
- Campbell, G.S.; Jungbauer, J.D.; Bidlake, W.R.; & Hungerford, R.D. 2000. *Predicting the effect of temperature on soil thermal conductivity*. Soil Science Vol. 158 n° 5: 307-313.
- Ministerio de Agricultura, Pesca y Alimentación 1986. *Métodos Oficiales de Análisis*. Tomo III. Ed. Secretaría General Técnica M.A.P.A., Madrid: 532 p.
- Noborio, K.; McInnes, K.J. 1993. *Thermal conductivity of salt affected soils*. SSSA Jour., 57:329-334
- Rubio, C.M.; Josa, R.; Villar, J.M.; Fonseca, F.; & Ferrer, F. 2008. *Development of laboratory analytical procedures to determine thermal properties in soils*. Proceed. of III International Meeting of the European Confederation of Soil Science Societies EUROSIL, Vienna.
- Rubio, C.M.; Josa, R.; Cobos, D.R.; Campbell C.S.; & Ferrer, F. 2009. *Hysteretic behaviour of thermal properties on porous media*. Advances in Studies on Desertification, Editum Univ. Murcia: 603-606
- Shiozawa, S.; Campbell, G.S. 1990. *Soil thermal conductivity*. Remotes sensing Rev. 5: 301-310
- Skinner, S.I.M.; Halstead, R.L. & Brydon, J.E.; 1959. *Quantitative manometric determination of calcite and dolomite in soils and limestones*. Canadian J. Soil Science, n° 39: 197-204
- Soil Survey Staff (1998): *Keys to Soil Taxonomy*. 8th Ed. US. Government Printing Office. Washington, DC, 541p.
- Walkley, A.; Black, I.A. 1934. *An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method*. Soil Science, n° 37: 29-38



Do stakeholders know what happens to soil after forest fires? A case study in Central Portugal

Cristina Ribeiro^a, Celeste Coelho^a, Sandra Valente^{a*}, Teresa Carvalho^a, Elisabete Figueiredo^b

^a CESAM – Centro de Estudos do Ambiente e do Mar; Departamento de Ambiente e Ordenamento, Universidade de Aveiro, 3810-193 Aveiro;

^b GOVCOPP – Unidade de Investigação em Governança, Competitividade e Políticas Públicas, Secção Autónoma Ciências Sociais, Jurídicas e Políticas - Universidade de Aveiro, 3810-193 Aveiro

* sandra.valente@ua.pt

Key-words: Forest fires.

Introduction

The integration of ecological and social aspects is essential to a successful post-fire management (Toman et al., 2008). Forest fires produce major impacts on soil, water and vegetation. Fires can produce on-site and off-site degradation impacts that result in property damage, ecosystems disruption and ultimately in loss of human life and injuries. If environmental impacts of fires are well known, the integration of this knowledge on forestry practices is far from being completely addressed. Ferreira et. al. (2008) demonstrate that fires affect negatively soil properties (infiltration rate, porosity, conductivity and storage capacity), organic matter and soil structure and also increase overland flow and erosion yields, mainly due to the destruction of ground cover and major changes in soil structure. The mitigation of these impacts demands a combined post-fire intervention including public authorities, forest owners and local stakeholders. Nevertheless there is a low public awareness about the importance of those interventions (Ribeiro et. al, 2010).

Fire management is a complex issue which comprises a set of different activities ranging from pre-fire up to post-fire interventions (Toman et. al, 2008). These interventions focus in three different stages of action, namely: i) prevention of large fires; ii) mitigation of fire impacts; and iii) burned areas rehabilitation. At all these stages, interventions require trust and confidence between all the stakeholders. This is even more necessary in post-fire intervention, where public opinion is affected by the occurrence of the event. Olsen and Schindler (2010) referred the need of establishing a long term commitment between organizations and citizens as an essential tool to promote post-fire management acceptance. The knowledge about the community where post-fire interventions takes place is also a very important aspect, since it can influence the decision-making process about management. Past experience showed that more active communities are better prepared to respond, plan and collaborate with agencies on post-fire intervention (Steelman et. al, 2004 in Ryan and Hamim, 2008).

Studies developed in burned forest areas demonstrated that the success of the implementation of post-fire techniques relies on the social capital and on the involvement of citizens in post-fire planning and management (Olsen and Schindler, 2010). Since post-fire intervention is a complex process, it should be integrated in the management process, including prevention actions, such as reduction of fuel to mitigate fire risk (Toman et. al, 2008). Financial and technical support to communities is also of paramount relevance to promote pos-fire interventions.



Sustainable Forest Management (SFM) demands the involvement of communities, forest agencies, forest entrepreneurs and public agencies (Leskinen, 2004; Dhubháin et. al, 2008) throughout the entire process. In fact, public participatory approaches can only be successful if a social learning process is embraced since the beginning (Leskinen, 2004). The participatory planning aims to improve decisions about forest management, reduce conflicts of interest and achieve consensus about the goals and fundamental actions to SFM (Ryan and Hamim, 2008). Another important aspect is, as mentioned, to develop trust between public entities, forest organizations and citizens (Olsen and Shindler, 2010). This is extremely important to change perceptions about the role and actions of each stakeholder as well as to develop partnerships and joint work towards SFM. Ryan and Hamim (2008) highlight that the public perception about the institutional framework of natural resources management depends on pre-existent confidence on the entities and on past collaboration experiences. However, other aspects such as socio demographic characteristics and individual and social perceptions about environment are also important variables influencing those perceptions.

Objectives

The main aim of this communication is to discuss forest owners and managers' social perceptions regarding the effects of fires on soil and the need of post-fire intervention to mitigate soil degradation. This study was carried out under the scope of RECOVER project which aims to develop immediate soil management strategies for recovery after forest fires. Under this project a social survey was undertaken in Pessegueiro do Vouga parish representing a typical forest landscape of Central Portugal. This area is integrated in the municipality of Sever do Vouga in which the main land use is forest, mostly occupied by *Pinus pinaster* and, more recently, *Eucalyptus globulus*. The area has been recurrently affected by intense fires. Forest is mainly composed by small-holdings and it is a complementary, even residual, activity regarding family income. Together with the above mentioned aspects, this circumstance is reflected in low levels of intervention on forest.

Methodology

The data collection, using a semi-structured interview, was developed in two phases. In the first phase, the interview was applied to the forest owners living at the study area. A sample of 28 respondents representing 15% of the total forest owners within the parish, was used considering their distribution by age groups, by size of the forest holdings and by the dominant forest species. In the second phase the interview was applied to local entities, such as the local authority of Pessegueiro do Vouga parish, the City Council of Sever do Vouga, the Technical Forest Office of Sever do Vouga, the Agricultural Cooperative of Sanfins, the head of Sever do Vouga Fire Brigade, and a forest enterprise - Portucel Soporcel. The aim of this methodology was to collect data on the possible different visions about forest fires and forest management, as well as to obtain information in order to compare intervention and decision making and management perspectives.

The respondents were asked questions on the environment impacts of forest fires, in particular soil changes. Questions related to post fire interventions to remediate fire effects on the soil, the techniques available, their knowledge on those recovery actions and their acceptance and the implementation of those techniques in their land, were also considered.



Results and conclusions

Despite the recognition of the relevance of social and institutional aspects regarding social and economic effects of forest fires, environmental damages of large fires are also very important and demand particular efforts from the forest owners producers. Several studies have demonstrated some environmental benefits of prescribed burning, namely to vegetation and biodiversity such as reducing organic matter accumulation and increasing landscape diversity (Ferreira et. al, 2009).

This communication aims to discuss whether local stakeholders related with forest management are aware of fire effects on soil. In fact, changes on soil structure and soil quality were mentioned both by forest owners and local entities. These changes are mostly linked with erosion, soil permeability and fertility. Respondents recognized that soil degradation after fire is observed in different ways: such as small rills, loss of topsoil and also the appearance of a drier horizon or a stony soil. Most respondents also perceived changes on soil infiltration after fire, by the increase of water runoff. However, two respondents mentioned the opposite effect. Finally, the increase of soil fertility after a fire was also perceived as a beneficial consequence due to the incorporation of ashes on the soil.

More than 50% of forest owners were affected by fires in their own properties. The forest owners' main interventions after fire are not directly related with the mitigation of fire effects on soil. These interventions are mainly linked with the removal of burned wood and litter and the planting of new trees (Ribeiro et. al, 2010). The forest owners absenteeism, lack of interest and low investment on forestry was also mentioned by the local entities as a constraint to forest management.

Concerning the implementation of specific post-fire management techniques, the results show that forest owners have no knowledge about their existence. However some respondents referred practices that can mitigate soil erosion, such as cutting the branches which cover the soil after fire. Mulching, application of barriers, channels cleaning and paths treatments are examples of post-fire techniques largely used in the USA, Canada and Australia burned areas to mitigate immediate soil erosion (Robichaud et. al, 2000; Robichaud and Brown, 2005). Some respondents from local entities recognized some of these techniques. The implementation of these techniques is almost inexistent, except some on-going research experiences (Coelho et. al, in this conference) and public interventions. In fact, individual intervention on forest is focused on production areas, aiming to have some economic profit from timber production. The implementation of these measures demands a long-term vision, which does not exist in the current Portuguese forest management framework.

This study also addressed the predisposition of forest owners to increase their knowledge about post-fire intervention. Most respondents demonstrated interest to obtain information through practical demonstrations and training on the field. In parallel, the entities interviewed demonstrated willingness to collaborate in these activities, as well as in promoting local partnerships to achieve such purpose.

The literature review highlights the relevance of trust and cooperation between entities, stakeholders and general citizens. The acceptance and implementation of post-fire techniques to reduce soil erosion can only be possible if this involvement is achieved. The empirical evidence shows the existence of interest and willingness to cooperate from both categories of respondents interviewed.

In brief, to the question present in the title - do stakeholders know what happens to soil after forest fires? – and considering the evidence provided by the study, a very accurate



answer would be: yes, they do. But due to lack of knowledge of mitigation techniques available and cooperation, this it is not reflected in their interventions.

Acknowledgment

The research described in this paper was developed under several projects, namely on the framework of RECOVER project (PTDC/AGR-AAM/73350/2006) funded by Fundação para a Ciência e para a Tecnologia (FCT), and RAA project, funded by the Permanent Forest Fund (IFADAP/INGA).

References

- Coelho, C., Prats, S., Carvalho, T., Pinheiro, A., Ferreira, A., Soares J. 2011. *Effectiveness of two mulch treatments controlling soil erosion and water conservation*. Proceedings book of the International Meeting of Fire Effects on Soil Properties (in prep.). 15-19 March of 2011 - Guimarães, Portugal
- Coelho, C., Valente, S., Ferreira, A., Soares, J., Carvalho, T., Ribeiro, C. 2010. *Forest Fire Versus desertification in Portugal*. International Conference on Combating Land Degradation in Agricultural Areas (LANDCON 1010). October 11-15, 2010. Xi'an, China.
- Dhubháin, Á.N., Fléchar, M.C., Moloney, R., O'Connor, D. 2008. *Stakeholders' perceptions of forestry in rural areas—Two case studies in Ireland*. Land Use Policy, 7, pp. 9.
- Ferreira A.J.D., Silva J.S., Coelho C.O.A., Boulet A.K., Keizer J.J., 2009 *The Portuguese Experience in Managing Fire Effects In: Fire Effects on soils and restoration strategies*. Cérda A. e Robichaud P. (eds) Land Reconstruction and Management. Vol 5. 401-424pp
- Ferreira, A., Ritsema, C., Coelho, C., Boulet, A.K., Keizer, J. 2008. *Soil and water degradation processes in burned areas: Lessons learned from a nested approach*. Catena, 74, 273-285.
- Leskinen, L.A. 2004. *Purposes and challenges of public participation in regional and local forestry in Finland*. Forest Policy and Economics, 6, 605-618.
- Olsen, C.S., and Shindler, B.A. 2010. *Trust, acceptance, and citizen–agency interactions after large fires: influences on planning processes*. International Journal of Wildland Fire 19: 137-147.
- Ribeiro, C., Figueiredo, E., Coelho, C., Valente, S., Carvalho, T. 2010. *Uma árvore não faz a floresta? Análise da percepção dos proprietários florestais face aos incêndios e sua actuação*. Em: E. Figueiredo, E. Kastenholz, M.C. Eusébio, M.C. Gomes, M.J. Carneiro, P. Batista, S. Valente (Org.). IV Congresso de Estudos Rurais – Mundos Rurais em Portugal: Múltiplos Olhares, Múltiplos Futuros. Universidade de Aveiro, Aveiro, 4 a 6 de Fevereiro, pp. 172-173.
- Robichaud, Peter R.; Beyers, Jan L.; Neary, Daniel G. (2000). *Evaluating the effectiveness of postfire rehabilitation treatments*. Gen. Tech. Rep. RMRS-GTR-63. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.
- Robichaud, P. R.; Brown, R. E. (2005). *Postfire Rehabilitation Treatments: Are We Learning What Works?* Proceedings of the 2005 Watershed Management Conference. July 19-22, Williamsburg, VA. 13 p.
- Toman, E.L.; Shindler, B.; Absher, J.; McCaffrey, S. 2008. *Postfire Communications: The Influence of site visits on local Support*. Journal of forestry 25-30



Comparison of the effects of post-fire soil stabilization treatments for soil erosion control on selected soil properties in Galicia (NW Spain)

M.T. Fontúrbel^{a*}, M. Díaz-Raviña^b, J.A. Vega^a, S.J. González-Prieto^b, C. Fernández^a, A. Martín^b, E. Jiménez^a, A. Barreiro^b, T. Carballas^b

^aCentro de Investigación Forestal-Lourizán, Consellería de Medio Rural. Xunta de Galicia. Apdo 127, 36080 Pontevedra (Spain);

^bDepartamento de Bioquímica del Suelo, Instituto de Investigaciones Agrobiológicas de Galicia (CSIC), Apartado 122, 15780 Santiago de Compostela (Spain)

* maria.teresa.fonturbel.lliteras@xunta.es

Key-words: Post-fire; Mulching; Seeding; Soil erosion; Soil properties.

Introduction

Wildfires are one of the main disturbance factors in Atlantic and Mediterranean forests from Spain. The first rainfall events after fires, especially if they are of high intensity, can cause an intense erosive action and/or important soil nutrient losses and changes in soil properties affecting the forest ecosystem recovery (Díaz-Fierros et al., 1990; Soto and Díaz-Fierros, 1998; Vega et al., 2005; Fernández et al., 2005). Soil degradation caused by fires can also affect negatively soil microorganisms (Certini, 2005; Carballas et al., 2009); thus, in burnt areas, there is the urgent need for post-fire land management practices in order to re-establish the microbial population and hence improve soil quality for forest restoration. However, despite of post-fire stabilization treatments (e.g. mulching, seeding, erosion barriers) applied to hill-slopes are recommended in order to minimize the fire effects (Bautista et al., 1996; Badía and Martí, 2000; Villar et al., 2004; Robichaud, 2009; Bautista et al., 2009), the impact of different post-fire rehabilitation techniques on soil microbial communities has not been evaluated in this temperate humid zone.

Objectives

This study has been conducted in an experimentally burned shrubland ecosystem in the N.W. of Spain, in order to evaluate the effect of experimental fires and two post-fire stabilization treatments (mulching and seeding) on: a) soil microorganisms (mass, activity, diversity); and b) to evaluate the efficacy of different biochemical properties as soil quality bioindicators.

Methodology

The study was conducted in an experimental field located at an altitude of 660 a.s.l., in Cabalar (A Estrada, 42° 38' 58'' N; 8° 29' 31'' W; N.W. Spain) with temperate and rainy climate. The soil, developed over a parent material of granite and with a slope of 38-54%, has a vegetation representative of many oceanic climate shrublands in Galicia dominated by gorse *Ulex europaeus* L. and some *Pteridium aquilinum* (L.) Kuhn., *Ulex gallii* Planch., *Daboecia cantabrica* (Huds.) K. Koch and *Pseudoarrenhaterum longifolium* Rouy, with a height of 123 cm on average and 100% of ground cover.

Nineteen experimental plots (30 x 10 m each) were established and a fuel inventory was carried out. Fifteen of these plots were burned and four unburned plots were used as control unburned soils. In June 2009, the shrub was cut and laid down directly on the ground to favour litter and duff combustion. The fuel inventories were repeated just after burning. Just before burning, samples from different fuel portions and mineral soil were

randomly taken from ten points per plot to determine moisture content.

The fires were conducted with the backfire technique. The rates of fire spread and the flame length were recorded. Soil temperatures at soil mineral surface and 2 cm of depth during the fires were monitored with ten thermocouples K type per plot. The meteorological conditions (air temperature, relative humidity and wind direction and velocity) were recorded during the fires. The percentage of surface covered by litter and duff and bare soil were also measured along the same transect. The litter depth was measured using metal pins placed flush with the litter surface at 1 m intervals along the transect. The change in the litter thickness immediately after the fire was determined.

After the fire the following soil treatments were considered using 4 replicates by treatment: unburnt soil as a control; b) burnt soil; c) burnt soil with 232 g m⁻² of straw mulch; d) burnt soil with a mixture of seeds at a rate of 45 g m⁻² (*Lolium multiflorum*, 35%; *Trifolium repens*, 25%; *Dactylis glomerata*, 20%; *Festuca arundinacea*, 10%; *Festuca rubra*, 5%; *Agrotis tenuis*, 5%). To accurately evaluate the effectiveness of these techniques, the evolution of several biochemical and biological (microbial biomass, enzymatic activities of C, N and P cycles, and microbial potential substrate utilization capacity) properties were quantified in the different plots.

The microbial biomass C was determined using the fumigation-extraction method (Díaz-Raviña et al., 1992). The β -glucosidase, urease and phosphatase activities were assayed as reported by Eivazi and Tabatabai (1988), Kandeler and Geber (1988) and Trasar-Cepeda et al. (1985), respectively. The microbial community was characterized by the community-level carbon source utilization (Biolog Ecoplates) (Garland and Mills, 1991) by means of the average colour development (AWCD), based on C substrate utilization in each well of microplate, recorded as optical density (OD) at 590 nm at 24-h intervals and plate readings after 72 h of incubation. The microbial richness (MR) was expressed as the number of oxidized C substrates in the microplates. The Shannon-Weaver index (H), which determines the substrate diversity, was calculated as: $H = -\sum p_i (\ln p_i)$, where p_i is the ratio of the activity on each substrate (OD_i) to the sum of the activities on all substrates ($\sum OD_i$).

In order to evaluate the effect of the different treatments on the biochemical and microbiological properties analyzed, the values of three field replicates with the same treatment were averaged (mean $\pm$ SD). The data were analyzed by a two way analysis of variance to determine the percentage of the variation attributable to the treatment and time factors. For the same sampling time, the data were analyzed by a standard analysis of variance and, in the cases of significant F statistics, the Tukey's minimum significant difference test was used to separate the means.

Results and conclusions

The results show that the experimental fires progressed slowly, producing a high surface fuel consumption, while duff was irregularly consumed (Vega et al., 2010). The temperatures recorded in the mineral soil during the fire indicated a moderate soil heating on the soil surface, without heat penetration into the soil (Vega et al., 2010).

The evolution of the soil biochemical and microbiological properties in the 0-5 cm mineral soil layer (Table 1) shows that the experimental fires caused an initial significant decrease in microbial C and urease activity and increases of soil pH and in several microbial parameters measured by means of the community-level physiological profile (average colour development, microbial richness and Shannon-Weaver index). These

effects were aminorated with time; thus, after 6 months only a significant effect was still observed on the microbial C and phosphatase activity values.

In general, sampling time was the factor that explained most of the variance (35-60%) whereas the treatment explained only 9-22% of variance and the interaction between these factors explained a further 16-33% of the variance of glucosidase and AWCD data. The data clearly indicated that although the experimental fires combined or not with some rehabilitation technique (straw mulching and seeding) had an influence on soil microorganisms, this influence was lower than that showed by the sampling time, which seems to indicate that these fires were not of importance as disturbance agents for microorganisms of these ecosystems from the temperate humid zone. Likewise no significant changes were observed in most physico-chemical properties analyzed (Martin et al., 2010) as consequence of the same fires. These slight fire effects are probably associated to the low temperatures reached by soil during these fires (Vega et al., 2010).

Table 1. Evolution of soil biochemical and microbiological properties over six months in the different soil treatments. Treatments: C, unburnt soil; B, burnt soil; B+M, burnt soil plus straw addition; B+S, burnt soil plus seeding.

Soil property	Time (days)	Treatment			
		C	B	B+M	B+S
Microbial biomass C (mg kg ⁻¹)	0	2158 ±206 a	1641 ±227 a	1709 ±318 a	1726 ±266 a
	1	1809 ±313 a	1188 ±176 c	1571 ±46 ab	1426 ±204 bc
	90	1577 ±186 a	1267 ±326 ab	1076 ±137 b	1175 ±185 ab
	180	2251 ±201 a	1874 ±131 b	1967 ±207 ab	1848 ±155 b
Glucosidase (µg p-nitrophenol g ⁻¹ h ⁻¹)	0	95.3 ±7.8 ab	108.8 ±6.0 ab	112.7 ±14.4 a	89.2 ±12.2 b
	1	101.5 ±13.7 a	90.3 ±8.4 a	96.1 ±9.3 a	80.8 ±15.3 a
	90	149.6 ±17.2 a	95.1 ±18.5 b	100.4 ±30.0 b	86.7 ±28.0 b
	180	105.3 ±8.9 a	104.4 ±19.3 a	85.7 ±21.3 a	110.2 ±18.3 a
Urease (µg NH ₄ ⁺ g ⁻¹ h ⁻¹)	0	105.1 ±14.7 a	84.7 ±17.6 a	86.7 ±14.4 a	91.7 ±8.2 a
	1	93.7 ±13.7 a	61.4 ±8.2 b	63.6 ±13.2 b	62 ±10.3 b
	90	57.2 ±9.8 a	39.1 ±10.0 b	30.8 ±3.2 b	38.4 ±3.6 b
	180	96.7 ±15.6 a	70.6 ±12.6 a	70.5 ±8.7 a	68.3 ±19.2 a
Phosphatase (µg p-nitrophenol g ⁻¹ h ⁻¹)	0	1042 ±184 a	929 ±120 a	795 ±95 a	1015 ±52 a
	1	945 ±111 a	592 ±305 a	657 ±181 a	851 ±221 a
	90	583 ±90 a	451 ±115 a	439 ±94 a	512 ±98 a
	180	1068 ±96 a	800 ±53 b	827 ±43.5 b	857 ±125 b
Average colour development (AWCD)	0	0.700 ±0.026 a	0.744 ±0.289 a	0.535 ±0.24 a	0.742 ±0.149 a
	1	0.680 ±0.099 b	1.062 ±0.207 a	0.923 ±0.11 ab	0.936 ±0.150 ab
	90	0.831 ±0.046 b	1.028 ±0.123 ab	1.230 ±0.22 a	1.055 ±0.184 ab
	180	0.834 ±0.087 a	0.899 ±0.089 a	0.962 ±0.06 a	1.005 ±0.135 a
Microbial richness (MR)	0	21.8 ±1.9 a	20.3 ±5.0 a	19.5 ±3.4 a	21.8 ±3.2 a
	1	20.8 ±1.1 b	25.3 ±1.5 a	24.3 ±2.1 a	24.3 ±2.1 a
	90	23.3 ±0.9 b	26.8 ±1.7 a	26.5 ±1.3 a	26.3 ±2.1 a
	180	23.0 ±1.4 a	24.5 ±1.7 a	24.8 ±1.3 a	25.8 ±2.1 a
Shannon-Weaver index (H)	0	2.91 ±0.07 a	2.84 ±0.21 a	2.83 ±0.17 a	2.92 ±0.17 a
	1	2.87 ±0.04 b	3.03 ±0.02 a	3.02 ±0.05 a	3.03 ±0.09 a
	90	2.97 ±0.05 b	3.10 ±0.09 a	3.15 ±0.06 a	3.11 ±0.07 a
	180	2.99 ±0.06 a	3.06 ±0.04 a	3.08 ±0.07 a	3.11 ±0.08 a

For same sampling time different letters denote significant differences ($P < 0.05$)

References

- Badía, D., Martí, C. 2000. Seeding and mulching treatments as conservation measures of two burned soils in the central Ebro valley, NE Spain. *Arid Soil Research Rehabilitation* 13: 219-232.
- Bautista, S., Bellot, J., Vallejo, V.R. 1996. Mulching treatment for postfire soil conservation in a semiarid ecosystem. *Arid Soil Research Rehabilitation* 10: 235-242.



- Bautista, S., Robichaud, P. R., Bladé, C. 2009. Post-fire mulching. In: *Fire effects on soils and restoration strategies* (A. Cerdá, P. Robichaud, eds.), Science Publishers, p. 353-372.
- Carballas, T., Martín, A., Díaz-Raviña, M. 2009. Efecto de los incendios forestales sobre los suelos de Galicia. In: *Efecto de los incendios forestales sobre los suelos en España* (Artemi Cerdá, Jorge Mataix-Solera, eds.). Cátedra Divulgación de la Ciencia. Universitat de València, Cap. 3.6, p. 269-301.
- Certini, G. 2005. Effects of fire on properties of forest soils: a review. *Oecologie* 143: 1-10.
- Díaz-Fierros, F., Benito, E., Vega, J.A., Castelao, A., Soto, B., Pérez, R., Taboada, T. 1990. Solute loss and soil erosion in burnt soil from Galicia (NW Spain). In: *Fire in ecosystems dynamics. Mediterranean and Northern Perspectives* (F.G. Goldammer, M.J. Jenkins, eds.), SPB Goldammer, The Hague, p. 103-106.
- Díaz-Raviña, M., Prieto, A., Acea, M.J., Carballas, T. 1992. Fumigation-extraction method to estimate microbial biomass in heated soils. *Soil Biology and Biochemistry* 24: 259-264.
- Eivazi, F., Tabatabai, M.A. 1988. Glucosidases and galactosidases in soils. *Soil Biology and Biochemistry* 20: 601-606.
- Fernández, C., Vega, J.A., Fonturbel, T., Pérez-Gorostiaga, P., Jiménez, E., Madrigal, J. 2007. Effects of wildfire, salvage logging and slash treatments on soil degradation. *Land Degradation and Development* 16: 37-51.
- Garland, J.L., Mills, A.L. 1991. Classification and characterization of heterotrophic microbial communities on the basis of patterns of community-level sole-carbon-source utilization. *Applied and Environmental Microbiology* 57: 2351-2359.
- Kandeler, E., Gerber, H. 1988. Short-term assay of urease activity using colorimetric determination of ammonium. *Biology and Fertility of Soils* 6: 68-72.
- Martín, A.; Díaz-Raviña, M.; Carballas, T.; Vega, J.A.; Jiménez, E.; Fonturbel, T. 2010. Caracterización físico-química de suelo quemado con diferentes tratamientos de rehabilitación. . Actas Jornadas Internacionales sobre Investigación y Gestión para la protección del suelo y restauración de los ecosistemas forestales afectados por incendios forestales. FUEGORED 2010.
- Robichaud, P.R. 2009. Post-fire stabilization and rehabilitation. In: *Fire effects on soils and restoration strategies. Vol. 5 Land reconstruction and management* (A. Cerdá, P.R. Robichaud, eds.). Science Publishers, Enfield, USA, p. 299-320.
- Soto, B., Díaz-Fierros, F. 1998. Runoff and soil erosion from areas of burnt scrub: comparison of experimental results with those predicted by WEPP model. *Catena* 31: 257-270.
- Trasar-Cepeda, M.C., Gil Sotres, F., Guitián Ojea, F. 1985. Determinación de la actividad de la fosfatasa en suelos gallegos. Precisiones al método de Saratchandra y Perrott. *Anales de Edafología y Agrobiología* 44: 987-991.
- Vega, J.A., Fernández, C., Fonturbel, T. 2005. Throughfall, runoff and soil erosion alter prescribed burning in gorse shrubland in Galicia (NW Spain). *Land Degradation and Development* 16: 37-51.
- Vega, J.A., Fernández, C., Fonturbel, T., Jiménez, E., Díaz-Raviña, M., Martín, A., Carballas, T. 2010. Comparación de tratamientos de mulching y siembra de herbáceas para control de erosión tras fuego experimental en matorral de Galicia. Actas FUEGORED, Santiago de Compostela.



Villar, M.C., Petrikova, V., Díaz-Raviña, M., Carballas, T. 2004. Changes in soil microbial biomass and aggregate stability following burning and soil rehabilitation. *Geoderma* 122: 73-82.

Acknowledgements

This study was supported by the Consellería de Medio Rural de la Xunta de Galicia (08MRU002400PR).



Rock gabion, rock armoring, and culvert treatments contributing to and reducing erosion during post-fire flooding – Schultz Fire 2010

Daniel G. Neary^{a*}, Karen A. Koestner^a, Ann Youberg^b

^a USDA Forest Service, Rocky Mountain Research Station, 2500 Pine Knoll Drive, Flagstaff, Arizona 86001 (USA);

^b Arizona Geological Survey, 416 Congress Street, Suite 100, Tucson, Arizona 85701 (USA).

* dneary@fs.fed.us

Key-words: Gabions; culverts; rock armoring; erosion; wildfire.

Introduction

The Schultz Fire burned 6,100 ha on the eastern slopes of the San Francisco Peaks of the Coconino National Forest in north-central Arizona. The fire burned between June 20th and 30th, 2010, across moderate to very steep ponderosa pine and mixed conifer watersheds. One of the Burned Area Emergency Response treatments on Coconino National Forest lands consisted of the placement of large rock armoring on targeted fill slopes of a high elevation road that carries a water pipeline supplying water to the city of Flagstaff, Arizona (Robichaud et al. 2000). Other Forest treatments consisted of culvert removal at 30 channel crossings on another Forest road that transects the Schultz Fire at a lower elevation. On urbanized private lands below the Fire, no road culverts were initially removed or upgraded. A major, unarmored drainage ditch was fitted with sixteen rock-filled wire cage gabions to reduce channel incision in unconsolidated alluvial fan sediments. Rainfall beginning in mid-July after the wildfire produced a typical series of floods that caused substantial soil erosion, debris flows, and channel incision (Neary et al. 2008).

Objectives

This paper examines the effectiveness of gabion, armoring, and culvert treatments for erosion control after the Schultz Fire and discusses the reasons for failure or success. An objective is to also make recommendations for future use of these erosion control techniques.

Methodology

Rock Armoring: This treatment was done on the Waterline Road after the fire at 17 drainage crossings (Figure 1A). It consisted of placing 294 m³ of large rocks (30-60 cm diameter) below the road on potential water flow paths. The downhill end of each rock armoring array was anchored to the ground by large logs.

Culvert Treatments: Culverts were removed at 30 locations along the Schultz Pass Road (Forest Road 420) on Coconino National Forest lands (Figure 2A.). Low water crossings were then graded to allow vehicle passage. A number of culverts (30) on private land were selected for comparison. They ranged in diameter from 30 to 100 cm and were left in place according to individual land owner dictates.

Rock Gabions: After the flood of July 20th, 18 rock-wire gabions were placed at roughly equal distances in an unlined ditch along Campbell Avenue in the Timberline

neighborhood. The individual gabion cages were about 60 x 60 cm in cross-section and 2-3 m long. The drainage ditch was rated at a capacity of $14.2 \text{ m}^3 \text{ sec}^{-1}$. The ditch was constructed on a straight fall line down the alluvial fan with a gradient of 4%. Since utility lines were buried in soil on both sides of the ditch, the wing walls of the gabions were not adequately keyed into the ditch slopes. This limitation had a major impact on the performance of the gabions during a rainfall and flood flow event of July 30th. The functioning of the gabions was evaluated and photo-documented during the actual flood flow.

Results and Conclusions

Rock Armoring: The large rock armoring on the slopes below the upper elevation Waterline Road failed completely in the storm of July 20th (Figure 1B). All of it was washed away by the high water flows and deep gully incisions in that storm and subsequent storms. At most of the armored crossings, debris flows and runoff carrying much larger rocks than the armoring rocks (30 – 60 cm diameter) crossed the road and washed out the armored sections. The erosion control treatments were simply overwhelmed by the magnitude of the flood events. The size of the armoring pad rocks was too small to process high velocity flows coming off steep, 100%+ slopes. Flood flows lower on the mountain were powerful enough to knock over 13 Mg Jersey barriers. Larger rocks (1+ m in diameter) should have been used but there was probably not enough time to organize delivery of resources of that size. This erosion control technique contributed to the post-fire erosion and did nothing to reduce it. Therefore, this treatment is not recommended in steep terrain unless adequately sized rock material can be obtained.



Figure 1. Rock armoring along the Waterline Road before (A) and after (B) the July 20th flood.

Culvert Removal: The low-water channel crossings on Forest Road 420 where culverts were removed functioned satisfactorily (Table 1) and prevented addition of road fill and fill-breach surges to the stormflow (Figure 2A). Some minor maintenance is required to keep the crossings trafficable after floods. Road culverts in the urban area were grossly under capacity and most were either buried, breached, or bypassed, increasing in the amount of sediment transported to lower elevations (Table 1, Figure 2B). In some instances, home owners replaced storm-damaged or poorly functioning culverts with larger diameter culverts only to have the same failure rate. Of the two that were successful in the private ownership area, one was designed as a concrete surfaced low-

water crossing. The other had a set of four 1-m wide culverts located in a depression that followed the gradient of the alluvial fan. This set of culverts was actually installed by Coconino County on a county road. The majority of the roads in the Timberline residential area are private, thus culvert sizing has not been standardized. Culvert removal on National Forest lands facilitated passage of flood flows from the upper slopes of the San Francisco Peaks. This treatment did not contribute to increased erosion and actually reduced potential erosion and flooding by eliminating the risk of road fill breaches. The culvert removal and low-water channel crossings treatment is recommended as a relatively inexpensive and effective means of coping with post-fire flood flows. Culverts on some private land would have performed better had been larger in diameter. However, others would have failed regardless of size due to excessive rock and woody debris. The best approach in most cases is culvert removal and construction of low-water crossings. Maintenance needs to be carried out on an as-needed basis after stormflow.

Table 1. Comparison of failure rates for culvert treatments, Schultz Fire 2010, Coconino County, Arizona.

Ownership	Location	Treatment	# of Culverts	Failure Rate
National Forest	FR 420	Culvert Removal	30	0%
Private	Timberline	Left In Place	30	93%



Figure 2. An example of (A) successful culvert removal and construction of low-water crossings on National Forest lands; and (B) a bypassed and breached, undersized culvert on private property, Schultz Fire, Arizona.

Rock Gabions: The gabions in the drainage ditch functioned for a short time but were then bypassed by flood flows, causing significant channel widening and transport of additional sediment (Figure 3). All of the gabions accumulated sediment on their upstream sides early in the storm event and then failed. Left side failures accounted for 56% (10). Only 11% (2) of the gabion failures occurred on the right side of the channel where the construction machinery was located (Figure 3A). An additional 33% (6) of the failures involved both sides of the gabion. The single factor contributing to the gabion failure was incomplete extension of the gabion wings into the left and right banks of the drainage ditch. The presence of phone, electricity, gas, water, and cable TV lines on both sides of the ditch restricted placement of the gabions.



Figure 3. Gabion construction along Campbell Avenue prior to the July 30, 2010, storm (A); and results during the storm event showing gabion failure and channel widening (B).

Figure 3B shows a phone line (black pipe downstream of a junction box) that was exposed by lateral widening of the Campbell ditch at a gabion. All the gabions had to be removed after the July 20th storm to reduce further channel widening and to make room for channel armoring with concrete. One section of the channel surface that was armored with concrete functioned successfully during the July 20th event. Gabion wire baskets can be used to reduce erosion from post-fire flood flows, but they need to be constructed correctly. Proper construction must include adequate gabion wing walls securely tied in 2-3 m beyond the channel slope breaks to prevent water from working around the wings. The center of the gabion should be at mid-channel and the lowest part of the structure. Channel flow velocities must also be considered. The Campbell Avenue channel has a slope of 4% so the average flow velocity was over 1 m s^{-1} with enough velocity to maintain hyperconcentrated streamflow. High flow velocities and the potential for structure failure were reasons why the Burned Area Emergency Response team (Robichaud et al. 2000) decided to not use channel structures like gabions above the Timberline area.

References

- Neary, D.G.; Ryan, K.C.; DeBano, L.F. (Editors) 2005 (Revised 2008). *Fire effects on soil and water*. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42, Volume 4: Fort Collins, CO. 250 p.
- Robichaud, P.R.; Beyers, J.L.; Neary, D.G. 2000. *Evaluating the effectiveness of post-fire rehabilitation treatments*. USDA Forest Service General Technical Report RMRS-GTR-63. Fort Collins, CO. 85 p.
- Schiechtl, H.M.; Stern, R. 1997. *Water bioengineering techniques: for watercourse, bank and shoreline protection*. John Wiley & Sons, New York. 193 p.



Effectiveness of two mulch treatments controlling soil erosion and water conservation

Celeste Coelho^{a*}, Sérgio Prats^a, Teresa Carvalho^a, Alexandra Pinheiro^a, António Ferreira^b, João Soares^a

^a Centro de Estudos do Ambiente e do Mar, Departamento de Ambiente e Ordenamento, Universidade de Aveiro, 3810-193 Aveiro (Portugal);

^b Centro de Estudos de Recursos Naturais, Ambiente e Sociedade, Escola Superior Agrária de Coimbra, Bencanta, 3040-316 Coimbra (Portugal).

* coelho@ua.pt

Key-words: Forest fires; Mulch; Soil Conservation.

Introduction

After a forest fire landscapes become altered and more susceptible to undesirable effects in ecosystems like the loss of sediments and surface runoff, but susceptibility will be greater following an intense rainfall event, especially if no vegetation is present (Cerdá, Doerr, 2008). In such cases, emergency interventions are needed to minimize fire impacts because they can offer some sort of protection.

If fire destroys the accumulated forest floor material and vegetation, expose soil to raindrop impact, and may originate water repellent conditions (Robichaud and Brown, 2005; Shakesby and Doerr, 2006).

Forest fires can affect hillslopes, channels and forest roads. Hillslope treatments are considered as the first line of defence against soil erosion allowing the reduction of surface runoff (Robichaud *et al.* 2000; Robichaud and Brown, 2005).

There are several techniques that may be used to this end but one of the most known is mulch. Mulch treatment consists in spreading organic material over the soil surface enabling interception raindrop; increasing roughness, which delays overland flow, and allows the infiltration of rain water during storms (Jordán *et al.* 2010). Mulch can also be provided naturally by the fall of leaves or needles, in case of conifer forests, but only if the severity of burn was low or moderate so the needles in canopy may fall covering the ground (Robichaud and Brown, 2005). When this happens there are less runoff and erosion than in areas affected by higher burned severity.

In newly burnt and unburnt pine and eucalyptus forest in Portugal, overland flow and soil losses were monitored to assess the impacts of the following post-fire treatments: application of different quantities of logging litter; rip-ploughing compared with minimum tillage prior to planting eucalyptus seedlings; and clearance of pine needles and vegetation. Eucalyptus logging litter reduced soil losses by up to 95 per cent. The impact of pine logging litter was equivocal, but removal of pine needles increased soil losses eleven fold (Shakesby *et al.* 1996).

Mulch treatments improved physical and chemical properties of Fluvisols under semi-arid conditions (Jordán *et al.*, 2010).

It is important to note that the performance of the treatment is dependent on time of application after fire and rainfall intensity, especially in the first year after fire, when erosion susceptibility is higher (Robichaud and Brown, 2005).



Objectives

The main goal was to assess the performance of two mulch treatments: chopped bark mulch and clear-cut material such as big stems, branches and corks as a mitigation technique of soil erosion and runoff, by evaluating the soil characteristics before and two years after the treatment application.

Methodology

The case study area is located in Pessegueiro do Vouga parish, Municipality of Sever do Vouga, Portugal. The main land use is forest, mostly occupied by *Pinus pinaster* and more recently, *Eucalyptus globulus*. This area burned in August of 2007 and treatments were applied in December 2007. Two sites were selected for treatment: a Pine (*Pinus pinaster* Aiton) and an Eucalyptus (*Eucalyptus globulus* Labill).

12 bounded runoff plots (2x8m) were installed: 8 in Eucalyptus site and 4 in Pine site. Each one was equipped with one gerlach trap, one tipping bucket and three collecting tanks.

The treatment selection was made based on the characteristics of the burned study area: one intervention treatment for Pine site (Treatment 1) and one emergency treatment for the Eucalyptus site (Treatment 2). Treatment was made randomly in both sites. At the Pine site post-fire clearcutting debris as stems, barks and leafs was applied in two plots and the other two remained as control (no treatment). At the Eucalyptus site chopped bark eucalypt mulch was applied in four plots and another four were used as control.

Treatment 1 was implemented in a i) slope of 25°; ii) fire intensity was moderate and iii) ratio of application 1,75 Kg/m², corresponding to 80% cover in each plot. Treatment 2 was implemented in a i) slope of 30°; ii) fire intensity was high and iii) application ratio was 0,87 kg/m² corresponding to 70% cover for each plot.

Several parameters were measured in the field, in fortnightly or week intervals, such as i) runoff water ii) sediment loss and iii) soil surface cover. Organic matter content was estimated in the laboratory.

Results and conclusions

The main results related to i) overland flow; ii) soil erosion; iii) organic matter content and iv) soil cover are described below.

i) Overland Flow

At the Eucalyptus site all plots showed very similar runoff response to rainfall, before treatment, where overland flow increased with rainfall amount. After treatment, there was a significant reduction in overland flow in treated plots, two times less than in control plots.

At the Pine site no significant difference in overland flow response, between treated and control plots, before and after the treatment application.

ii) Soil Loss

Soil losses between plots groups, before treatment, were homogeneous, although slightly lower in Pine site comparing to Eucalyptus site.

After treatment in Eucalyptus site treated plots showed a reduction in sediment loss production compared with the control group.

For Pine site treatment did not interfere with sediment production. Soil losses remained very low both for treated and untreated plots.

iii) Organic Matter Content

In Eucalyptus site organic matter content both in control and treated plots is very close. Organic matter percentage in treated plots accounted for more than 50%, and even reached 70% of the total sediment loss. These values may be explained by the presence of ashes and death vegetal material on top of the plots. However treated plots showed higher organic matter amount than control plots.

In Pine site treated plots most of the organic matter content remained below 50% of sediment loss but in control plots organic matter percentage below and above 50% was very similar through time. This can be explained by a high percentage of litter present that difficult the sediment transport by water.

iv) Soil Cover

In Eucalyptus site the presence of stones was always high, ashes, shrubs and ground level vegetation had the lowest expression even two years after fire.

It became clear that when the presence of stones was higher all the other elements, like litter and ashes, in soil decreased. This may be explained by runoff that has a decisive role in dragging lighten loose material from soil surface. When litter increased stone amount decreased due to the protective ability of litter in minimizing entrainment.

In Pine site the amount of litter, ashes and stones was always higher than any other type of soil cover. There was some ash fluctuation in this site: increasing and decreasing along the monitoring period depending on transect location. Ashes are a very light and thin material that can either be transported by water or wind to downstream locations. For this reason there was some ash accumulation in small depressions along hillside length causing the increase or decrease in ash percentage manifested in the conducted transects.

Ground level vegetation and shrubs presence was very poor and bare soil percentage was also very low revealing that most of the burned area had some kind of cover most of the time. Bare soil increased when the other cover types (such as litter and stones) decreased, as expected. Vegetation did not develop leaving soil uncovered and susceptible to water erosion by runoff.

Main results indicate that:

- i) Chopped bark eucalypt mulch reduced soil loss as well as runoff generation;
- ii) Treatment with chopped bark reduced soil loss above 80%;
- iii) Organic matter loss increased with rainfall amount but chopped bark eucalypt had contributed to its reduction. In Pine site litter had that role, minimizing organic matter loss;
- iv) Two years after forest fire there is still low vegetation in place, with stones the more expressive cover in Eucalyptus site and litter, in the Pine site;
- v) Chopped bark showed clear advantage over stems, bark and leaf mulch.

Acknowledgment

The research described in this paper was developed under several projects, namely on the framework of RECOVER - “Estratégias de remediação de solos imediatamente após incêndios florestais” (PTDC/AGR-AAM/73350/2006), funded by the Foundation for Science and Technology (FCT) of Portugal, and RAA - “Recuperação de Áreas Ardidas” Project, founded by the Permanent Forest Fund (IFAP-FFP).



References

- Cerdá, A., Doerr, S.H. (2008) The effect of ash and needle cover on surface runoff and erosion in the immediate post-fire period. *Catena* 74, 256-263.
- Jordán, A., Zavala, L.M., Gil, J. (2010) Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. *Catena* 81,77-85.
- Robichaud, P. R.; Brown, R. E. (2005) Postfire Rehabilitation Treatments: Are We Learning What Works? Proceedings of the 2005 Watershed Management Conference. July 19-22, Williamsburg, VA. 13 p.
- Robichaud, Peter R.; Beyers, Jan L.; Neary, Daniel G. (2000) Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.
- Shakesby, R.A., Boakes D. J., Coelho, C.O.A., Gonçalves, A.J.B., Walsh, R.P.D. (1996) Limiting the soil degradational impacts of wildfire in pine and eucalyptus forests in Portugal: A comparison of alternative post-fire management practices, *Applied Geography*, 16(4) 337-355.
- Shakesby, R.A. and Doerr, S.H. (2006) Wildfire as a hydrological and geomorphological agent. *Earth-Science Reviews* 74, 269-307.

Preliminary data of soil properties and soil erosion following a wildfire and different post-fire soil stabilization treatments in Laza (NW Spain)

M. Díaz-Raviña^{a*}, A. Martín^a, A. Barreiro^a, A. Lombao^a, M.J. Gómez^a, A. Couto-Vázquez^a, L. Iglesias^b, F. Díaz-Fierros^b, T. Carballas^a

^a Departamento de Bioquímica del Suelo, Instituto de Investigaciones Agrobiológicas de Galicia (CSIC), Apartado 122, 15780 Santiago de Compostela (Spain);

^b Departamento de Edafología y Química Agrícola, Facultad de Farmacia, Universidad de Santiago de Compostela, 15782 Santiago de Compostela (Spain).

* mdiazr@iiag.csic.es

Key-words: fire, physical and chemical properties, mulching, seeding, soil erosion.

Introduction

Forest fires are common events in Galicia (N.W. Spain) causing the destruction of vegetation and soil degradation (Carballas et al., 2009), which produce enormous irreversible losses of soil and nutrients due to runoff and erosion processes (Díaz-Fierros et al., 1990; Soto and Díaz-Fierros, 1998; Vega et al., 2005). It is well-known that post-fire stabilisation treatments applied to hillslopes can reduce erosion (Bautista et al., 1996; Badía and Martí, 2000; Robichaud, 2009); however, these techniques have not been implemented in this temperate humid zone.

Objective

The aim of the present study was to evaluate the impact of fire and different post-fire stabilisation treatments on soil quality of a shrubland ecosystem in the N.W. Spain as well as to determine their efficacy to control post-fire erosion.

Methodology

The study was performed in a shrubland ecosystem located in Laza (Ourense, NW Spain) affected by a wildfire on September 2010 (1700 ha of surface were burned) and highly susceptible to soil erosion after the fire event (slope 30-50%). Four treatments were established by triplicate (3 x 20 m plots): unburnt control soil (U), burnt soil (B), burnt soil with rye seeds at a rate of 10 g m⁻² (B+S), burnt soil with 250 g m⁻² of straw mulch (B+M). Soil samples were taken from the top layer (0-2 cm) immediately and 4 months after the wildfire. The following soil properties were monitored in the fraction < 2 mm: granulometric composition and texture, moisture content and water retention capacity, aggregate stability, soil water repellence, pH (in water and KCl), electric conductivity and organic matter content. The methods described by Guitián-Ojea and Carballas (1976) were utilized to determine most properties analyzed. Soil water repellence was assessed using the molarity of ethanol droplet (MED) test (Roy and McGill, 2002) and the aggregate stability following the procedure described by Kemper and Rosenau (1986). Soil erosion was measured in the burned plots at 3 sampling times (1, 2 and 3 months after the wildfire when important rain events occurred) using collectors for runoff (Soto and Díaz-Fierros, 1998).

Results

The physico-chemical and chemical properties obtained in the 0-2 cm layer of the different soil treatments immediately and 4 months after wildfire are showed in Table 1. The results showed that most parameters analysed experienced immediate fire induced

changes, the comparison of values obtained for unburnt and burnt soils showing, among other changes, that immediately after fire pH increased 0.5 units and electric conductivity 6.4 times whereas organic matter and water field capacity were reduced considerably (35-66%). These effects were attenuated with time but for some properties they lasted for 4 months.

Table 1. Soil properties in the different soil treatments immediately and 4 months after the wildfire (mean values $\pm$ SD of three field replicates). Treatments: U, unburned soil; B, burnt soil; B+S, burnt soil plus seeding; B+M, burnt soil plus straw addition.

Soil property	Time (months)	Soil treatments			
		U	B	B+S	B+M
Moisture (%)	0	22.5 $\pm$ 0.7	9.3 $\pm$ 2.1	7.7 $\pm$ 1.8	8.5 $\pm$ 1.1
	4	44.9 $\pm$ 1.4	32.4 $\pm$ 0.7	34.4 $\pm$ 3.9	32.1 $\pm$ 2.3
Sand (%)	0	18.1 $\pm$ 1.1	28.4 $\pm$ 0.6	27.9 $\pm$ 2.2	28.1 $\pm$ 0.3
Lime (%)	0	60.7 $\pm$ 1.4	55.1 $\pm$ 0.4	55.0 $\pm$ 0.8	55.0 $\pm$ 0.1
Clay (%)	0	21.2 $\pm$ 1.7	16.5 $\pm$ 1.1	17.2 $\pm$ 1.5	16.9 $\pm$ 0.5
Aggregate stability (%)	0	94 $\pm$ 2.0	95 $\pm$ 2	96 $\pm$ 1	91 $\pm$ 1
Water repellence	0	Very severe	Very severe	Very severe	Very severe
Water field capacity (g water kg ⁻¹)	0	899 $\pm$ 6	603 $\pm$ 7	577 $\pm$ 5	590 $\pm$ 18
	4	924 $\pm$ 3	612 $\pm$ 3	679 $\pm$ 9	623 $\pm$ 1
pH _{water}	0	3.67 $\pm$ 0.05	4.15 $\pm$ 0.0	4.12 $\pm$ 0.01	4.13 $\pm$ 0.01
	4	3.94 $\pm$ 0.01	4.48 $\pm$ 0.01	4.46 $\pm$ 0.01	4.55 $\pm$ 0.01
pH _{KCl}	0	2.81 $\pm$ 0.01	3.19 $\pm$ 0.00	3.18 $\pm$ 0.00	3.18 $\pm$ 0.01
	4	2.80 $\pm$ 0.00	3.06 $\pm$ 0.00	3.07 $\pm$ 0.00	3.14 $\pm$ 0.00
Electric conductivity (μ S cm ⁻¹)	0	16 $\pm$ 1	102 $\pm$ 10	102 $\pm$ 12	102 $\pm$ 9
	4	30 $\pm$ 5	28 $\pm$ 3	29 $\pm$ 0	38 $\pm$ 7
Organic matter (g kg ⁻¹)	0	261 $\pm$ 12	93 $\pm$ 26	83 $\pm$ 19	88 $\pm$ 7
	4	228 $\pm$ 9	176 $\pm$ 5	189 $\pm$ 14	184 $\pm$ 20

The soil losses due to wildfire are showed in Table 2 and Figure 1. Sediments data indicated that in the short-term mulching treatment was the most effective to control post-fire erosion since soil losses to respect to burnt control were reduced by 82% and 72% after the first and the second rain events, respectively, whereas seeding slightly reduced soil losses only after the second rain event. Over a 3-month period the mean sediment yield from the untreated plots was reduced by 37-89% when post-stabilisation treatments were applied, the highest effectiveness being observed for mulching (Fig. 1). The results also seem to indicate that the sediment composition was affected by mulching treatment (data not showed).

Table 2. Sediments yield during the first three months following wildfire and treatment application (mean values $\pm$ SD of three field replicates). Treatments: U, unburned soil; B, burnt soil; B+S, burnt soil plus seeding; B+M, burnt soil plus straw addition.

Soil treatment	Sampling time	Sediment yield (kg ha ⁻¹)
B	1	54 $\pm$ 12
	2	234 $\pm$ 75
	3	731 $\pm$ 404
B+S	1	62 $\pm$ 29
	2	155 $\pm$ 90
	3	422 $\pm$ 133
B+M	1	10 $\pm$ 7
	2	62 $\pm$ 80
	3	40 $\pm$ 36

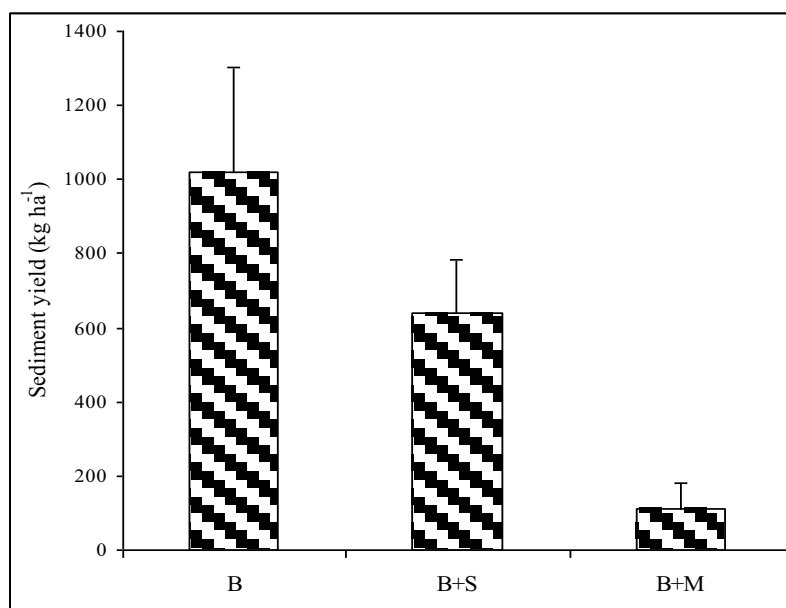


Figure 1. Cumulative sediments yield during the first three months following wildfire and treatment application (Mean values $\pm$ SE of three field replicates). Treatments: U, unburned soil; B, burnt soil; B+S, burnt soil plus seeding; B+M, burnt soil plus straw addition.

Conclusions

The results clearly showed that: a) wildfire affected drastically most physico-chemical and chemical soil properties analyzed and b) mulching was the most effective treatment in reducing sediments yield over the whole three months period after the wildfire.

Acknowledgements. This study was supported by the Consellería de Medio Rural de la Xunta de Galicia (08MRU002400PR) and by the Ministerio de Ciencia e Innovación (AGL2008-02823), Spain.

References

- Badía, D., Martí, C. 2000. Seeding and mulching treatments as conservation measures of two burned soils in the central Ebro valley, NE Spain. *Arid Soil Research Rehabilitation* 13: 219-232.
- Bautista, S., Bellot, J., Vallejo, V.R. 1996. Mulching treatment for postfire soil conservation in a semiarid ecosystem. *Arid Soil Research Rehabilitation* 10: 235-242.
- Carballas, T., Martín, A., Díaz-Raviña, M. 2009. Efecto de los incendios forestales sobre los suelos de Galicia. In: *Efecto de los incendios forestales sobre los suelos en España* (Artemi Cerdá, Jorge Mataix-Solera, eds.). Cátedra Divulgación de la Ciencia. Universitat de València, Cap. 3.6, p. 269-301.
- Certini, G. 2005. Effects of fire on properties of forest soils: a review. *Oecologie* 143: 1-10.
- Díaz-Fierros, F., Benito, E., Vega, J.A., Castelao, A., Soto, B., Pérez, R., Taboada, T. 1990. Solute loss and soil erosion in burnt soil from Galicia (NW Spain). In: *Fire in ecosystems dynamics. Mediterranean and Northern Perspectives* (F.G. Goldammer, M.J. Jenkins, eds.), SPB Goldammer, The Hague, p. 103-106.
- Gutián-Ojea, F., Carballas, T. 1976. *Técnicas de Análisis de Suelos*. Editorial Pico Sacro, Santiago de Compostela, Spain.



- Kemper, W.D., Rosenau, R.C. 1986. Aggregate stability and size distribution. In: A.Klute (ed.), *Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods*. ASA-SSSA, Madison, p. 425-442.
- Robichaud, P.R. 2009. Post-fire stabilization and rehabilitation. In: *Fire effects on soils and restoration strategies. Vol. 5 Land reconstruction and management* (A. Cerdá, P.R. Robichaud, eds.). Science Publishers, Enfield, USA, p. 299-320.
- Roy, J.L., McGill, W.B. 2002. Assessing soil water repellency using the molarity of ethanol droplet (MED) test. *Soil Science* 167: 83-97.
- Soto, B., Díaz-Fierros, F. 1998. Runoff and soil erosion from areas of burnt scrub: comparison of experimental results with those predicted by WEPP model. *Catena* 31: 257-270.
- Vega, J.A., Fernández, C., Fonturbel, T. 2005. Throughfall, runoff and soil erosion after prescribed burning in gorse shrubland in Galicia (NW Spain). *Land Degradation and Development* 16: 37-51.



Geomorphic aspects of post-fire soil erosion – Schultz Fire 2010

Ann Youberg^{a*}, Karen A. Koestner^b, Daniel G. Neary^b, Peter E. Koestner^c

^a Arizona Geological Survey, 416 Congress Street, Suite 100, Tucson, Arizona 85701 (USA);

^b USDA Forest Service, Rocky Mountain Research Station, 2500 Pine Knoll Drive, Flagstaff, Arizona 86001 (USA);

^c USDA Forest Service, Rocky Mountain Research Station, Tonto National Forest, 2324 East McDowell Road, Phoenix, AZ 85006 (USA).

* ann.youberg@azgs.az.gov

Key-words: Wildfire; soil erosion; geomorphology; debris flows; Schultz Fire.

Introduction

The summer of 2010 brought wildfires and near record monsoon rains to northern Arizona, USA, which generated debris flows and floods that caused extensive damage. The human-caused Schultz Fire on the Coconino National Forest northeast of Flagstaff was the largest wildfire in Arizona during 2010, burning 6,100 ha between June 20th and 30th. Ignited by an abandoned campfire, high winds drove the fire over approximately 60% of the total area burned during the first 12 hours (U.S. Forest Service, 2010). The majority of the area burned at moderate (27%) or high (40%) severity across slopes of 30% to over 100%, through forests of ponderosa pine and mixed conifer. Nine of 11 watersheds were almost completely burned, with areas of high burn severity covering more than 50% in 3 watersheds and more than 70% in 2 others.

The San Francisco Peaks are a remnant stratovolcano that rises nearly 1,500 m above the alluvial fans that surround it. Within the burned area, geomorphic zones include east-facing, steep, upper mountain slopes flanked by incised Pleistocene fan deposits of the upper piedmont. Immediately east of the burned area, unincised, coalescing Holocene alluvial fans have been heavily modified by residential developments. Prior to the fire, only a few well-defined channels existed on the steep mountain slopes and upper piedmont. Many drainages in these areas consisted of low swales located between thickly forested ridges or on broad Pleistocene fan heads. Gravel soils, derived from mixed igneous rocks and cinders, were quite permeable with high infiltration rates (51-152 mm hr⁻¹) under pre-fire conditions (U.S. Forest Service, 2010). East of the fan heads, swales transitioned to channels confined several meters below the Pleistocene piedmont surface. Near the eastern forest boundary, flows from the channels emerge onto the unincised Holocene fans with residential developments. Upper mountain slopes are the source for high-energy water, coarse sediments, and woody material. Ephemeral swales and channels on the steep mountain basin have slopes that can exceed 30%, while well-defined ephemeral lower-piedmont channels slope up to 5-7%.

In this region, summer thunderstorms tend to develop preferentially over mountains due to orographic lifting. The Schultz Fire was followed by rains from the 4th wettest monsoon on record in Flagstaff. The largest storm occurred on 20 July and produced 45 mm of rain in 45 minutes, with a peak 10-minute intensity of 24 mm. This short duration, high-intensity precipitation event produced debris flows from numerous small, steep basins on the upper mountain slopes. Floods and debris flows eroded former swales into channels up to 4 m deep. Rills and gullies formed on the hillslopes removing the O horizon (10-30 cm). A second high-intensity storm on 16 August delivered 27 mm of rain in 46 minutes, with a peak 10-minute intensity of 15 mm, producing more debris flows. Numerous other storms from July through October produced sediment-laden flood flows. Erosion from



debris flows, floods, rills and gullies removed a substantial amount of soil from the burned area. While debris flows were confined to forest lands, multiple sediment and ash-laden floods caused extensive damage to residential homes, property and infrastructure up to 10 km from the burn, east of the forest boundary.

Objectives

Wildfires can dramatically change infiltration and runoff responses in soils, especially on steep slopes (DeBano et al. 1998, Neary et al. 2008), significantly increasing runoff and erosion. Post-fire sediment-laden flood flows occur more frequently than debris flows, but debris flows can be significantly more destructive than floods. Evaluating the potential for debris flows following a fire is an important aspect of post-fire hazard assessments. Factors affecting the occurrence of debris flows include burn severity, geology, catchment size and gradient, storm characteristics, especially short-duration, high-intensity precipitation, and storm movement through the basin (Cannon et al., 2004; Cannon et al., 2000; Wohl and Pearthree, 1991). The objective of this study is to assess factors affecting the occurrence of post-fire debris flows in the small, steep upper basins of the burned watersheds in order to identify those factors more likely to influence debris-flow occurrence, thus providing better information for assessing post-fire geologic hazards in Arizona.

Methodology

There were two components to this work; a field study and a GIS analysis. The field study, focused on the southern half of the fire, consisted of four north-south transects across five burned watersheds and west-east traverses in the main channels of three of those watersheds. Deposit characteristics were used to determine the occurrence of debris flows or flood flows, and to document the downstream extent of debris flows.

Channel profiles and basin morphology were derived for 28 small, steep upper basins where debris flows and floods were generated using GIS software, tools and methods (Figure 1). Basin outlets were identified using channel profile gradient changes, field observations, location of deposits, and analysis of aerial photographs flown in October, 2010, at a scale of 1:12,000. Basins were classified based on evidence of the occurrence of debris flows or flood flows. All debris-flow basins (Figure 1, orange basins) also had flood flows, but basins classified as flood (Figure 1, blue basins) only experienced flood flows. Spatial analyses were conducted to determine proportional areas of burn severity in each basin, and to assess the influence of the different soils in each basin. Soils data were extracted from the GIS-based Terrestrial Ecosystem Survey (TES; <http://alic.arid.arizona.edu/tes/units.asp>) mapped by the Coconino National Forest. TES map units are delineated based on soils, landscape position and vegetation.

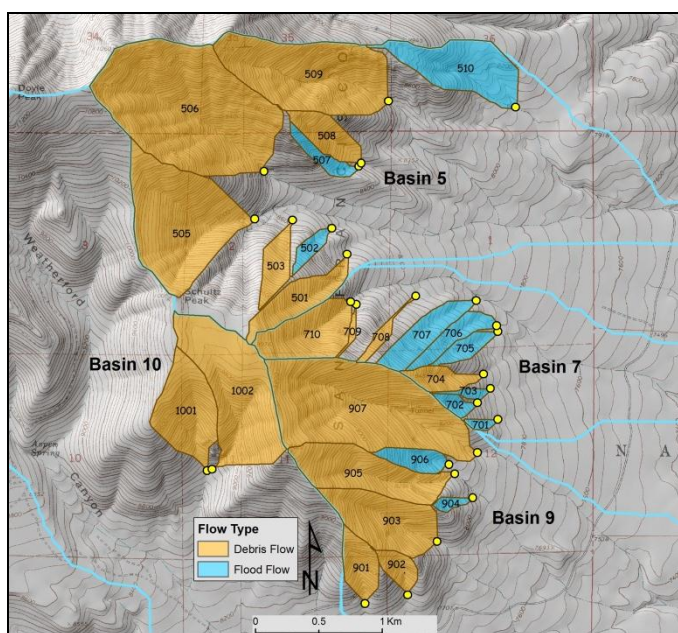


Figure 1. Small, steep basins mapped according to flow types. Basins with evidence of debris flows, along with floods, are in orange. Basins with evidence of only flood flows are in blue. Yellow dots represent locations of basin outlets.

Results and Conclusions

Flows in 28 basins were classified as producing post-fire debris flows, debris flows in addition to floods, or flood flows only. Seventeen of 28 basins were completely burned (100%), while total burned areas in the other 11 basins ranged from 88% to 99%. The percent of the basins burned at high severity ranged from 37-100%; three basins were completely burned at high severity. The basin with the lowest percent area burned produced debris flows while one basin that was completely burned (100%) produced only flood flows.

Watershed area for flood-flow basins ranged from 0.02-0.34 km² with an average area of 0.08 km². Debris-flow basin areas ranged from 0.01-1.11 km² with an average area of 0.34 km². Mean basin slopes varied from 35-52% with an average of 45% for flood-flow basins, while debris-flow basins varied from 42-64% with an average of 57%. The average channel slope ranged from 25-44% with an average of 34% for flood-flow basins, and 26-48% with an average of 38% for debris-flow basins. Although there is substantial overlap in many of the morphologic characteristics of these basins, the debris-flow producing basins were generally larger and steeper than the flood-flow only basins.

Three TES map units (613, 785, and 790) composed the majority of the soils within the basins. The soils are well-graded gravels (GW) to silty, sandy gravels (GM) derived from mixed igneous rocks and cinders. These soils were quite permeable with high infiltration rates under pre-fire conditions. Erosion hazards for these three units are classified as severe. Mass wasting hazards are classified as moderate to severe. Soil losses due to sheet and rill erosion are estimated at 3 to 13 Mg ha⁻¹ yr⁻¹ under pre-fire conditions (<http://alic.arid.arizona.edu/tes/units.asp>). Under post-disturbance conditions these rates are expected to increase 8-19 times, with estimates ranging from 52 to 97 Mg ha⁻¹ yr⁻¹. TES unit 613 has the largest post-disturbance soil loss estimates of the 3 units. Soils from this unit covers the majority of mid to lower hillslopes for all basins, and entire hillslopes for 5 of 11 flood-flow basins and 3 of 17 debris-flow basins. TES units 785 and 790 are more limited in extent and compose soils in the headwaters and upper slopes of only a



few basins. Unit 785 is found in 3 flood-flow and 10 debris-flow basins, while unit 790 is found only in 3 debris-flow basins. Although the characteristics between these map units vary somewhat, and all are composed of highly erodible soils in a post-disturbance environment, post-fire debris flows tend to initiate high in channels and close to ridge tops. It is likely that TES units 785 and 790 played a larger role in debris-flow generation than TES unit 613, however additional analysis is required to understand this relationship. Changes to watershed soils and hydrologic characteristics can be quite dramatic following a wildfire. The Schultz Fire was a high impact fire dominated by moderate to high burn severity across steep densely forested slopes that were completely, or nearly completely, burned. In Arizona, the wildfire season is immediately followed by monsoon precipitation. Short-duration, high-intensity rainfall on severely burned basins can result in a dramatic amount of geomorphic work and landscape changes in a short period of time. A significant amount of soil was removed from the hillslopes and channels within the Schultz Fire burn area during the 2010 monsoon, and elevated sediment delivery and movement is likely to continue for several years. Research will continue on the Schulz Fire to document landscape changes and ecosystem recovery.

References

- Cannon, S.H. 2001. *Debris-flow generation from recently burned watersheds*. Environmental and Engineering Geoscience. 7: 321-341.
- Cannon, S.H.; Rea, A.; Parrett, C.; Pierce, K.L.; Gartner, J.E. 2004. *Tools and methodologies for the prediction of post-wildfire debris-flow activity and hazard delineation*: U. S. Geological Survey. Reston, VA, United States., 18 p.
- DeBano, L.F.; Neary, D.G.; Ffolliott, P.F. 1998. *Fire's effects on ecosystems*. John Wiley & Sons, New York. 333 p.
- Neary, D.G.; Ryan, K.C.; DeBano, L.F. (Editors) 2005 (Revised 2008). *Fire effects on soil and water*. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42, Volume 4: Fort Collins, CO. 250 p.
- U.S. Forest Service. 2010. *Burned Area Emergency Response Report, July 8, 2010*. Coconino National Forest, Flagstaff, Arizona. 167 p.
- Wohl, E.E.; Pearthree, P.A. 1991. *Debris flows as geomorphic agents in the Huachuca Mountains of southeastern Arizona*. Geomorphology 4: 273-292.



Soil properties in burned and unburned Mediterranean shrublands of Montesinho Natural Park, Northeast Portugal

Felícia Fonseca^{a*}, Micaela Leite^b, Tomás de Figueiredo^a

^a Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança (ESAB/IPB), Apartado 1172, 5301-855 Bragança, Portugal.

^b Master degree student

* ffonseca@ipb.pt

Key-words: Fire; Shrubs areas; Soil properties.

Introduction

Large areas of shrubland are being destroyed by fire every year in the Mediterranean region, where this is a most relevant environmental problem. Anthropogenic fire in shrublands for obtain better pastures for cattle, is relatively common practice in the Montesinho Natural Park (PNM), Northeast Portugal. During burning, plant cover and litter layers are consumed, and the mineral soil is heated, resulting in changes to physical, chemical, mineralogical, and biological soil properties (Hubbert et al., 2006). The combination of combustion and heat transfer produces temperature gradients in soil (Certini, 2005). The extent and duration of the fire effects on soil properties depend on fire behavior, specially related to fire severity, as well as the climatic conditions, mainly to the characteristics of subsequent rainfall events (De Luís et al., 2001; Certini, 2005). A direct effect of fire on soil surface is the creation a continuous film water-repellent which reduces permeability and increase runoff (Imeson et al. 1992). In Mediterranean ecosystems, where the torrential rainfall events are frequent in autumn and winter (from October to March), this is a critical period, when the soil susceptibility to water erosion processes is increased after a fire (Andreu et al., 2001). The frequency increase of fires and intense rainfalls have a larger potential to reduce soil fertility by erosion and nutrient losses (Thomas et al., 1999).

The effect of fire on the organic matter content is deeply variable, and depends on several factors including fire type, intensity, duration and even slope (González-Pérez et al., 2004). Depending on fire severity, the organic matter can suffer slight distillation, charring, or complete oxidation (Certini, 2005). Fire induced changes to cycles of soil nutrients (Certini, 2005) and the majority of nutrient elements released from burned vegetation are in forms which are easily dissolved, with exception of soil phosphorus that increased the insolubility after fire. In sum, fires caused modifications on physical and chemical soil properties that, in turn, affect soil water permeability, capacity to absorb rainfall, support the various life forms and resistance to erosion and leaching processes.

Objectives

The aim of this study was to compare physical and chemical soil properties in burned and unburned shrubs areas under Mediterranean climate conditions, 6 months after the fire.

Methodology

The study site was selected on the basis of having adjacent burned and unburned shrubs areas on similar climatic, soil conditions and species composition in Montesinho Natural Park. The shrub vegetation consisted mainly of *Cytisus multiflorus* and *Ulex europeus*. Climate is Mediterranean, with 12° C mean annual temperature and 740 mm mean annual

rainfall, concentrated from October to March (INMG, 1991). The fire occurred in early October 2009 and the soil samples were collected in March 2010. During this period the precipitation was 1384 mm and in October was 151 mm (<http://esa.ipb.pt/clima.php>). Thus, the properties of ash and soil may have been strongly modified by erosion and leaching (Gimeno-García et al., 2007).

In burned and unburned areas, disturbed soil samples were collected at depths 0-5, 5-10, 10-15, 15-20 and 20-30 cm ($n = 8$ in each case), to assess organic matter, nutrients concentration, soil pH and soil texture. Bulk density and permeability were determined in undisturbed samples, collected in 100 cm³ cylinders (bulk density in the same depths above referred and permeability in the 0-5 cm layer). Porosity was calculated from bulk density assuming a particle of 2.65 g cm⁻³ (Ekinici, 2006; Hubbert et al., 2006). Burn severity was estimated qualitatively from post-fire fuel size diameter and degree of litter consumption (Hubbert et al., 2006; Are et al., 2009).

Results and Conclusions

After the fire, increases in average bulk density are observed, ranging from 5% to 10% for layers 20-30 cm and 0-5 cm respectively, with a corresponding decrease in porosity and permeability (Table 1). Similar results were obtained by Hubbert et al. (2006).

Table 1. Soil bulk density, total porosity and permeability ($n = 8$ in each case) before and after burning (mean $\pm$ standard deviation)

Depth (cm)	Burned			Unburned		
	Bulk density (g cm ⁻³)	Total porosity (%)	Permeability (cm h ⁻¹)	Bulk density (g cm ⁻³)	Total porosity (%)	Permeability (cm h ⁻¹)
0-5	1.30 $\pm$ 0.22 ^a	51.05 $\pm$ 8.19 ^a	47.12 $\pm$ 24.52 ^a	1.17 $\pm$ 0.22 ^a	55.76 $\pm$ 6.29 ^a	51.68 $\pm$ 34.87 ^a
5-10	1.30 $\pm$ 0.27 ^a	50.80 $\pm$ 4.90 ^a		1.21 $\pm$ 0.13 ^a	54.29 $\pm$ 10.25 ^a	
10-15	1.41 $\pm$ 0.14 ^a	46.84 $\pm$ 7.02 ^a		1.29 $\pm$ 0.19 ^a	51.16 $\pm$ 5.12 ^a	
15-20	1.35 $\pm$ 0.11 ^a	49.03 $\pm$ 8.75 ^a		1.27 $\pm$ 0.23 ^a	52.23 $\pm$ 4.25 ^a	
20-30	1.42 $\pm$ 0.14 ^a	46.58 $\pm$ 4.20 ^a		1.35 $\pm$ 0.11 ^a	49.11 $\pm$ 5.12 ^a	

For each line and variable, different letters indicate significant differences between burned and unburned areas ($P < 0.05$)

The soil textural classes were not affected by fire. However, there were slight changes in silt and clay contents, which in general, varied in opposite directions, with gains of silt and losses of clay in soil (Table 2). The decrease in clay content suggested that there was formation of stable aggregates of finer particles into larger silt-size particles, which resulted in an increase of silt after burning (Hubbert et al., 2006; Are et al. 2009). Also, González-Pérez et al. (2004) referred that soils tend to coarser textures after fire.

Table 2. Effects of burning on particle-size distribution (mean $\pm$ standard deviation)

Depth (cm)	Burned				Unburned			
	Sand	Silt	Clay	Textural classes	Sand	Silt	Clay	Textural classes
	(%)				(%)			
0-5	44.0 $\pm$ 3.4 ^a	34.8 $\pm$ 1.9 ^b	21.2 $\pm$ 2.7 ^a	Loam	48.8 $\pm$ 2.8 ^b	30.5 $\pm$ 2.3 ^a	20.7 $\pm$ 2.3 ^a	Loam
5-20	44.7 $\pm$ 3.6 ^a	34.5 $\pm$ 2.7 ^a	20.8 $\pm$ 1.4 ^b	Loam	45.4 $\pm$ 3.1 ^a	31.9 $\pm$ 2.5 ^a	22.7 $\pm$ 2.0 ^a	Loam
20-30	40.6 $\pm$ 2.5 ^a	39.2 $\pm$ 3.5 ^b	20.2 $\pm$ 5.2 ^a	Loam	47 $\pm$ 2.3 ^b	30.6 $\pm$ 1.8 ^a	21.9 $\pm$ 2.3 ^a	Loam

For each line and variable, different letters indicate significant differences between burned and unburned areas ($P < 0.05$)

Results concerning soil chemical properties as affected by fire are presented in Table 3. Burning leads to a decrease in sum exchange bases with reflexes in soil pH values. Soil

pH decreased in all layers after fire, but this decrease is more visible in 0-5 cm. Decreases in pH after the fire were also reported by others authors (Rashid, 1987; Franco-Vizcaíno and Sosa-Ramirez, 1997). The temperatures reached by fire were low, indicated by incomplete combustion of the fuel resulting in lower release of bases. Giovannini and Lucchesi (1997) observed that the soil pH decreased at temperatures up to 395°C, followed by a clear increase at higher temperatures. In deep layers the pH values remain similar to the unburned area meaning a progressive increase with time apparently due to the infiltration of dissolved salts (Rashid, 1987).

Soil organic matter (SOM) increased in the first 15 cm, decreasing in deeper layers. In field observations it was visible huge quantities of charred materials deposited on surface soil. After a moderate fire, an increase of SOM is usually observed suggesting a substantial inclusion of charred plant materials (González-Pérez et al., 2004) and the presence of residual ashes (Pardini et al., 2004). In soil layer 0-5 cm, a coupled increase in SOM and in total N content was found. Although, burning usually results in losses of N by volatilization (Wienhold and Klemmedson, 1992), the frequent entrance in the burnt areas of N-fixer species (Johnson and Curtis, 2001), can explain the high increase of total N in upper layer (0-5 cm).

Phosphorus extractable decreased in all layers after the fire, while potassium increased, with exception of the first layer (0-5 cm). Despite effect of fire in phosphorus solubility decrease (Rashid, 1987) this and other nutrients are generally deposited on the soil in ash, where they are susceptible to loss by erosion and leaching (Wienhold and Klemmedson, 1992). As heavy rains fell, summing a total of 1384 mm from the moment which fire occurred (October 2009) to the moment of soil sampling (March 2010), soil erosion and leaching can have been relevant and the accumulation of some elements can have occurred within the soil profile.

Table 3. Chemical soil properties in burned and unburned shrublands six months after burning (mean $\pm$ standard deviation)

Depth (cm)	pH (H ₂ O)	SOM (%)	Total N (%)	Extractable P (mg kg ⁻¹)	Extractable K (mg kg ⁻¹)	Sum exchange bases (cmol (+) kg ⁻¹)
Burned						
0-5	4.78 $\pm$ 0.32 ^a	7.55 $\pm$ 3.36 ^b	0.12 $\pm$ 0.14 ^b	14.25 $\pm$ 4.90 ^a	147.13 $\pm$ 39.49 ^a	3.92 $\pm$ 0.78 ^a
5-10	4.69 $\pm$ 0.27 ^a	4.03 $\pm$ 0.84 ^a	0.06 $\pm$ 0.09 ^a	9.17 $\pm$ 7.39 ^a	118.88 $\pm$ 25.12 ^a	3.10 $\pm$ 0.42 ^a
10-15	4.69 $\pm$ 0.28 ^a	3.28 $\pm$ 0.46 ^a	0.02 $\pm$ 0.02 ^a	8.23 $\pm$ 7.12 ^a	112.63 $\pm$ 20.74 ^a	2.96 $\pm$ 0.26 ^a
15-20	4.74 $\pm$ 0.28 ^a	2.05 $\pm$ 0.79 ^a	0.01 $\pm$ 0.01 ^a	10.67 $\pm$ 8.91 ^a	102.88 $\pm$ 17.99 ^a	3.03 $\pm$ 0.27 ^b
20-30	4.70 $\pm$ 0.23 ^a	1.25 $\pm$ 0.97 ^a	0.01 $\pm$ 0.01 ^a	8.03 $\pm$ 4.52 ^a	83.13 $\pm$ 8.34 ^a	2.88 $\pm$ 0.26 ^a
Unburned						
0-5	5.18 $\pm$ 0.38 ^b	4.84 $\pm$ 0.54 ^a	0.03 $\pm$ 0.02 ^a	34.26 $\pm$ 25.18 ^b	164.88 $\pm$ 50.67 ^a	4.50 $\pm$ 0.59 ^a
5-10	4.85 $\pm$ 0.18 ^a	3.40 $\pm$ 0.62 ^a	0.14 $\pm$ 0.18 ^b	20.71 $\pm$ 24.12 ^a	105.75 $\pm$ 52.42 ^a	3.08 $\pm$ 0.31 ^a
10-15	4.87 $\pm$ 0.28 ^a	3.02 $\pm$ 0.66 ^a	0.03 $\pm$ 0.01 ^a	23.20 $\pm$ 22.90 ^a	92.75 $\pm$ 54.16 ^a	2.83 $\pm$ 0.20 ^a
15-20	4.84 $\pm$ 0.19 ^a	3.01 $\pm$ 0.92 ^b	0.02 $\pm$ 0.01 ^a	16.24 $\pm$ 17.04 ^a	87.75 $\pm$ 51.98 ^a	2.70 $\pm$ 0.19 ^a
20-30	4.75 $\pm$ 0.09 ^a	2.87 $\pm$ 0.61 ^b	0.09 $\pm$ 0.09 ^a	11.98 $\pm$ 9.44 ^a	84.63 $\pm$ 45.62 ^a	2.82 $\pm$ 0.30 ^a

For each column of the same depth and variable, different letters indicate significant differences between burned and unburned areas ($P < 0.05$)

The climatic conditions after fire (with high precipitation amounts, eventually leading high leaching rates and surface erosion) and low fire severity (indicated by the presence of incompletely burnt materials), and consequently lower ash deposition, may partly explain the changes in soil properties found among burned and unburned shrublands.



References

- Andreu, V., Imeson, A.C., Rubio, J.L., 2001. Temporal changes in soil aggregates and water erosion after a wildfire in a Mediterranean pine forest. *Catena*, 44: 69–84.
- Are, K.S., Oluwatosin, G.A., Adeyolanu, O.D., Oke, A.O., 2009. Slash and burn effect on soil quality of an Alfisol: Soil physical properties. *Soil and Tillage Research*, 103: 4-10.
- Certini, G., 2005. Effects of fire on properties of forest soils: a review. *Oecologia*, 143: 1-10.
- De Luís, M., García-Cano, M.F., Cortina, J., Raventós, J., González-Hidalgo, J.C., Sánchez, J.R., 2001. Climatic trends, disturbances and short-term vegetation Dynamics in a Mediterranean shrubland. *Forest Ecology and Management*, 147: 25-37.
- Ekinci, H., 2006. Effect of forest fire on some physical, chemical and biological properties of soil in Çanakkale, Turkey. *International Journal of Agriculture and Biology*, 8 (1): 102-106.
- Franco-Vizcaíno, E., Sosa-Ramirez, J., 1997. Soil properties and nutrient relations in burned and unburned Mediterranean-climate shrublands of Baja California, Mexico. *Acta Ecologica*, 18 (4): 503-517.
- Giovannini, G., Lucchesi, S., 1997. Modifications induced in soil physico-chemical parameters by experimental fires at different intensities. *Soil Science* 162 (7): 479-486.
- González-Pérez, J.A., González-Vila, F.J., Almendros, G., Knicker, H., 2004. The effect of fire on soil organic matter – a review. *Environment International*, 30: 855-870.
- Hubbert, K.R., Preisler, H.K., Wohlgemuth, P.M., Graham, R.C., Narog, M.G., 2006. Prescribed burning effects on soil physical properties and soil water repellency in a steep chaparral watershed, southern California, USA. *Geoderma*, 130: 284-298.
- Imeson, A.C., Verstraten, J.M., van Mulligen, E.J., Sevink, J., 1992. The effects of fire and water repellence on infiltration and runoff under Mediterranean type forest. *Catena*, 19: 345-361.
- INMG, 1991. Normas Climatológicas da Região de “Trás-os-Montes e Alto Douro” e “Beira Interior” Correspondentes a 1951-1980. Fascículo XLIX, Volume 3, Lisboa.
- Johnson, D.W., Curtis, P.S., 2001. Effects of forest management on soil C and N storage: meta analysis. *Forest Ecology and Management*, 140: 227-238.
- Pardini, G., Gispert, M., Dunjó, G., 2004. Relative influence of wildfire on soil properties and erosion processes in different Mediterranean environments in NE Spain. *Science of the Total Environment*, 328: 237-246.
- Rashid, G.H., 1987. Effects of fire on soil carbon and nitrogen in a Mediterranean oak forest of Algeria. *Plant and Soil*, 103: 89-93.
- Thomas, A.D., Walsh, R.P.D., Shakesby, R.A., 1999. Nutrient losses in eroded sediment after fire in eucalyptus and pine forests in the Mediterranean environment of Northern Portugal. *Catena*, 36: 283-302.
- Wienhold, B.J., Klemmedson, J.O., 1992. Effect of prescribed fire on nitrogen and phosphorus in Arizona chaparral soil-plant systems. *Arid Soil Research and Rehabilitation*, 6: 285-296.

How coal fires affect the clays: an interdisciplinary approach

Sorin - Corneliu Rădan^{a*} and Silviu Rădan^b

^a Geological Institute of Romania, 1 Caransebeș St., 012271 Bucharest, Romania;

^b National Institute of Marine Geology and Geoecology (GeoEcoMar), 23-25 Dimitrie Onciul St., 024053 Bucharest (Romania)

* sc.radan@yahoo.com

Key-words: coal fires; magnetic properties; clay mineralogy; baked clays; Romania.

Introduction

Spectacular changes in the magnetic properties of the clays inside “coal-bearing formations” have been achieved under natural conditions found in coal fires. Due to the presence of certain lignite seams capable of spontaneous ignition, changes comparable to thermal metamorphism occur, resulting in newly formed rocks: porcelanites and clinkers. These rocks represent the endproducts of this process, and at the same time, provide the mineralogical, petrological, geochemical, and magnetic evidence of the clay transformations as an effect of the coal fires. Consequently, an interdisciplinary approach of the subject is needed.

Objectives

A series of sequences with Pliocene lignite-clay cyclic alternations from Lupoaia and Jilț quarries, located in the western Dacic Basin (Romania), were investigated to show that the mineralogical and geochemical evolution of the argillaceous rocks – which underwent the influence of a strong thermal post-depositional perturbation – is clearly reflected by their (palaeo)magnetic properties. Such an integrated research is important for a correct detection of the Earth’s magnetic field, as well as for giving information on the spontaneous burning process of certain coal deposits and on its palaeoenvironmental impact and economic consequences.

Methodologies

The interdisciplinary approach of the problem under attention is based on field works (*i.e.* rock sampling and magnetic mapping) and laboratory studies (*e.g.* measuring of petromagnetic and palaeomagnetic parameters, mineralogical and geochemical analyses). The oriented (single) specimens have originated in both “initial”/“original” state of the magnetic recording medium/m.r.m. (Rădan, 2003) – represented by coal bearing formations – and the “subsequently affected by heating”/“modified” state. Besides, several oriented monolith-blocks (of about 25 cm) were collected from some lignite-clay sequences, and from a “minisection” (of about 4.5 m stratigraphic thickness, shown by a blue rectangle in Fig. 3), located in the area with thermally affected clays. All the single samples and the monolith-blocks were finally cut into cubic specimens (2 cm side) in order to measure the rock magnetic and palaeomagnetic parameters.

The natural remanent magnetisation (NRM), the characteristic remanent magnetisation (ChRM), the magnetic susceptibility (MS) and its anisotropy (AMS) were measured in the palaeomagnetic laboratory. Stereograms with the NRM and ChRM directions and others with the spatial distribution of the principal susceptibilities (maximum, intermediate and minimum) were carried out. Numerous “anisotropy diagrams” (*e.g.* L vs F, L vs P, T vs P’), *i.e.* concerning the magnetic lineation (L), magnetic foliation (F), the

anisotropy degree (P), the corrected anisotropy degree (P') and the shape factor (T), were performed and discussed.

“Original” (not-affected by burning) clays, as well as “baked clays” (*i.e.* porcelanites and clinkers) were analysed by X-ray diffractometry and the thermo-mineralogical characteristics were identified; besides, thin sections were analysed. A geochemical investigation was performed, as well.

The thermo-mineralogical, geochemical and rock magnetic characteristics, which were achieved in the laboratory, explain the magnetic anomalies produced by porcelanites, recorded along several profiles measured with a (Geometrics) portable proton magnetometer.

Finally, the palaeomagnetic technique, which was applied for the magnetostratigraphic correlation/calibration of the Pliocene lignite-clay cyclic alternations from the western Dacic Basin (Rădan, 1998, Rădan and Rădan, 1998), was used for constraining the time of the coal seam burning in the investigated area.

Results and conclusions

On the basis of the analyses performed by X-ray diffractometry and thin sections, the “original” clays (not-affected by heating) were characterised by clay mineral assemblages (illite, smectite, kaolinite, chlorite) and non-clay minerals (angular quartz and quartzite grains, feldspars/plagioclases, calcite, dolomite). A progressive destruction of the clay minerals and the development of newly-formed minerals (*e.g.* hematite, cristobalite, tridymite, mullite, spinel, cordierite and possible magnetite), characteristic for high temperature conditions, were recorded within the heat-affected rocks (see some examples, in Figs. 2 and 3). A correlation with the increasing temperature in successive stages, from slight baking to more or less total fusion, is feasible (Rădan *et al.*, 2001).

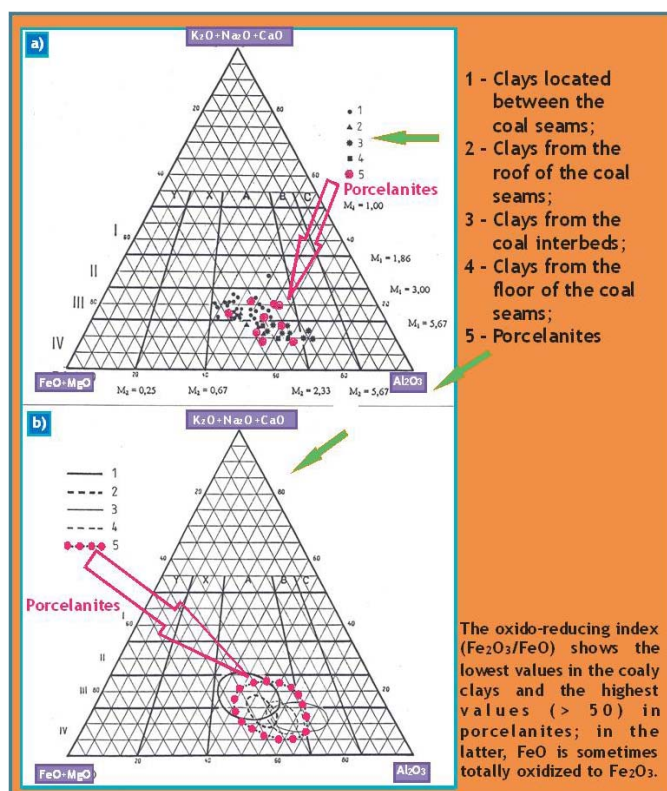


Fig. 1. Geochemical data for clayey rocks and porcelanites sampled in the western Dacic Basin (Lupoaia lignite quarry); Englund-Jorgensen/1973 diagrams. a) Chemical composition; b) Geochemical classification.

The geochemical data, based on bulk sample analyses, Englund-Jorgensen classification diagrams (two examples, in Fig. 1), the oxido-reducing index ($\text{Fe}_2\text{O}_3/\text{FeO}$), point out changes comparable to thermal metamorphism, providing interesting information related to the mineralogical changes taking place within the sediments.

Both mineralogical and geochemical evolution are clearly reflected by the magnetic properties of the investigated argillaceous rocks. For instance, the initial magnetic susceptibility (MS ; k_{in}) has considerably increased. High and very high MS amplitudes were recorded for porcelanites and porcelanite-like clays: the k_{in} values range between $200 \times 10^{-6} \times 4\pi$ SI and $1500 \times 10^{-6} \times 4\pi$ SI, sometimes reaching $12800 \times 10^{-6} \times 4\pi$ SI. The MS values measured for the “baked” clays are one to three magnitude orders higher than those which characterise the “fresh”/“original” clays. With regard to the AMS, the enhancement of several magnetic anisotropy parameters was observed: *e.g.*, the magnetic foliation (F) and the anisotropy degree (P) record values between 1.10 – 1.20, sometimes as high as the range 1.30 – 1.40. At the same time, due to the high and very high temperatures, often $250^\circ\text{--}400^\circ\text{C}$, but even $1100^\circ\text{--}1200^\circ\text{C}$ (see Fig. 3), the Curie point of ferromagnetic (*s.l.*) minerals was exceeded. As a consequence, the remanent magnetisation acquired in rocks/clays during their formation was modified, as well. On cooling, coming after heating above the Curie point, the porcelanite-like clays and the porcelanites acquire an important thermoremanent magnetisation (TRM) (other details, in Rădan, 1998). The remanent magnetisation records high and very high intensity values (I_{r}), mostly between 1 - 7 A/m, occasionally reaching 7982 A/m (see in Fig. 2 porcelanites defined by I_{r} values of 7050 mA/m). The NRM direction was also modified, usually showing a normal polarity (an example, in Fig. 2), in a position that is close to the zone where the actual geomagnetic field direction is located.

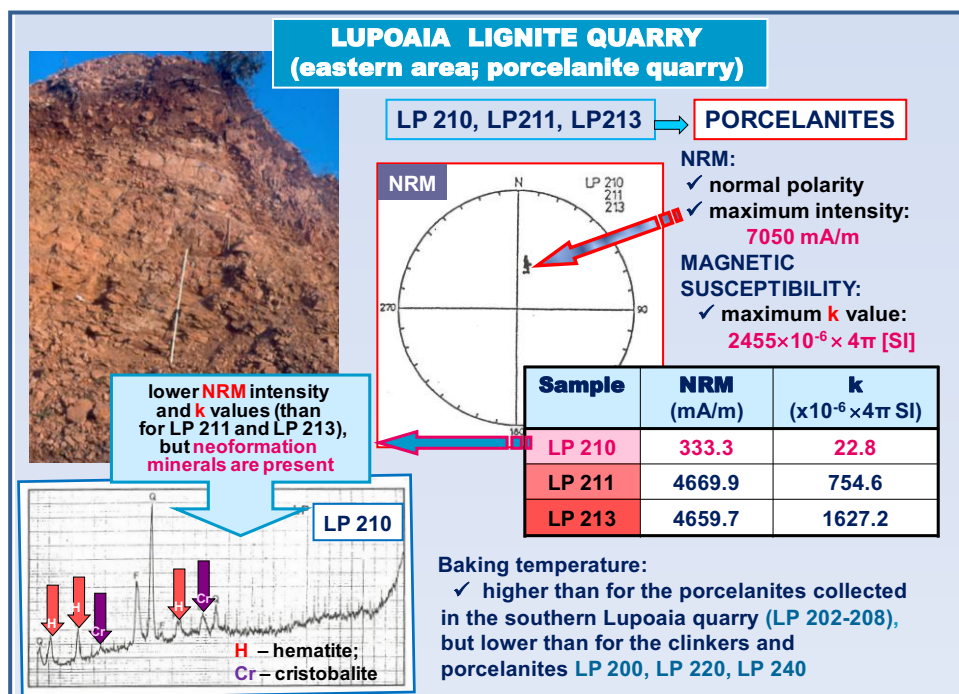


Fig. 2. An example with the effects of the coal fires on the clays: thermo-mineralogical and rock-magnetic signatures recovered from a “porcelanite quarry” in the western Dacic Basin [see Fig. 3, where the case of the highest temperature reached by the clinkers (sample LP200) is illustrated].

The palaeomagnetic signal shows the essential modifications suffered by the magnetic recording medium (in this case, the clays) due to the post-depositional perturbations as result of the natural coal paleofires; changes of the geomagnetic record that had been fixed in the “fresh”/“original” rocks are produced. So, the thermally un-affected clays, characterising the original (“initial”) state of the m.r.m., have recorded a reversed polarity, whereas the “porcelanites”, characterising the modified (“subsequent”) state of the m.r.m., located in the vicinity of the “fresh” clays, have printed a normal polarity of the geomagnetic palaeofield (see Fig. 3). The former polarity zone is assigned to the Gilbert Chron, namely to the lower part of the C2Ar Subchron (ATNTS-2004; 4.187 – 3.596 Ma; Lourens *et al.*, 2004), whereas the latter is assigned to the Brunhes Chron (ATNTS-2004; 0.781 – 0.00 Ma).

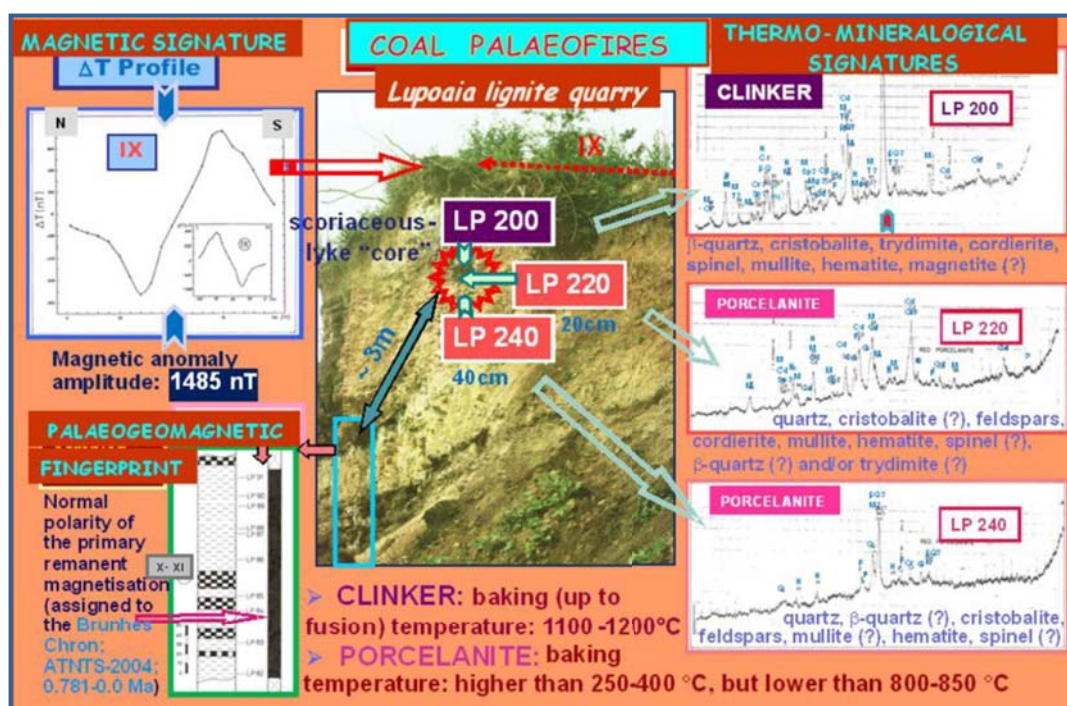


Fig. 3. Integrated model which illustrates an example of interdisciplinary approach of the problem concerning the effects of the coal palaeofires on the clays: geomagnetic, thermo-mineralogical and palaeogeomagnetic signals received from clinkers and porcelanites.

The fact that important changes occurred within the “magnetic recording medium” represented by sedimentary rocks is expressed by strong magnetic anomalies detected in areas with coal deposits; in the Lupoia – Motru area, amplitudes up to 1880 nT were measured (Rădan, 1998; Rădan and Rădan, 2011). An example is illustrated in Fig. 3, where the profile IX relieves a magnetic anomaly of 1485 nT.

Finally, we conclude that by this interdisciplinary approach various palaeo-/ rock-/ magnetic, thermo-mineralogical and geochemical markers were identified, and they explain how coal fires affect the clays, as result of a past natural autocombustion phenomenon taking place in the western Dacic Basin (Romania).

References (selected)

Rădan, S.C. 1998. *Contributions to the study of magnetic properties of rocks in a geophysical and geological context* (in Romanian). PhD Thesis, University of Bucharest, 332p.



- Rădan, S.C. , Rădan S. 2011. *Coal palaeofires in the western Dacic Basin (Romania): geophysical, mineralogical and geochemical signatures recovered from porcelanites and clinkers; a case history*. Proceedings Book, FESP III – “International Meeting of Fire Effects on Soil Properties”, 15-19 March, 2011 (in press).
- Rădan, S.C., Rădan, S., Rădan, M. 2001. *Integrated rock-magnetic, thermo-mineralogical and geochemical study of some porcelanites in the Lupoia zone (Dacic Basin, Romania)* (in Romanian, with an English abstract and summary). St. Cerc. Geologie, 46, Bucureşti, 111-141.



Contrasting effects of fire on forest and agricultural soils

C. Rumpel^{a,*}, B. Mary^b, Y. Rivas^c, Valentin, C.^d, Nocentini, C.^{a,e}, Certini, G.^e, Matus, F.^f

^a Bioemco Laboratory, Centre INRA Versailles-Grignon, Thiverval-Grignon, FRANCE;

^b Agronomie, INRA, Mons, France;

^c Escuela de Graduados, Universidad Austral de Chile, Valdivia, Chile;

^d Dipartimento di Scienza del Suolo e Nutrizione della Pianta, Università degli Studi di Firenze, Piazzale delle Cascine, Firenze, Italy

^f Departamento de Ciencias Químicas, Universidad de La Frontera, Temuco, Chile

* rumpel@grignon.inra.fr

Key-words: Charcoal; forest; agriculture.

Introduction

Fire affects in the first place the organic matter components of soil. In general, more than 90% of carbon from the aboveground biomass is lost immediately after fire. Charcoal, a stable organic matter pool, formed through the condensation of labile plant litter compounds and the formation of stable aromatic molecules is usually added to soil by wildfires (Alexis et al., 2007). Charcoal consists of a continuum of slightly burned plant residues to completely charred material. The nature and reactivity of this fire derived organic matter component may depend on precursor material as well as particle size (Rumpel et al., 2007; Nocentini et al., 2010). Therefore, charcoal added to soil could be quite different in agricultural and forestry settings. Moreover, at forested sites, in some cases addition of dried aboveground biomass was observed after fire (Alexis et al., 2007).

Objectives

This study compiles data from burned sites under different management in contrasting climatic regions. We hypothesized that fire in different management systems affects differently the organic matter compartment of soil and that these differences would be similar in different climatic regions. The objective of this paper is to point out the contrasting effects that fire may have concerning SOM storage and composition in forest and agricultural soils.

Methodology

We sampled forest and agricultural soils from France, Italy, Chile and Laos to cover several soil types and climatic regions. The agricultural sites were subject to regular slash burning within the last few years. The forest sites were also subject to burning. They were classified to have undergone fire of low medium and high intensity. In addition charcoal added to soil in the two different management systems was sampled and characterized. We studied the elemental composition of charcoal as well as burnt and unburnt soils. The chemical composition of the charcoal fractions, burnt and unburnt soil was studied by solid-state ¹³C nuclear magnetic resonante (NMR) spectroscopy and Curiepoint pyrolysis coupled to gaschromatography and mass spectrometry (GC/MS). These two methods give an overview about the chemical composition of charcoal and soil samples. The lignin component of charcoal and soils was studied after CuO oxidation and analysis of the phenolic CuO oxidation products by gaschromatography. Fire-derived black carbon in soil was quantified alter acid dichromate oxidation.

Results and conclusions

Our results showed that soil carbon stocks were similar even after prolonged slash burning in temperate agricultural soils, whereas increased carbon stocks were noted for tropical agricultural soils (Rumpel et al., 2006). Forest fire of all three intensities led to a decrease of soil carbon stocks compared to the unburned sites and an increase of the aromatic black carbon contribution to SOM (Matus et al., 2011; Certini et al., 2011). This may be explained by the fact, that in forest soils a large part of SOM is stored aboveground in the litter layers, which are usually heavily affected by fire. Moreover, the nature of fire in temperate agricultural systems is very different from forest systems; In agricultural systems, fire usually goes quickly and does rarely affect organic matter stored in the mineral soil. During forest fires, burning is usually stronger and remains for a longer. This impacts the fire effect on SOM composition, as underlined by changes of the soil lignin component and high aromatic carbon contribution (Fig. 1). In contrast, we did not find an increase in the black carbon contribution in agricultural soil under temperate climate. In a tropical environment we found the opposite, i.e. increased black carbon contribution to agricultural soils under slash burning and few aromatic carbon in forest soils (Fig. 1). The high amount of aromatic carbon in tropical agricultural soils could be explained by the woody nature of the precursor material, as slash burning normally affects fallow sites, with shrubs and trees. Thus the black carbon input may (1) be quantitatively more important than in temperate agricultural systems and (2) contain more stable components as mainly coarse charcoal particles were added to soil.

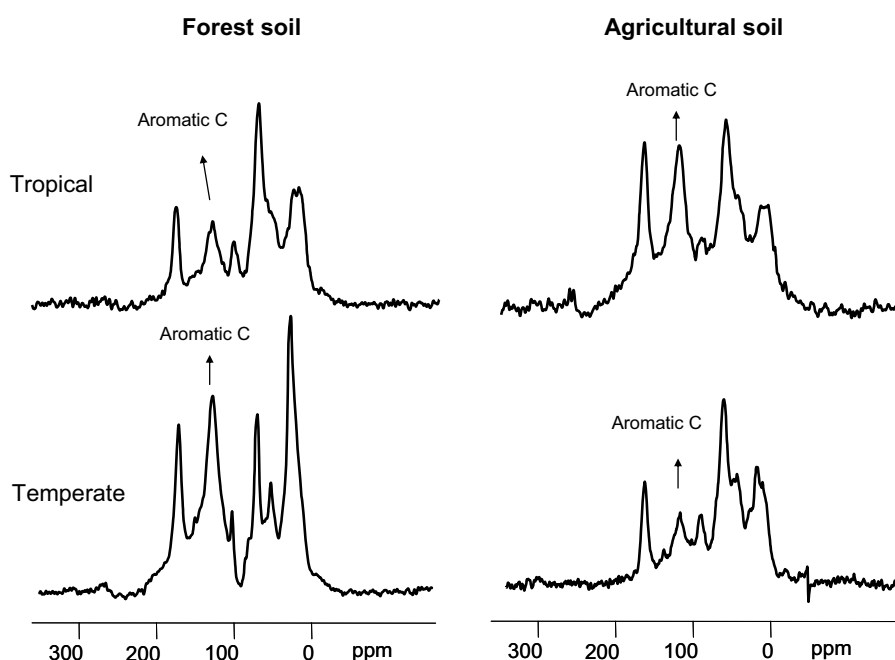


Figure 1. Chemical composition of topsoil horizons from forest and agricultural soils subjected to regular burning under temperate and tropical climate as seen by solid-state NMR spectroscopy.

Fine and coarse charcoal fractions sampled from agricultural and forest sites in a tropical climate were similar with regards to chemical composition and reactivity. Both fractions were changed completely compared to the precursor vegetation (Rumpel et al., 2007). The fine fraction, which contained higher amounts of nitrogen compared to the coarse fraction. Therefore, it was more reactive towards chemical oxidation and acid hydrolysis



compared to the coarse charcoal fraction, and may be more prone to microbial degradation. Charcoal sampled from a temperate agricultural soil, managed for 30 years of wheat stubble burning showed decreased carbon content and C/N ratio compared with the precursor material. But considering only small changes in chemical composition, the small input may be rapidly diluted in the mineral soil, therefore not affecting the quantity and chemical composition of its SOM component.

In conclusion, these opposite results obtained for forest and agricultural soils may be explained by different factors influencing the production and fate of black carbon once deposited on soil. These may include (1) precursor material, (2) nature of fire, (3) horizontal and vertical translocation, (4) susceptibility to microbial degradation and (5) incorporation into soil by bioturbation. Moreover, management practices and given socioeconomic context in different environmental settings strongly determine the effect of fire on soil.

Acknowledgments

The study was funded by the Chilean (FONDECYT project N° 1060421 and 1080065) the French (INSU, EC2CO project: QUANTICHAR) and Italian (PhD grant) government. We also thank the European commission for financial support under the 7th framework project “EUROCHAR”. We acknowledge ECOSSUD-CONICYT C08U01 for supporting collaboration between French and Chilean research groups.

References

- Alexis, M.A., Rasse, D.P., Rumpel, C., Bardoux, G., Péchot, N., Schmalzer, P., Drake, B., Mariotti, A., 2007. *Fire impact on C and N losses and charcoal production in a scrub oak ecosystem*. Biogeochemistry, 82, 201-216.
- Certini G., Nocentini C., Knicker H., Rumpel C., 2011. *Effect of a wildfire on the quantity and quality of soil organic matter in two coastal fire-prone pine forests of Tuscany*. Geoderma, submitted.
- Matus, F., Rivas, Y., Rumpel, C., Knicker, H., Garrido, E., 2011. *Comparison of black carbon contribution to Andisols under agriculture and forestry*. Geoderma, submitted.
- Nocentini, C., Certini, G., Knicker, H., Francioso, O., Rumpel, C., 2010. *Nature and reactivity of charcoal produced and added to soil during wildfire are particle-size dependent*. Organic Geochemistry, 41, 682-689.
- Rumpel, C., Alexis, M., Chabbi, A., Chaplot, V., Rasse, D.P., Valentin, C., Mariotti, A., 2006. *Black carbon contribution to soil organic matter composition in tropical sloping land under slash and burn agriculture*. Geoderma, 130, 35-46.
- Rumpel, C., González-Pérez, J. A., Bardoux, G., Largeau, C., and Gonzalez-Vila, F.J., Valentin, C., 2007. *Composition and reactivity of morphologically distinct charred materials left after slash-and-burn practices in agricultural tropical soils*. Organic Geochemistry, 38, 911-920.

Rill erosion rates in burned forests

Joseph W. Wagenbrenner^{a,b*}, Peter R. Robichaud^a

^a U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Moscow, Idaho, U.S.A.

^b Washington State University, Biological Systems Engineering, Pullman, Washington, U.S.A.

* jwagenbrenner@fs.fed.us

Key-words: Wildfire, burn severity, rill erosion, forest disturbance, sediment flux.

Introduction

Wildfires often produce large increases in runoff and erosion rates (e.g., Moody and Martin, 2009), and land managers need to predict the frequency and magnitude of post-fire erosion to determine the needs for hazard response and possible erosion mitigation to reduce the impacts of increased erosion on public safety and valued resources. The Water Erosion Prediction Project (WEPP) hillslope erosion model uses parameters based on field measurements to calculate the interrill and rill components of erosion (Nearing et al., 1989). Since rill erosion is the dominant hillslope erosion process in burned forests (Pietraszek, 2006), Robichaud et al. (2010) used simulated runoff experiments to compare rill erosion rates among unburned and burned forest plots in the western U.S. These experiments provided measurements of the magnitude of rill erosion in burned areas as compared to rates in unburned areas and also were used to calculate the rill erosion parameters needed for accurate prediction of post-fire erosion rates.

Rill flow, which occurs when sheet or interrill flow becomes concentrated, has more energy available for soil detachment than sheet wash because of the higher shear stresses resulting from the greater flow depths. Rill erosion can occur via several mechanisms, all analogous to stream channel erosion, including bed erosion, bank erosion, headcut formation, and sloughing. The rill erodibility parameter used in the WEPP model relates the sediment load of the flow to the hydraulic shear stress acting on the soil and, along with the hydraulic properties computed from the hydrologic model, is used to predict the rill erosion rates (Foster et al., 1995).

We recently reported some rill erodibility parameters for unburned and burned forests (Wagenbrenner et al., 2010), but it is unclear how much the parameter varies by location (e.g., climate, soil type, vegetation, etc.). Also, we do not know how quickly the rill erodibility parameter changes over time as the burned site recovers to its pre-burned hydrologic condition. Accurate predictions of post-fire erosion rates require that we address these questions.

Objectives

The goal of this study was to compare runoff rates, sediment flux rates, and rill erodibility parameters from simulated rill experiments among burned hillslopes in the western U.S. and Canada. The objectives were to: 1) Determine if the runoff rates or sediment flux rates varied by location or within 3 years of burning; 2) Determine if there are differences among rill erodibility parameters for burned areas based on location; and 3) Determine if the rill erodibility parameters for burned areas change within 3 years of burning.

Methodology

The seven study sites (North 25, Columbia Complex, Tripod, Terrace Mountain, Tower, School, and Red Eagle) (Figure 1) were in coniferous forests burned at high soil burn

severity and ranged in elevation from 1000 m to 1800 m. Soils and parent materials varied among the sites although the soil textures were all silt loams or sandy loams. Mean annual precipitation at the sites was between 600 and 1400 mm. Slopes ranged from 36 to 51%.

Hillslope plots, 9 m (4 m at the North 25 site) in the direction of the slope gradient, were established within either a few weeks (North 25, Columbia Complex, Tripod, and Terrace Mountain sites) or one year (Tower, School, and Red Eagle sites) of burning (Figure 1). The experiments consisted of controlled releases of water at 5 flow rates (nominally 7, 22, 30, 15, and 48 L min⁻¹) each for 12 min in succession. Runoff samples were collected approximately every 2 min during the 60 min experiments to calculate runoff and sediment flux rates (Robichaud et al., 2010). Runoff velocities and flow depths and widths were measured at each flow rate to calculate the rill erodibility parameters (Wagenbrenner et al., 2010). The experiments were repeated one year later at all sites except Tower and North 25, and two years later at all sites except Tower, North 25, and Terrace Mountain.

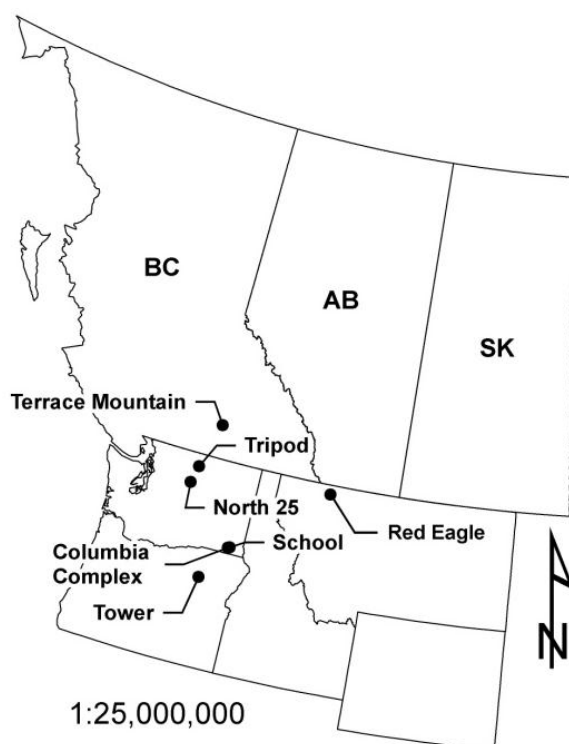


Figure 1. Locations of the seven sites in western North America

Results and conclusions

Runoff rates were highest in the year of the fire and averaged 17 L min⁻¹ (n = 4) with values ranging from 12 to 20 L min⁻¹ (Table 1). The runoff rates were lower in the first post-fire year (n = 6), when the mean value was 12 L min⁻¹, but ranged from 4 to 18 L min⁻¹. The means continued to decrease in the second and third post-fire years to 8 and 5.6 L min⁻¹, but the ranges were also relatively large (3 to 15 L min⁻¹ [n = 4] and 1 to 10 L min⁻¹ [n = 2], respectively) (Table 1). The mean runoff rates in the burned areas initially were 6 times greater than rate measured in unburned plots in the North 25 and Tower sites (2.7 L min⁻¹) (Robichaud et al., 2010) and by the third post-fire year the

burned runoff rates were still 2 times greater than the previously reported unburned rates (Table 1).

The sediment flux rates averaged 2.4 g s^{-1} and ranged from 0.8 to 4.6 g s^{-1} among the 4 sites in the year of the fire. In the first post-fire year, the mean sediment flux increased to 3.8 g s^{-1} , despite measured decreases in the 3 sites with data from the year of the fire and the first post-fire year (Table 1); the range also increased in the first post-fire year, and site values were between 0.3 and 9.2 g s^{-1} . The mean sediment flux decreased to 1.6 g s^{-1} in the second post-fire year, and the 4 site values were between 0.2 and 6.6 g s^{-1} . There was no change in sediment flux in the third post-fire year, when the mean for the 2 sites was 1.7 g s^{-1} (Table 1). As with the runoff rates, the sediment flux rates in the burned areas were initially 185 times greater than those reported in the unburned plots at the North 25 and Tower sites (0.013 g s^{-1}) (Robichaud et al., 2010). While this ratio decreased over time, the burned rates were still 130 times greater than the unburned plots in the third post-fire year.

Table 1. Mean runoff rates, sediment flux rates, and rill erodibility parameters by site and post-fire year. PFY refers to post-fire year; PFY 0 is the year of the fire.

Site	PFY	Runoff (L min^{-1})	Sed. flux (g s^{-1})	Erodibility (s m^{-1})
North 25	0	20	1.7	++
Columbia Complex	0	17	4.6	1.1×10^{-5}
Tripod	0	20	2.7	7.0×10^{-6}
Terrace Mountain	0	12	0.76	8.8×10^{-6}
Columbia Complex	1	9.5	3.1	1.0×10^{-3}
Tripod	1	17	2.1	6.3×10^{-6}
Terrace Mountain	1	8.7	0.29	1.1×10^{-5}
Tower	1	18	9.2	5.7×10^{-4}
School	1	16	7.2	4.7×10^{-5}
Red Eagle	1	4.3	0.54	4.3×10^{-5}
Columbia Complex	2	5.1	0.20	1.8×10^{-6}
Tripod	2	15	1.6	2.0×10^{-4}
School	2	9.1	4.5	1.0×10^{-4}
Red Eagle	2	2.8	0.27	1.4×10^{-5}
School	3	10	3.2	3.3×10^{-5}
Red Eagle	3	1.1	0.21	++

++ The erodibility was negative for this site/year combination.

The rill erodibility parameters averaged $8.9 \times 10^{-6} \text{ s m}^{-1}$ for the 3 sites with available data in the year of the fire and there was surprisingly little variation among the sites, despite the wide range in the sediment flux rates (Table 1). The rill erodibility values increased substantially to $2.0 \times 10^{-4} \text{ s m}^{-1}$ in the first post-fire year because of the very large value in the Columbia Complex site (Table 1). The mean rill erodibility decreased to $7.9 \times 10^{-5} \text{ s m}^{-1}$ in the second post-fire year. Only one of the two rill erodibility values was physically realistic in the third post-fire year, and the value was $3.3 \times 10^{-5} \text{ s m}^{-1}$. As with the runoff and sediment flux data, the rill erodibility values from the burned sites were between 6 and 130 times greater than the $1.5 \times 10^{-6} \text{ s m}^{-1}$ reported for the North 25 and Tower unburned sites (Wagenbrenner et al., 2010).

There were large variations in runoff rates, sediment fluxes, and rill erodibility parameters among the seven burned sites in this study. The post-fire runoff and sediment flux rates within sites decreased as time passed, but because of the averaging across sites, the means did not always decrease over time. There was much variability in the rill erodibility



values, and so there was no clear trend over time in these data. It appears that the differences in site characteristics cause enough of a difference in the data that different parameters may be needed to model rill erosion at different burned sites. It is not clear whether each site will need its own set of parameters, or if parameters can be grouped by some physical attribute such as soil texture or some fire-induced effect such as residual organic matter and still accurately represent the physical setting. The model(s) should also account for the rapid changes in the measured runoff and sediment flux rates in the first few years after burning. These results will help focus future analysis and research, and also allow land management agencies to better predict the effects of wildfire, especially with respect to hydrologic recovery.

References

- Foster, G.R., D.C. Flanagan, M.A. Nearing, L.J. Lane, L.M. Risse, and S.C. Finkner. 1995. Hillslope erosion component USDA-Water Erosion Prediction Project: Hillslope profile and watershed model documentation, Report no. 10, National Soil Erosion Research Laboratory, West Lafayette, Indiana.
- Moody, J.A., and D.A. Martin. 2009. Synthesis of sediment yields after wildland fire in different rainfall regimes in the western U.S. *Int. Journal of Wildland Fire*, 18: 96-115.
- Nearing, M., G. Foster, L. Lane, and S. Finkner. 1989. A process-based soil erosion model for USDA-Water Erosion Prediction Project technology. *Transactions of the American Society of Agricultural Engineering*, 32(5): 1587-1593.
- Pietraszek, J.H. 2006. Controls on post-fire erosion at the hillslope scale, Colorado Front Range. M.S. thesis, Colorado State Univ., Fort Collins.
- Robichaud, P.R., J.W. Wagenbrenner, and R.E. Brown. 2010. Rill erosion in natural and disturbed forests: 1. Measurements. *Water Resources Research*, 46: W10506.
- Wagenbrenner, J.W., P.R. Robichaud, and W.J. Elliot. 2010. Rill erosion in natural and disturbed forests: 2. Modeling approaches. *Water Resources Research*, 46: W10507.



Fire impact on soil and nutrient losses in schist mountain areas: central Portugal study

Richard Shakesby^{a*}, Carla Ferreira^b, Rory Walsh^a, Célia Bento^b, António Ferreira^b, Cathelijne Stoof^c

^a Department of Geography, College of Science, Swansea University, Singleton Park, Swansea SA2 8PP (UK);

^b Centro de Estudos de Recursos Naturais, Ambiente e Sociedade (CERNAS), Escola Superior Agrária de Coimbra, 3040-316 Bencanta (Portugal);

^c Land Degradation and Development Group, Wageningen University, Wageningen UR. P.O. Box 47, 6700 AA Wageningen (Netherlands).

* R.A.Shakesby@swansea.ac.uk

Key-words: wildfire, experimental fire, soil erosion, nutrient losses.

Introduction

Every year wildfires affect large areas world-wide. The Mediterranean region has both indigenous and introduced vegetation (often highly flammable, quick-growing, quick-drying) and a climate (hot and dry summers) well suited to such fires. According to Rulli *et al.* (2006), the average annual number of wildfires in the Mediterranean had reached 50,000 by the mid-2000s, which is twice the number during the 1970s. In addition, the average annual cumulative burnt area had reached 600,000 ha. Although the climate is conducive to wildfires, the increase in wildfire activity since the 1970s has been largely caused by socio-economic and demographic changes, which have brought about land use changes, notably the widespread abandonment of marginal agricultural areas, resulting in neglect of the vegetation and resulting accumulation of fuel load leading to increased risk of wildfires (Pausas *et al.*, 2008). Despite an ingrained fear of all types of fire in the region, the dramatic increase in fire activity over recent years has led to increased interest in, and acceptance of, the application of prescribed fire as a method of reducing fuel load, thereby reducing the likelihood of severe wildfires and their spread.

The environmental impacts of the fire are not limited to vegetation destruction. Soil structure, organic matter content, aggregate stability and soil water repellency can all be affected, with implications for hydrological and erosion processes as well as for nutrient export (e.g. Shakesby *et al.*, 1993; Coelho *et al.*, 2004). However, despite widespread recognition of the significance of increased losses of soil and nutrients after wildfire, only a few studies have quantified the degradational effects of prescribed fire (e.g. Úbeda *et al.*, 2005). Instead, it has been the benefits of preventing wildfire destruction that have tended to overshadow any concerns about the impacts of prescribed fire on long-term soil degradation.

Objectives

This paper aims to compare the impact of wildfire and prescribed fire on soil degradation, through the monitoring of sediment and nutrient losses following burning in neighbouring, relatively wet Mediterranean locations in north-central Portugal. To achieve this, a wildfire area has been monitored since it was burnt in July 2008 and an experimental fire was performed in a small catchment in February 2009 with similar geology, soils and vegetation. During the experimental fire, parts of the catchment were effectively burnt in a similar fashion to that experienced in a prescribed fire. Hillslope-scale measurements of sediment loss together with organic matter content, selected

nutrients (total nitrogen, available phosphorous and potassium, exchange calcium and magnesium) and pH were monitored for eroded sediments collected at different times after fire.

Methodology

The wildfire-affected study area (3.3 ha) is located near Camelo in Castanheira de Pêra municipality (40°02'32'' N, 08°09'19'' W), and has been monitored since the fire on July 3rd 2008. An experimental fire was carried out on February 20th 2009 in a nearby 9-ha catchment located in Vale Torto (40°06'19'' N, 08°07'00.72'' W), Góis municipality (Figure 1). Despite variation in fire behaviour within Vale Torto catchment, near-surface average soil temperatures reached during the fire did not exceed 100 °C, and much of the hillslopes where erosion was monitored was burnt in a similar fashion to that of a prescribed fire.



Figure 1. Location of the Camelo and Vale Torto study sites.

Both sites have similarly steep slopes (>20° on long rectilinear sections) and the soils (lithosols) overlying schist bedrock are thin and stony (up to 70% by weight of rock fragments). The climate is relatively wet (mean annual rainfall, 1200mm) but has typical Mediterranean characteristics, rainfall occurring mainly during winter depressional storms, and summers being relatively dry and warm. The vegetation is 'Atlantic-Mediterranean heath', which is dominated by *Pterospartum tridentatum* and *Erica spp.* with sporadic *Pinus pinaster* encroachment. Despite similar vegetation at both sites, the estimated fuel load (averaged from a series of plots) at the Camelo site (65 t/ha) was almost three times higher than at Vale Torto (23 t/ha).

Soil erosion was assessed at the hillslope scale using sediment fences (or 'silt fences'; Robichaud and Brown 2002) installed in topographic concavities near the base of hillslopes. They were constructed from permeable geotextile fabric supported on frameworks of steel stakes. In Camelo, there was a single sediment fence installed immediately after the wildfire, which had a contributing area of 589 m². In Vale Torto catchment, four sediment fences were installed 9 months prior to the fire, removed immediately prior to the fire and reinstalled after it. These fences had a range of contributing areas (498 to 4238 m²). The sediments trapped in all the fences have been collected at varying intervals. Long-term soil losses could be assessed from a weir-pool at Vale Torto and 16 m² erosion plot installed some 10 years before the experimental burn. They showed very low erosion rates.

The collected sediments were dried at 38°C, sieved manually (with mesh sizes ranging from 2 to 50mm) and weighed. Sediment samples from the fine fraction (<2mm) were then subjected to detailed analysis of pH (H₂O) (electrometrically 1:2.5 - L.Q.A.R.S., 1977), organic matter content (infra-red absorption spectrophotometry – LECO, 1997), total nitrogen (Kjeldahl method: Bremner, 1979), available phosphorus and potassium (Egner-Riehm method: LQARS, 1977), and calcium and magnesium (ammonium acetate method at pH7: Chapman, 1979). In addition, *in situ* soil samples were collected at depths of 0-2cm and 2-5cm from burned and unburned areas (in Camelo the unburned samples were collected immediately beyond the burnt area, while in Vale Torto the soil samples were collected before and after the experimental fire) to assess any changes in the same chemical parameters as analyzed for the eroded sediments.

In order to assess ground cover changes, several repeat-photographic plots 0.25 m² in size (five in Camelo and ten in Vale Torto) were set up at representative locations around the catchment. The photographs were taken through time to assess changes in vegetation and stone cover.

Results and conclusions

At the wildfire site, eroded soil was collected during sixteen monitoring periods, between July 2008 (immediately after the wildfire) and May 2010. At the experimentally burnt catchment, there were six pre-fire periods covering nine months, and fourteen post-fire periods, March 2009 to June 2010.

At Vale Torto, erosion increased after the experimental fire, but the peak was delayed. During the first four months after fire (up to June 2009), erosion was 2-5 times higher (0.0008 and 0.0108 t/ha) than before the fire (up to 0.0030 t/ha). During July 2009 - May 2010, however, erosion was up to 15 times higher, with 0.33 t/ha recorded up to a year after fire declining to no more than 0.05 t/ha after March 2010. Despite much higher soil erosion in the post-fire compared with pre-fire measurement period, soil losses overall were relatively modest. The autumn-winter period 2009-10 was particularly wet in Portugal. Rain fell in high amounts but it was probably the high intensities (up to 62.2 mm daily) in the later wet period that caused the higher soil erosion amounts.

As regards soil erosion at the wildfire site, it was on average 1-2 orders of magnitude higher (0.02-0.40 t/ha during the first year after the fire rising to 0.05 to 1.37 t/ha during the second year) than erosion rates measured at Vale Torto. It is difficult to demonstrate unequivocally that this difference in erosion was caused by differences in fire behaviour, but in most respects (geology, soil characteristics, slope gradient) Camelo and Vale Torto appear similar. The main differences are the size of the fuel load (65 vs 23 t/ha, respectively) and the nature of the fire (high severity wildfire *versus* the mostly low-moderate severity experimental fire). Erosion at both study sites shows an overall decline in the quantities of soil collected after winter 2009-10 despite large quantities of rainfall and some high intensities. This is thought to result from sediment 'exhaustion', development of a stone armour and vegetation recovery.

There is clear evidence of preferential removal of organic matter and nutrients after fire at both sites. For example, bulked 0-2cm depth *in-situ* soil <2mm in size sampled from unburned and immediately post-burn soils shows respectively average organic matter contents of 11.0% and 29.2%, compared with averages of 24.0% and 58.0% in post-fire eroded sediment. At Vale Torto, the organic matter content in burned soil ranged between 20.0% immediately after the fire and one year later, and decreased to 11.9% two years after the fire. Sediments eroded before the fire had organic matter contents in the range 15.2-49.9%, whereas after the fire contents rose to 26.4-100%. As regards nutrients,



there were increases in the burned top soil layer and raised values in eroded sediments at both sites. Nutrient concentration in eroded sediments tended to be slightly higher at the wildfire site compared with the average values at the experimentally-burnt catchment, but the latter showed considerable spatial variability. Although ash and charred organic matter doubtless released some nutrients for plant growth, the soil's thin, stony and compacted character probably promoted much of this material being transported downslope.

Post-fire nutrient concentrations in eroded sediment changed with time, but still remained at comparatively high levels one year after fire at both study sites. Despite the rapid appearance of new shoots from resprouting vegetation in particular, the thin degraded nature of the soil was in large part responsible for a slow recovery of other vegetation vital for protecting the soil. As a result, the vegetation did not produce a very effective ground cover for at least two years after the fire.

Our results suggest that progressive degradation of the thin stony soils could result from regular application of prescribed fire. Clearly, this would have serious repercussions for soil degradation and thus forest management. These possible impacts need to be taken into account in future prescribed fire planning.

References

- Bremner, J.M. 1979. Total Nitrogen. *In*: Black, A.; Evans, D.D., White, J.L., Ensminger, L.E. and Clark, F.E. (eds) *Methods of Soil Analyses. Part 2*. American Society of Agronomy, USA.
- Chapman, H.D. 1979. Total Exchangeable Bases. *In*: Black, A.; Evans, D.D.; White, J.L.; Ensminger, L.E.; Clark, F.E. (eds) *Methods of Soil Analyses. Part 2*. American Society of Agronomy, USA.
- LECO 1997. *Instruction Manual SC-144DR Dual Range Sulfur and Carbon Analysis System*. LECO Corporation, St. Joseph.
- Laboratório Químico Agrícola Rebelo da Silva (LQARS) 1977. *Sector de Fertilidade do solo*. DGSA – Ministério da Agricultura, Lisboa.
- Pausas, J.G., Llovet, J., Rodrigo, A. and Vallejo, V.R. 2008. Are wildfires a disaster in the Mediterranean basin? A review. *International Journal of Wildland Fire* 17, 713-723.
- Robichaud, P.R. and Brown, R.E. 2002. *Silt fences: an economic technique for measuring hillslope erosion*. USDA Forest Service General Technical Report RMRS-GTR-95, Rocky Mountain Research Station, Ft. Collins, CO.
- Shakesby, R.A., Coelho, C.O.A., Ferreira, A.D., Terry, J.P. and Walsh, R.P.D. 1993. Wildfire impacts on soil erosion and hydrology in wet Mediterranean forest, Portugal. *International Journal of Wildland Fire* 3, 95-110.
- Úbeda, X., Lorca, M., Outeiro, L.R., Bernia, S. and Castellnou, M. 2005. Effects of prescribed fire on soil quality in Mediterranean grassland (Prades Mountains, north-east Spain). *International Journal of Wildland Fire* 14, 379-384.



3rd International Meeting of Fire Effects on Soil Properties
15-19 March 2011 | University of Minho | Guimarães, Portugal



Universidade do Minho



Soil microbial community structure as affected by a wildfire in Laza (NW Spain)

A. Lombao*, A. Barreiro, A. Martín, M. Díaz-Raviña

Departamento de Bioquímica del Suelo, Instituto de Investigaciones Agrobiológicas de Galicia (CSIC),
Apartado 122, 15780 Santiago de Compostela (Spain)

* alba.lombao@yahoo.es

Key-words: Fire, microorganisms, PLFA pattern, post-fire stabilisation treatments.

Introduction

Microorganisms are the main agents responsible for long-term sustainability of soil ecosystems since they control the breakdown of organic matter and, hence, the net fluxes and amounts of soil carbon and nutrients through decomposition, mineralization and immobilization processes (Nannipieri et al., 2003); there is, therefore, concern about the effect of wildfires on soil microbial communities. Studies concerning the characterization of microbial communities in burnt soils are scarce and have focused on soil biochemical properties (Carballas et al., 2009); however, despite its interest, there is no information on microbial diversity or microbial community structure of soils affected by wildfires.

Nowadays molecular biology techniques, such as the analysis of phospholipid fatty acid patterns, allow us to study the microbial community structure of soil ecosystems. Thus, by phospholipid fatty acid analysis it is possible to examine broad scale patterns in microbial composition and generally, after the application of multivariate statistical analyses, the whole community fatty acids profiles indicate which communities are similar or different (Frostegård et al., 2011). Characterization of soil microbial communities by this technique gives results that very closely represent the *in situ* soil conditions and hence it is currently used for monitoring soil quality changes under wide ranges of soil types, management practices, climatic origins and different perturbations (Frostegård et al., 1993a,b; Zelles, 1999; Díaz-Raviña et al., 2006; Barreiro et al., 2010).

Objective

The present work is the first attempt to characterize, by means of the analysis of phospholipid fatty acid (PLFA) patterns, soil microbial population in a forest ecosystem from temperate humid zone (Laza, NW Spain) affected by a high severity wildfire.

Methodology

The study was performed in a shrubland ecosystem located in Laza (Ourense, NW Spain) affected by a wildfire on September 2010 (1700 ha of surface were burned) and highly susceptible to soil erosion after the fire event (slope 30-50%). Four treatments were established by triplicate (3 x 20 m plots): unburnt control soil (U), burnt soil (B), burnt soil with rye seeds at a rate of 10 g m⁻² (B+S), burnt soil with 250 g m⁻² of straw mulch (B+M). Initially the unburnt soil showed a silt loam texture, pH of 3.7 and high organic matter content of 261 g kg⁻¹ and burnt soil had a slightly higher pH (4.2) and lower organic matter content (93 g kg⁻¹). Measurements of these biochemical and microbiological properties were made on burnt soil samples collected from the top layer (0-2 cm) immediately and 4 months after the wildfire as well as on unburnt soil samples in an adjacent plot used as control.

The microbial community structure was determined by the PLFA analysis using the procedure and nomenclature described by Frostegård et al. (1993b). The PLFAs were designated in terms of total number of carbon atoms, double bonding and position of the double bonds. The prefixes a, i, cy and Me refer to anteiso, iso, cyclopropyl and methyl branching, respectively. Non-specific branching was designed by br whereas cis and trans configurations were indicated by c and t, respectively. The total microbial biomass (totPLFAs) was estimated as the sum of all the extracted PLFAs. The sum of the PLFAs, considered to be predominantly of bacterial origin (i15:0, a15:0, i16:0, 16:1 ω 9, 16:1 ω 7c, i17:0, a17:0, cy17:0, 18:1 ω 7 and cy19:0), was used as an index of the bacterial biomass (bactPLFAs), and the quantity of the 18:2 ω 6, 18:3 ω 3 and 16:1 ω 5 PLFA were used as an indicator of the fungal biomass (fungPLFAs) (Frostegård and Bååth, 1996; Kaiser et al., 2010). The i14:0, i15:0, i16:0 and 10Me18:0 PLFAs are predominantly found in gram-positive (G^+) bacteria, and the cy17:0, cy19:0, 16:1 ω 7c and 18:1 ω 7 PLFAs characterise gram-negative (G^-) bacteria (Basanta et al., 2006). They were used to calculate the G^-/G^+ bacteria ratio. The data corresponding to the concentrations of all the individual PLFAs, expressed in mole percent and logarithmically transformed, were subjected to a principal component analysis (PCA) to elucidate the main differences in the PLFA patterns.

Results and conclusions

The total microbial biomass and the biomass of specific groups obtained in the 0-2 cm layer of the different soil treatments immediately after wildfire are showed in Table 1.

Table 1. Total (TotPLFA), fungal (FungPLFA) and bacterial (BactPLFA) biomass, expressed as phospholipids fatty acids (PLFAs) content; Gram-negative and Gram-positive bacteria; and FungPLFA/BactPLFA and G^-/G^+ ratios in different soil treatments (mean values $\pm$ SD of three field replicates) immediately after the wildland fire. Treatments: U, unburned soil; B, burnt soil; B+S, burnt soil plus seeding; B+M, burnt soil plus straw addition.

	Soil treatments			
	U	B	B+S	B+M
Total PLFA (nmol g ⁻¹)	358 $\pm$ 46	189 $\pm$ 24	256 $\pm$ 80	223 $\pm$ 47
FungPLFA (nmol g ⁻¹)	84.2 $\pm$ 12.1	38.8 $\pm$ 4.8	50.7 $\pm$ 19.0	44.7 $\pm$ 8.4
BactPLFA (nmol g ⁻¹)	123 $\pm$ 15	64.8 $\pm$ 8.9	87.6 $\pm$ 26.8	76.2 $\pm$ 16.1
Gram ⁻ bactPLFA (nmol g ⁻¹)	70.6 $\pm$ 9.4	35.6 $\pm$ 4.7	45.3 $\pm$ 14.5	40.5 $\pm$ 6.8
Gram ⁺ bactPLFA (nmol g ⁻¹)	33.4 $\pm$ 3.0	18.4 $\pm$ 2.7	26.3 $\pm$ 8.4	22.4 $\pm$ 5.6
FungPLFA/BactPLFA	0.68 $\pm$ 0.02	0.60 $\pm$ 0.01	0.57 $\pm$ 0.04	0.59 $\pm$ 0.02
Gram ⁻ /Gram ⁺	2.11 $\pm$ 0.09	1.93 $\pm$ 0.02	1.74 $\pm$ 0.16	1.83 $\pm$ 0.14

The phospholipid fatty acid analysis indicated that the totPLFAs in the burnt soils were 30-50% of those in the corresponding unburnt samples. Specific groups of microorganisms were also affected by fire in the same way as totPLFA; the extent of these changes was similar for different microbial groups although fungPLFA/bacPLFA and Gram⁻/Gram⁺ ratios seem to decrease slightly after fire. A similar initial microbial biomass reduction, estimated by means of PLFA analysis, was also observed for several burnt soils in Atlantic and Mediterranean forests (Basanta et al., 2006; Barreiro et al., 2010; Barcenas-Moreno et al., 2011). These effects diminished over time but they still persist after 4 months; thus, the principal component analysis performed with the whole data set (samples collected immediately and 4 months after the fire) showed that PLFA pattern



allow us to differentiate between unburnt and burnt samples (data not shown). The data indicated the usefulness of the PLFA analysis to detect the immediate and short-term impact of wildfire and soil stabilization treatments on the soil microbial communities and hence on the soil quality of these soils from NW Spain.

Acknowledgements

This study was supported by the Ministerio de Ciencia e Innovación (AGL2008-02823), Spain and by the Consellería de Medio Rural de la Xunta de Galicia (08MRU002400PR).

References

- Barcenas-Moreno, G., García-Orenes, F., Mataix-Solera, J., Mataix-Beneyto, J., Bååth, E. 2011. Soil microbial recolonisation after a fire in a Mediterranean forest. *Biology and Fertility of Soils* (in press. DOI: 10.1007/s00374-010-0532-2).
- Barreiro, A., Martín, A., Carballas, T., Díaz-Raviña, M. 2010. Response of soil microbial communities to fire and fire fighting chemicals. *Science of the Total Environment* 408: 6176-7178.
- Carballas, T., Martín, A., Díaz-Raviña, M. 2009. Efecto de los incendios forestales sobre los suelos de Galicia. In: *Efecto de los incendios forestales sobre los suelos en España* (Artemi Cerdá, Jorge Mataix-Solera, eds.). Cátedra Divulgación de la Ciencia. Universitat de València, Cap. 3.6, p. 269-301.
- Díaz-Raviña, M., Bååth E., Martín, A., Carballas, T. 2006. Microbial community structure in forest soils treated with a fire retardant. *Biology and Fertility Soils* 42: 465-471.
- Frostegård, A., Bååth, E. 1996. The use of phospholipid fatty acid analysis to estimate bacterial and fungal biomass in soil. *Biology and Fertility of soils* 22:59-65.
- Frostegård, A., Tunlid, A., Bååth, E. 1993a. Phospholipid fatty acid composition, biomass, and activity of microbial communities from two soil types experimentally exposed to different heavy metals. *Applied and Environmental Microbiology* 59: 3605-3617.
- Frostegård, A., Tunlid, A., Bååth, E. 1993b. Shifts in the structure of soil microbial communities in limed forests as revealed by phospholipid fatty acid analysis. *Soil Biology and Biochemistry* 25:723-730.
- Frostegård, A., Tunlid, A., Bååth, E. 2011. Use and misuse of PLFA measurements in soils. *Soil Biology and Biochemistry* (in press. DOI:10.1016/j.soilbio.2010.11.021).
- Kaiser, C., Frank, A., Wild, B., Koranda, M., Richter, A. 2010. Negligible contribution from roots to soil-borne phospholipid fatty acid fungal biomarkers 18:2 ω 6,9 and 18:1 ω 9. *Soil Biology and Biochemistry* 42:1650-1652.
- Nannipieri, P., Ascher, J., Ceccherini, M.T., Landi, L., Pietramellara, G., Renella, G. 2003. Microbial diversity and soil functions. *European Journal Soil Science* 54: 655-670.
- Zelles, L. 1999. Fatty acid patterns of phospholipids and lipopolysaccharides in the characterisation of microbial communities in soil: a review. *Biology Fertility Soils* 29: 111-129.



Immediate and short-term effects of a wildfire on soil biochemical properties in Laza (NW Spain)

A. Barreiro*, A. Lombao, A. Martín, M. Díaz-Raviña

Departamento de Bioquímica del Suelo, Instituto de Investigaciones Agrobiológicas de Galicia (CSIC),
Apartado 122, 15780 Santiago de Compostela (Spain)

* anabarreiro@iiag.csic.es

Key-words: Fire, microbial biomass, enzymatic activities, soil respiration, [3H]-leucine incorporation.

Introduction

Soil microorganisms play a very important role in soil fertility not only because of their ability to carry out biochemical transformation but also due to their importance as a source and sink for mineral nutrients (Nannipieri et al., 2003). Therefore, the soil microbial communities response to fire is of crucial importance to evaluate soil quality changes induced by this perturbation as well as to study the recovery of these fire affected soils.

Objective

The aim of the present study was to examine the immediate and short-term impact of a high severity wildfire on soil microbial communities in a forest ecosystem from temperate humid zone (Laza, NW Spain).

Methodology

The study was performed in a shrubland ecosystem located in Laza (Ourense, NW Spain) affected by a wildfire on September 2010 (1700 ha of surface were burned) and highly susceptible to soil erosion after the fire event (slope 30-50%). Four treatments were established by triplicate (3 x 20 m plots): unburnt control soil (U), burnt soil (B), burnt soil with rye seeds at a rate of 10 g m⁻² (B+S), burnt soil with 250 g m⁻² of straw mulch (B+M). Initially the unburnt soil showed a silt loam texture, pH of 3.7 and high organic matter content of 261 g kg⁻¹ and burnt soil had a slightly higher pH (4.2) and lower organic matter content (93 g kg⁻¹). The response of microbial communities was analyzed measuring microbial biomass C and several properties related with the activity of soil microorganisms such as soil respiration, an index of overall microbial activity, specific enzymatic activities related with the C and N cycles. The microbial biomass C was determined using the fumigation-extraction method (Díaz-Raviña et al., 1992) and soil respiration by measurement of the CO₂ evolved during 10 days (Díaz-Raviña et al., 1988). The β -glucosidase, and urease activities were assayed as reported by Eivazi and Tabatabai (1988) and Kandeler and Geber (1988). The bacterial activity was also determined by means of the incorporation of labelled leucine into bacteria extracted after homogenization-centrifugation (Bååth et al., 2001). Measurements of these biochemical and microbiological properties were made on burnt soil samples collected from the top layer (0-2 cm) immediately and 4 months after the wildfire as well as on unburnt soil samples in an adjacent plot used as control.

Results

The biochemical properties obtained in the 0-2 cm layer of the different soil treatments immediately and 4 months after wildfire are showed in Table 1. The data showed that



wildfire initially reduced mass and activity, particularly the later, of soil microorganisms, but results varied depending on the microbial property analyzed; thus, for example, while β -glucosidase activity was slightly modified as consequence of high burn severity, microbial C was decreased by 55% and reductions for urease and leucine incorporation rates reached values of 85-90%. In contrast, soil respiration values increased notably following wildfire.

Table 1. Soil properties in the different soil treatments immediately and 4 months after the wildfire (mean values $\pm$ SD of three field replicates). Treatments: U, unburned soil; B, burnt soil; B+S, burnt soil plus seeding; B+M, burnt soil plus straw addition.

Soil property	Time (months)	Soil treatments			
		U	B	B+S	B+M
Microbial biomass C (mg kg ⁻¹)	0	803 $\pm$ 71	351 $\pm$ 49	355 $\pm$ 15	358 $\pm$ 70
	4	1135 $\pm$ 108	508 $\pm$ 74	520 $\pm$ 99	553 $\pm$ 130
Glucosidase (μ g p-nitrophenol g ⁻¹ h ⁻¹)	0	49.0 $\pm$ 2.8	51.7 $\pm$ 22.6	50.5 $\pm$ 3.7	49.3 $\pm$ 20.6
	4	37.7 $\pm$ 0.6	83.2 $\pm$ 13.8	80.6 $\pm$ 31.8	96.6 $\pm$ 11.4
Urease (μ g NH ₄ ⁺ g ⁻¹ h ⁻¹)	0	16.9 $\pm$ 2.1	2.7 $\pm$ 0.9	2.5 $\pm$ 0.3	2.4 $\pm$ 1.2
	4	21.8 $\pm$ 1.3	6.8 $\pm$ 0.4	8.3 $\pm$ 2	7.8 $\pm$ 0.8
Bacterial activity (x 10 ⁻¹⁷ mol Leu ml ⁻¹ h ⁻¹)	0	3.78 $\pm$ 1.02	0.66 $\pm$ 0.06	0.37 $\pm$ 0.10	0.07 $\pm$ 0.01
	4	6.44 $\pm$ 1.66	4.54 $\pm$ 0.86	7.38 $\pm$ 2.63	4.68 $\pm$ 1.32
Soil respiration (mg kg ⁻¹)	0	958 $\pm$ 38	1518 $\pm$ 376	1681 $\pm$ 94	1600 $\pm$ 115

Thereafter the microbial biomass and activity recovered, but three months after the fire the values were still lower than those in the corresponding unburnt soil. This is consistent with previous studies performed in the same temperate humid zone showing changes in several biochemical and microbiological properties as consequence of the impact of prescribed fires and wildland fires, the effect being highly dependent on soil temperature reached during the fire (Díaz-Raviña et al., 1992; 1996; Basanta et al., 2002, 2004; Villar et al., 2004; Carballas et al., 2009). The data also indicated that the biomass C induced changes are more persistent than those observed on microbial activity indices.

Conclusion

The data clearly showed that high severity wildfire modified drastically mass and activity of microorganisms of these soils from temperate humid zone, although microbial parameters showed a different sensitivity to detect the impact of fire.

Acknowledgements

This study was supported by the Ministerio de Ciencia e Innovación (AGL2008-02823), Spain and by the Consellería de Medio Rural de la Xunta de Galicia (08MRU002400PR).

References

- Bååth, E., Petersson, M., Söderberg, K.H. 2001. Adaptation of a rapid and economical microcentrifugation method to measure thymidine and leucine incorporation by soil bacterial. *Soil Biology and Biochemistry* 33: 1571-1574.
- Basanta, M.R., Díaz-Raviña, M., Cuiñas P., Carballas, T., 2004. Field data of microbial response to a fire retardant. *Agrochimica* 48: 51-60.
- Basanta, M.R., Díaz-Raviña, M., González-Prieto, S.J., Carballas, T., 2002. Biochemical properties of forest soils as affected by a fire retardant. *Biology and Fertility of Soils* 36: 377-383.



- Carballas, T., Martín, A., Díaz-Raviña, M. 2009. Efecto de los incendios forestales sobre los suelos de Galicia. En: *Efecto de los incendios forestales sobre los suelos en España* (Artemi Cerdá y Jorge Mataix-Solera, eds.). Cátedra Divulgación de la Ciencia. Universitat de València, Cap. 3.6, p. 269-301.
- Díaz-Raviña, M., Acea, M.J., Carballas, T. 1988. Microbial biomass and metabolic activity in four acid soils. *Soil Biology and Biochemistry* 20: 817-823.
- Díaz-Raviña, M., Prieto, A., Acea, M.J., Carballas, T. 1992. Fumigation-extraction method to estimate microbial biomass in heated soils. *Soil Biology and Biochemistry* 24:259-264.
- Díaz-Raviña, M., Prieto, A., Bååth, E. 1996. Bacterial activity in a forest after soil heating and organic amendments measured by the thymidine and leucine incorporation techniques. *Soil Biology and Biochemistry* 28: 419-426.
- Eivazi, F., Tabatabai, M.A., 1988. Glucosidases and galactosidases in soils. *Soil Biology and Biochemistry* 20: 601-606.
- Kandeler, E., Gerber, H., 1988. Short-term assay of urease activity using colorimetric determination of ammonium. *Biology and Fertility of Soils* 6: 68-72.
- Nannipieri, P., Ascher, J., Ceccherini, M.T., Landi, L, Pietramellara, G., Renella, G. 2003. Microbial diversity and soil functions. *European Journal Soil Science* 54: 655-670.
- Villar, M.C., Petrikova, V., Díaz-Raviña, M., Carballas, T. 2004. Changes in soil microbial biomass and aggregate stability following burning and soil rehabilitation. *Geoderma* 122: 73-82.



Near infrared spectroscopy to estimate temperatures of burned soils: importance of sample variability in model construction

Andrea Pérez-Bejarano^{a*}, César Guerrero^a, Jorge Mataix-Solera^a, Victoria Arcenegui^a, Gema Bárcenas^b, Jose Martín Soriano-Disla^a, Jorge Mataix-Beneyto^a

^a Environmental Soil Science Group (GEA). Department of Agrochemistry and Environment. Miguel Hernández University of Elche, Avd. De la Universidad, s/n, 03202 Elche, Alicante (Spain);

^b MED_Soil Research Group. Department of Crystallography and Agrochemistry. University of Sevilla.

*andrea.perez@umh.es

Key-words: burned soils, fire severity, fire intensity, wildfires.

Introduction

Near infrared spectroscopy (NIR) has been used to develop models to estimate the Maximum Temperature Reached (MTR) in burned soils (Guerrero et al., 2007; Arcenegui et al., 2008; Arcenegui et al., 2010). NIR spectroscopy obtains the reflectance spectra of a sample in the range of the NIR region (780-2500 nm). In this region, different chemical bonds of organic molecules absorb the radiation. The radiation is absorbed in accordance with the concentration of these compounds. Therefore, NIR spectra contain information about the organic composition of the soil, which can be modified by the effect of fire (Guerrero et al., 2007).

To obtain models with high accuracy, the samples used to construct them have to be representative of those that we want to predict. For this reason, to estimate the MTR in samples burned in wildfires -where there is high spatial heterogeneity- the models constructed should include this variability.

Objectives

The main objective of this study is to assess the prediction capacity of NIR models as a function of the variability included in them by comparing models constructed from a heated 'pooled sample' (obtained by mixing different samples), with others constructed from heated non-mixed samples (which it is thought that they will include more variability in the model than one pooled sample).

Methodology

Soils from three different sites in the province of Alicante (SE Spain) were sampled (the main soils characteristics are given in table 1). In each site, six samples were collected. One sample was obtained by pooling different subsamples which were taken from different points (named pooled sample), and the other five were taken as individual samples (named from A to E), one sample per point. Once in laboratory, all samples were air-dried and sieved to <2mm.

Table 1. main characteristics of soils (0-5cm depth)

Site ^a	Tm ^b (°C)	Pm ^b (mm)	Soil type (SSS, 2006)	Texture ^c (% sand, silt, clay)	OM ^d (%)	pH	CaCO ₃ (%)
PI	15.8	277	Xerorthent	31, 56, 13 SL	7.7	8.0	7.0
M	18.2	302	Xerorthent	57, 22, 21 CSL	6.2	7.9	57.6
A	13.8	706	Haploxeroll	33, 32, 35 CL	12.6	7.5	46.9

^a PI: Sierra de Pinoso; M: Sierra del Maigmo; A: Sierra de Aitana.

^b Tm: Mean annual temperature; Pm: Mean annual precipitation.

^c Sand: 2-0.05 mm; silt: 0.05-0.002 mm; clay: <0.002 mm.; SL: silty loam; CSL: clay sandy loam; CL: clay loam.

^d OM: organic matter content.

To construct the models, the six samples per site were split into aliquots which were heated in a muffle-furnace at different temperatures (70°, 100°, 200°, 300°, 400°, 500°, 600° and 700°C) and times (between 5' and 60 minutes with a 5 minutes interval), obtaining 96 heated aliquots per sample. The soil temperature was recorded every 30 seconds with a thermocouple.

Model construction

After cooling, the NIR spectrum of each aliquot was obtained using a Fourier-Transform near-infrared spectrophotometer which scanned the samples on reflectance mode from 12.000 to 3800cm⁻¹. Then the spectra were related with the MTR using PLS (Partial Least Squares) regressions.

To assess the differences in the prediction capacity, different groups of models for each soil were constructed:

1- Models of non mixed samples:

These models were constructed with the spectra of the heated aliquots of the non mixed samples. They were constructed with each of the individual samples and making pairs, sets of three and sets of four samples, with all possible combinations between them. These models were applied to estimated the MTR of the individual samples which did not belong to the model applied (table 2).

2- Models of the pooled sample:

These models were constructed with the heated aliquots of the pooled sample. With the aim to compare these models with those constructed with the non mixed samples, four models with different number of spectra (24, 48, 72 and 96) were constructed. These models were applied to estimated the MTR of the heated individual samples (table 2).

Table 2. scheme of the samples used for each model construction, and the predictions realized with each model.

Models constructed with one sample (n=24)		Models constructed with two samples (n=48)		Models constructed with three samples (n=72)		Models constructed with four samples (n=96)	
Sample used in the model construction	Predicted samples	Samples used in the model construction	Predicted samples	Samples used in the model construction	Predicted samples	Samples used in the model construction	Predicted samples
a	b, c, d, e	a+b	c, d, e	a+b+c	d, e	b+c+d+ e	a
b	a, c, d, e	a+c	b, d, e	a+b+d	c, e	a+c+d+e	b
c	a, b, d, e	a+d	b, c, e	a+b+e	c, d	a+b+d+e	c
d	a, b, c, e	a+e	b, c, d	a+c+d	b, e	a+b+c+e	d
e	a, b, c, d	b+c	a, d, e	a+c+e	b, d	a+b+c+d	e
-		b+d	a, c, e	a+d+e	b, c	-	
		b+e	a, c, d	b+c+d	a, e		
		c+d	a, b, e	b+c+e	a, d		
		c+e	a, b, d	b+d+e	a, c		
		d+e	a, b, c	c+d+e	a, b		
Pooled sample with 24 spectra	All individual samples	Pooled sample with 48 spectra	All individual samples	Pooled sample with 72 spectra	All individual samples	Pooled sample with 96 spectra	All individual samples

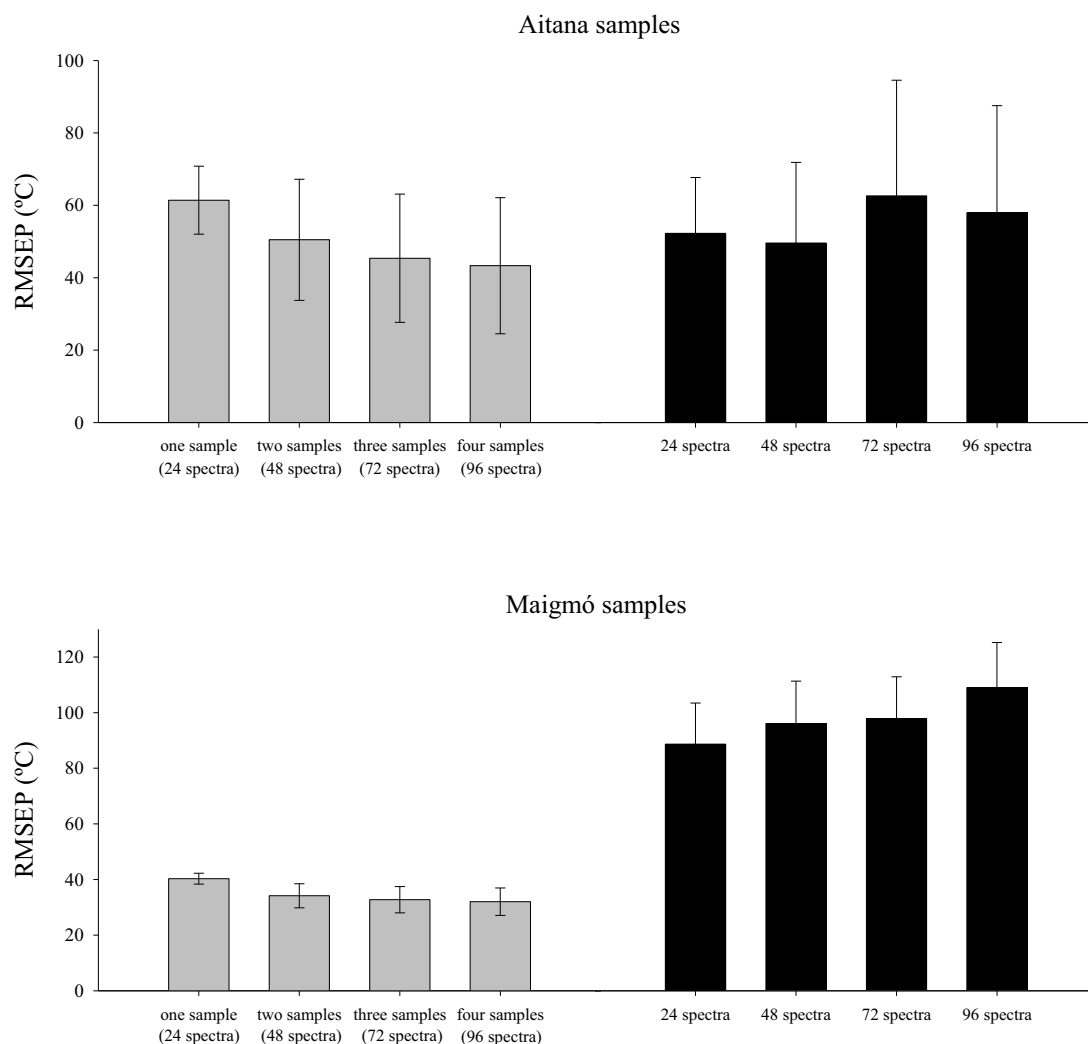
All of the models were constructed using the same conditions and procedures, ie: the rank of temperatures was the same in all the models, they were constructed using the entire spectral region, the same preprocessing of the spectra, and the same rank (number of PLS included in the model).

To assess differences between the two groups of models (models of pooled sample and models of non-mixed samples), a comparison among the mean error of prediction (RMSEP) was done. To do this, an average of the prediction results of models of non-mixed samples for each category (24, 48, 72 and 96 samples) was done. A description of statistics used follows:

$$RMSEP = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^n (Differ_i)^2} \quad \text{where} \quad Differ_i = (Y_i^{measured}) - (Y_i^{predicted})$$

Results and conclusions

As it is shown in figure 1, generally the lower values of RMSEP were obtained with the models of non-mixed samples. The reason seems to be because these models contain more information about the soil variability and can adequately describe the diversity found in the samples to predict.



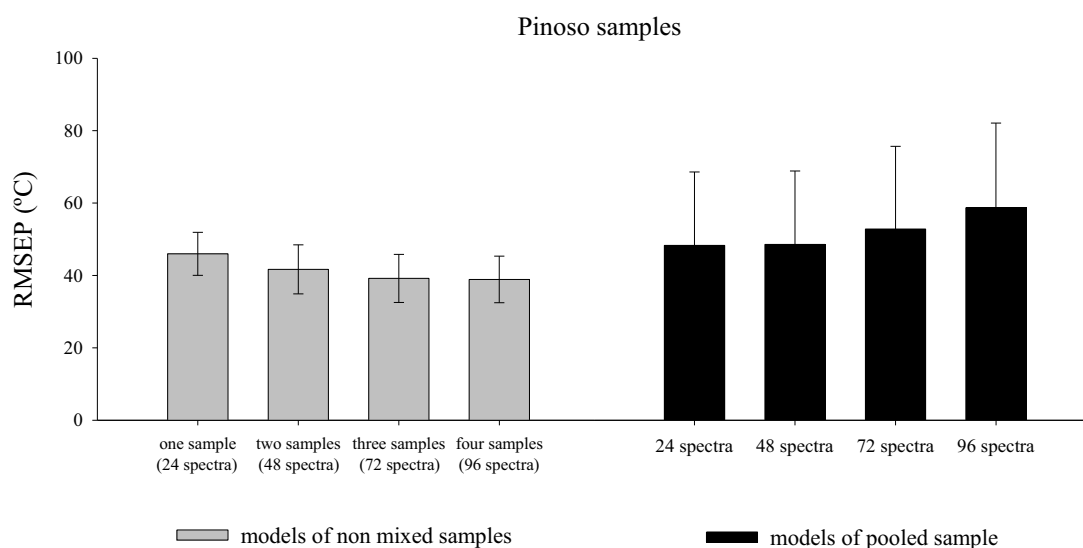


Figure 1. mean error of prediction of the different groups of models for each soil.

On the other hand, the models of non-mixed samples show better results while increasing the number of samples, being the opposite for models of pooled sample. These could be because in the models of non-mixed samples we are adding spectra of individual samples which provides new information to the model, but in the models of pooled sample we are always adding the same information.

In conclusion, the results show that the lower values of RMSEP were obtained with the models constructed with the highest number of non-mixed samples. Our results demonstrate that including variability in NIR models is of a great importance to obtain highly accurate predictions.

References

- Arcenegui, V., Guerrero, C., Mataix-Solera, J., Mataix-Beneyto, J., Zornoza, R., Morales, J., Mayoral, A.M. 2008. *The presence of ash as an interference factor in the estimation of the maximum temperature reached in burned soils using near-infrared spectroscopy (NIR)*. Catena 74: 177–184.
- Arcenegui, V., Mataix-Solera, J., Zornoza, R., Pérez-Bejarano, A., Mataix-Beneyto, J., Gómez, I. 2010. *Estimation of the maximum temperatures reached on burned soils using near-infrared spectroscopy: effects of soil sample pre-treatment*. Geoderma 158: 85-92.
- Guerrero, C., Mataix-Solera, J., Arcenegui, V., Mataix-Beneyto, J., Gómez, I. 2007. *Near-infrared spectroscopy to estimate the maximum temperatures reached on burned soils*. Soil Science Society of America Journal 71: 1029-1037.
- Soil Survey Staff. 2006. Keys to Soil Taxonomy. 10th ed. NRCS, Washington, DC.



ADAPTACLIMA - Adaptation to the effects from climate change in the AVE

António Bento Gonçalves^{a*}, António Vieira^a, Flora Leite^b, José Martins^c, Domingos Silva^c, Vera Soares^c

^a Centro de Estudos em Geografia e Ordenamento do Território (CEGOT), Núcleo de Investigação em Geografia e Planeamento (NIGP), Departamento de Geografia, Minho University, Campus de Azurém, 4800-058 Guimarães (Portugal);

^b Centro de Estudos em Geografia e Ordenamento do Território (CEGOT), Núcleo de Investigação em Geografia e Planeamento (NIGP), Departamento de Geografia (Ph.D. Student), Minho University, Campus de Azurém, 4800-058 Guimarães (Portugal);

^c AMAVE Associação de Municípios do Vale do Ave.

* bento@geografia.uminho.pt

Key-words: Ave, Forest fires, climate change, temperature, rain.

Introduction and objectives

There is a wide array of studies and evidence that climate is changing and these changes will manifest themselves very differently in different areas of the planet.

The project “ADAPTACLIMA - Adaptation to the effects from climate change” (InterReg Sudoe) is based on the preparation of a series of studies on forecasting and analysing the vulnerabilities and potentialities in Southeast European territories, with the aim of creating a collaborative network of stable institutions permitting both the transmission of knowledge and exchange of experiences among members of the partnership as well as mutual learning and co-generation of new knowledge. The fundamental task of the network will be the preparation of a Plan for Adaptation to Climate Change in Space SUDOE, that can be implemented in the participating areas. Among the challenges facing SUDOE to combat climate change, two of them represent the strategic objectives of the project ADAPTACLIMA: on the one hand, the alert the populations of the SUDOE space to the real consequences of climate change; and, secondly, to promote and develop measures which will help adapt society to future scenarios derived from these changes.

In the northwest of Portugal and in particular in AVE region, one of the main impacts expected from climate change is an increase in number and size of fires and their recurrence.

As a consequence, an increase of the erosion of the top soil layer, where the only nutrients available are located in most Portuguese soils, is expected (Bento Gonçalves et al., 2008).

Methodology

Under the project ADAPTACLIMA, we proceeded assess the magnitude of climate change on various regions of South-western Europe, including the AVE and use the results of project PRUDENCE (<http://prudence.dmi.dk>) containing a series of climate change projections for Europe with a horizontal resolution of about 50 km.

These projections were made by different institutions using different meteorological European regional climate models based on global model HadAM3H, which is one of the global models used in IPCC (Intergovernmental Panel on Climate Change) and one that offers better results for the current climate.

Thus, for each of the regional model we obtained a projection for the period 2071-2100 and a control simulation for the period 1961-1990, which served as the basis for the simulation.

Following this preliminary analysis, a more detailed analysis for the region of AVE was carried out, taking into account the meteorological stations deployed in the north-western Portuguese territory.

With no weather stations in AVE, we chose the three closest: Porto (Pedras Rubras), Braga and Montalegre, having analyzed the series of maximum, minimum and average temperature, and precipitation (total) of the three stations mentioned above, located in Northwest Portugal (figure 1, TABLE I, II), during a 39 year period (1970-2009), in order to identify and quantify the major trends.

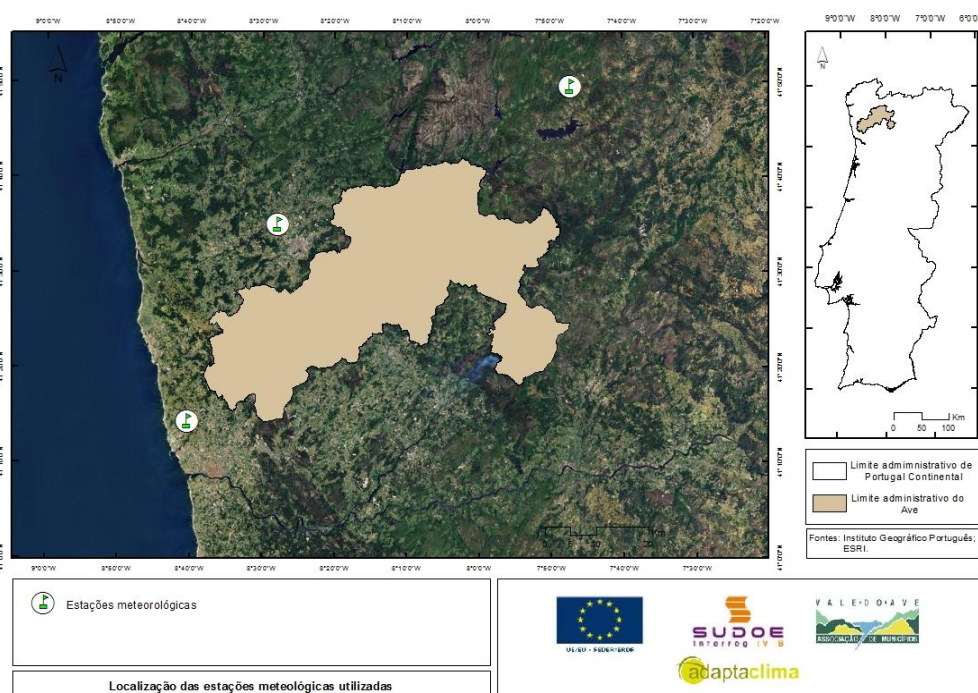


Figure 1. Weather stations

Table I. Weather stations used for temperature

	Station	Inicial year	Final year	Type of station
1	Braga (Posto Agrário)	1970	2006	Manual
1	Braga (Merelim)	2007	2009	Automatic
2	Montalegre	1970	1999	Manual
2	Montalegre	2000	2009	Automatic
3	Porto/Pedras Rubras	1970	1998	Manual
3	Pedras Rubras	1999	2009	Automática

Source: Consellería de Medio Ambiente Territorio e Infraestruturas. MeteoGalicia.

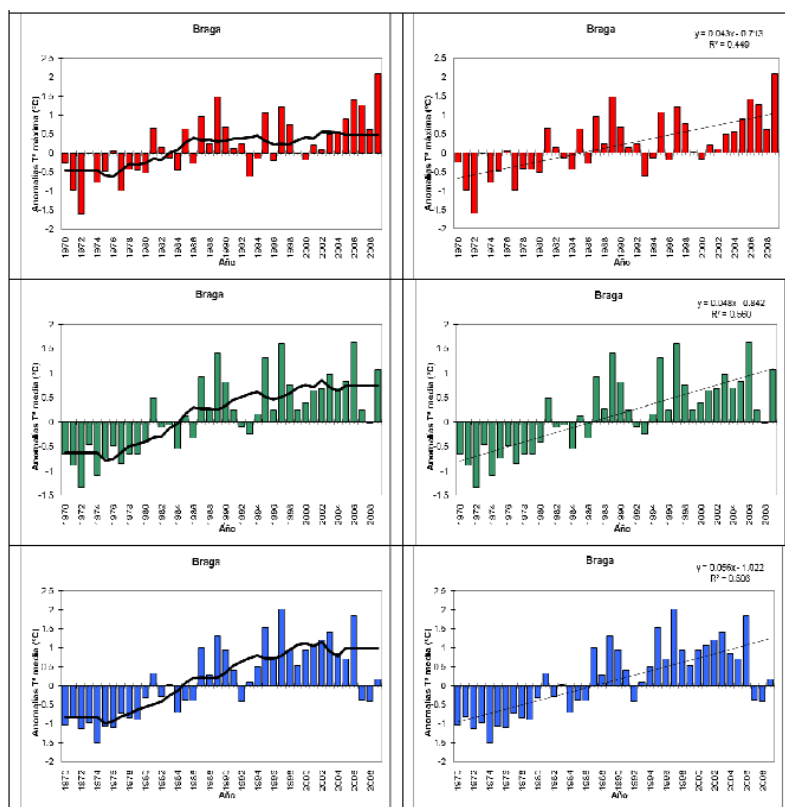
Table II. Weather stations used for rainfall

	Station	Inicial year	Final year	Type of station
1	Braga (Posto Agrário)	1970	2006	Manual
1	Braga (Merelim)	2007	2009	Automatic
2	Montalegre	1970	2009	Manual
3	Porto/Pedras Rubras	1970	2009	Manual

Source: Consellería de Medio Ambiente Territorio e Infraestruturas. MeteoGalicia.

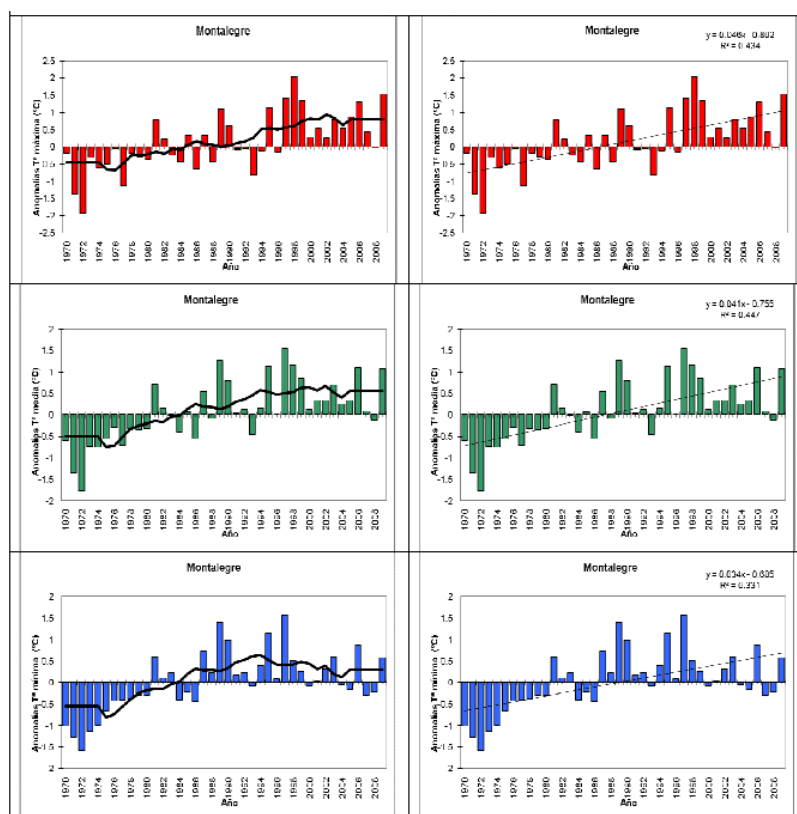
Results and conclusions

Annually, an increase of maximum temperature, minimum and average of around 0.5 °C/decade is observed for the series of Braga and Montalegre (Figure 2, 3). For the series of P. Rubras, there is an increase of 0.5° C/decade in average and minimum temperature, and 0.2°C/decade for the maximum temperature (Figure 4).



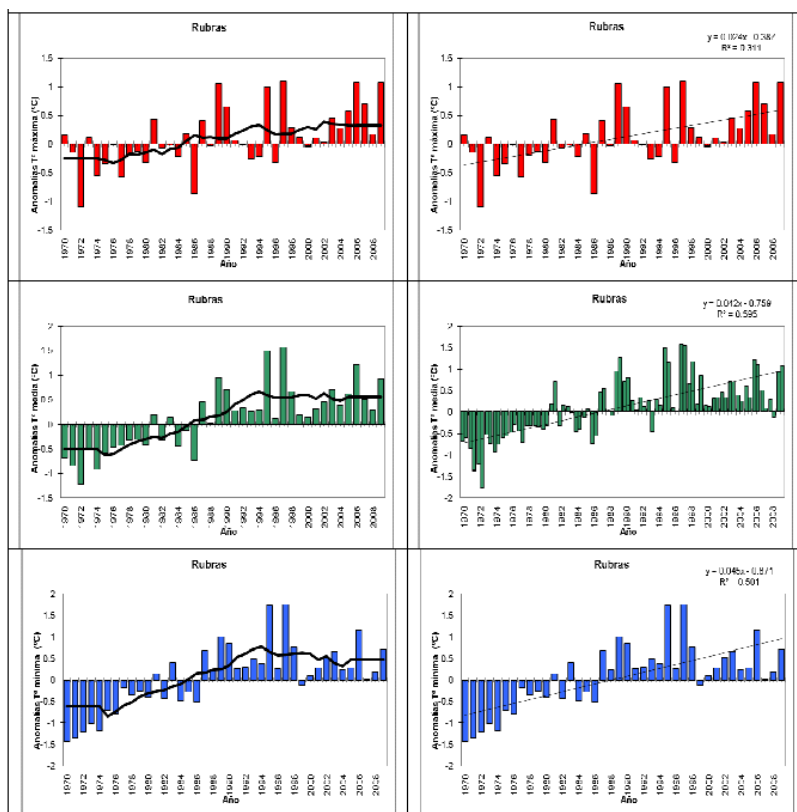
Source: Consellería de Medio Ambiente Territorio e Infraestruturas. MeteoGalicia.

Figure 2. Temperature annual trend (Braga weather station).



Source: Consellería de Medio Ambiente Territorio e Infraestruturas. Meteogalicia.

Figure 3. Temperature annual trend (Montalegre weather station).

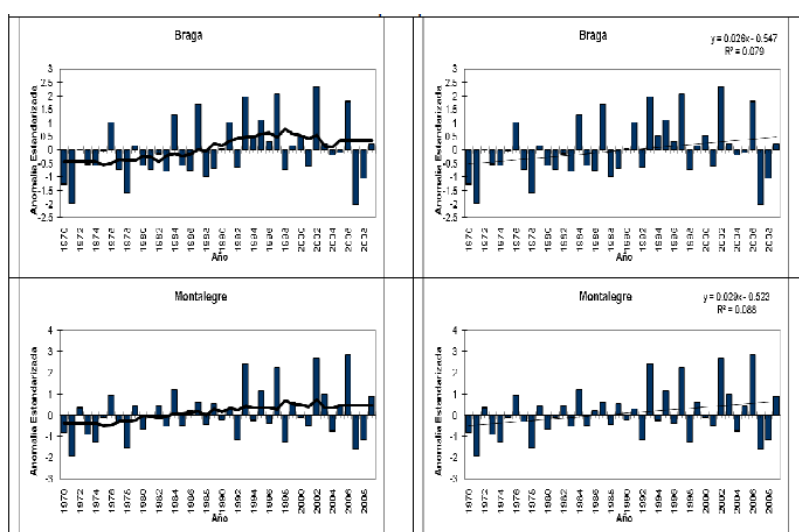


Source: Consellería de Medio Ambiente Territorio e Infraestruturas. Meteogalicia.

Figure 4. Temperature annual trend (P. Rubras weather station).

The increase in temperature is more significant from the mid 1970's as seen in the sharp change of outstanding temperature anomalies (Figure 2, 3, 4). The highest increase (0.7°C/decade) is observed in the spring series and for all temperatures considered. On a monthly bases we highlight the month of March, with an increase of close to 1°C/decade for the series of Braga and Montalegre and 0.6 °C/decade for P. Rubras. There is also a decrease in the frequency of cold days and nights, especially in the spring and summer. In general, it is possible to identify a significant increase in the number of hot days in the spring and summer seasons (about 1.5 days per decade in spring and 2.5 days per decade in summer). In the analysis of the frequency of warm nights, there is also an increase in October for the series of Braga and in all seasons for the series of P. Rubras.

Regarding the results of the trends observed for rain, it is possible to observe an increase in the rainfall in autumn (1.58%/decade for Braga, 1.97%/decade for Montalegre) (Figure 5).



Source: Consellería de Medio Ambiente Territorio e Infraestruturas. MeteoGalicia.

Figure 5. Rainfall annual trend (Braga and Montalegre weather station)

The weather conditions that occur in Portugal, especially during the summer, are favourable to fires. However, the ignition and spread of a fire depends on the interaction of several factors besides the weather, including the presence of fuel and the rugged terrain.

It is expected that the fire regimes immediately respond to climate change, and may even outweigh the direct effects of global warming in the patterns of specie distribution and productivity.

In terms of plant life, those better adapted to fire will dominate, generating monospecific formations or small variations at the same age

Climate change may cause a substantial increase in risk fire. In addition, in any of the scenarios described, the period of fire occurrence will extend throughout the year, implying a larger fire-fighting organizational structure, which will maintain higher levels of alert for longer periods each year.



References

- Agência para a Prevenção de Incêndios Florestais/Instituto Superior de Agronomia, Plano Nacional Defesa da Floresta Contra Incêndios. Estudo Técnico I – Diagnóstico, Visão e Objectivos Estratégicos, 2005.
- Bento Gonçalves, A. J., Vieira, António A., Ferreira, António D. e Coelho, Celeste, “Caracterização geomorfológica e implementação de um sistema integrado de informação, em ambiente SIG, no âmbito do projecto RECOVER (Estratégias de remediação de solos imediatamente após incêndios florestais”. Revista Geografia Ensino & Pesquisa, V. 12, nº 1, Santa Maria, Rio Grande do Sul, Brasil, 2008, p.3721-3735.
- F. D. Santos, K. Forbes, R. Moita (editores), Mudança Climática em Portugal. Cenário, Impactes e Medidas de Adaptação – SIAM, Sumário Executivo e Conclusões, Gradiva, Lisboa, 2001.
- Instituto do Ambiente, Programa Nacional para as Alterações Climáticas. Anexo Técnico, Floresta, 2006.
- MeteoGalicia, Informe sobre impactos en el Val do Ave - Portugal. Relatório Interno. Consellería de Medio Ambiente Territorio e Infraestruturas, Galicia, 2010.
- MeteoGalicia, Informe sobre evidências em Portugal. Relatório Interno. Consellería de Medio Ambiente Territorio e Infraestruturas, Galicia, 2010.



The importance of pine needles in reducing soil erosion following a low/medium intensity wildfire in Junceda (Portugal) – an experimental design

António Bento Gonçalves^{a*}, António Vieira^a, Luciano Lourenço^b, José Salgado^c, Luís Mendes^c, Américo Castro^c, Flora Ferreira Leite^d

^a Centro de Estudos em Geografia e Ordenamento do Território (CEGOT), Núcleo de Investigação em Geografia e Planeamento (NIGP), Departamento de Geografia, Minho University, Campus de Azurém, 4800-058 Guimarães (Portugal);

^b Centro de Estudos em Geografia e Ordenamento do Território (CEGOT), Núcleo de Investigação Científica de Incêndios Florestais (NICIF), Departamento de Geografia da Faculdade de Letras, Coimbra University, 3004-530 Coimbra (Portugal);

^c Departamento de Geografia (M.Sc. Student), Minho University, Campus de Azurém, 4800-058 Guimarães (Portugal);

^d Centro de Estudos em Geografia e Ordenamento do Território (CEGOT), Núcleo de Investigação em Geografia e Planeamento (NIGP), Departamento de Geografia (Pd.D. Student), Minho University, Campus de Azurém, 4800-058 Guimarães (Portugal).

* bento@geografia.uminho.pt

Key-words: Forest fires, low/medium intensity, pine needles, soil erosion, low cost treatments

Introduction

Portugal is traversed each year by fires, showing a positive trend for an annual increase in their number and in the area scorched, as well as an increase in the recurrence of fires (Ferreira-Leite *et al.*, 2011) and occurrence of large fires (Ferreira-Leite, 2010).

As a consequence, the erosion of the top layer of soil occurs. In most Portuguese soils, it is in these layers that the only nutrients are available (Burch *et al.* 1989; Imeson *et al.* 1992; Shakesby *et al.* 1993; Scott & Schulze 1992; Scott 1993; Andreu *et al.* 1994; Coelho *et al.* 1995a, b; Pierson *et al.* 2002; Coelho *et al.* 2004; Cerdà & Lasanta 2005; Benavides-Solorio & MacDonald 2005, Bento-Gonçalves *et al.*, 2008).

In a climate of Mediterranean characteristics, the export of sediments and nutrients usually occurs within the first 4 / 6 months after the fire, so it is essential to study and implement a set of solutions that reduce the loss of materials (Shakesby *et al.*, 1993, Bento-Gonçalves e Coelho, 1995, Shakesby *et al.*, 1996, Walsh, 1998; Ruiz and Luque, 2010, Bento-Gonçalves e Lourenço, 2010, Vega *et al.*, 2010).

However, this process is highly dependent on the recurrence of fires, their intensity and severity, spatial variability of soil hydrophobicity (Jungerius e DeJong 1989; Ritsema e Dekker 1994; Coelho *et al.* 2004) as well as on the local characteristics (altitude, slope, exposure, climate, geology, ...), so it is necessary to adapt the different soil strategies to each situation, as was demonstrated in early research in Central Portugal (Lourenço, 1989; Lourenço and Bento-Gonçalves, 1990; Lourenço, Bento-Gonçalves and Monteiro, 1991).

Objectives

Most of the soil protection measures after fire are expensive and difficult to implement. Thus, the Soil Protec¹ (Emergency measures to protect soils after forest fires) project aims to test low cost treatments to reduce soil erosion immediately after low/medium intensity forest fires in *Pinus pinaster* stands in the northwest of Portugal.

¹ Funded by CEGOT – Centro de Estudos em Geografia e Ordenamento do Território.

We aim to test the role of pine needles available at the actual site of the fire - which are partly due to them falling after the fire of low/medium intensity - as a protective agent against soil erosion (photos 1 and 2) and, also, compared with the role of straw.



Photo 1 and 2. Pine needles

Methodology

Following the great fire (1479.68 ha) which occurred in Geres, in the municipality of Terras de Bouro ('freguesias' of Covide, Rio Caldo and Vilar da Veiga), in August 2011, six plots were installed in a low to medium intensity scorched area of *Pinus pinaster*. Each plot was 10 meters long by 2,5 meters wide (Fig. 1).

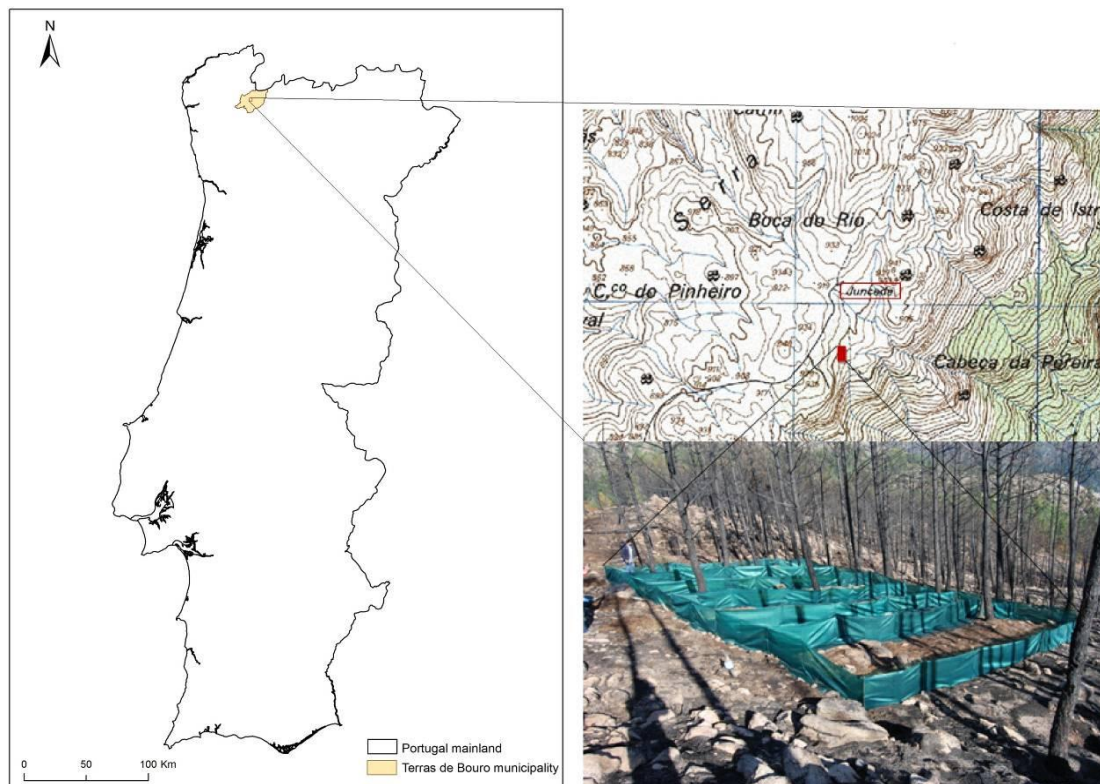


Figure 1. Study area (Junceda, Terras do Bouro - Portugal)

Each plot (photo 3) was mapped using a total station (photo 4), thus allowing not only to identify the exact area of each plot, but also to trace 3 cross sections (at the top, in the middle and at the base) in each one, which we repeated systematically.



Photo 3. Burnt control plot;



Photo 4. Survey of the plots and the study area with a total station

Were subsequently applied straw (2, 4 and 8 kg) and pine needles (2 and 4 kg) in five plots and one was left as a control sample (Fig. 2).

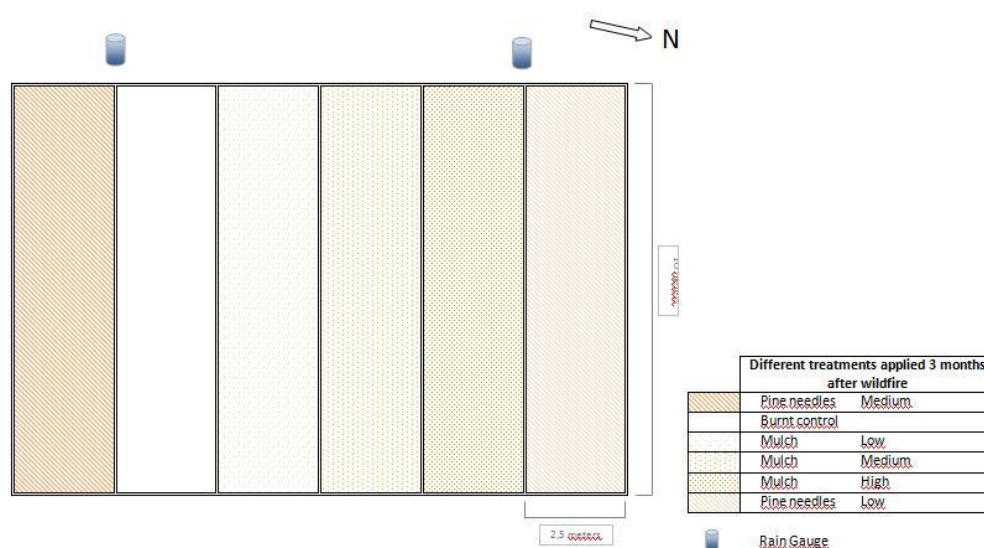


Figure 2. Research design for testing post-wildfire urgent mitigation measures

At the same time a topographic survey was conducted, also using a total station, of the slope where the plots were installed.

Conclusions

The geomorphologic Modeling we are implementing through the “Soil Protec” project will help us to understand the processes acting on the slopes and their response to the proposed remediation mechanisms, enabling the production of relevant information for the development of inexpensive strategies for soil protection.

The ultimate goal is to recommend measures that will allow those responsible for the management of the scorched areas, after a swift identification of the critical areas in which the interventions should occur, to obtain the best conservation results at the lowest possible price and without introducing external elements to the forest environment of the

mountain. This procedure will have a significant impact on the conservation of soil, on vegetation recovery, and therefore on the functioning of the ecosystem.

References

- Andreu, V., Forteza, J., Rubio, J. L., Cerni, R. (1994) - "Nutrient losses in relation to vegetation cover on automated field plots". In Rickson, R. J. (Ed.) *Conserving Soil Resources*. Cambridge Univ. Press, 116-126.
- Benavides-Solorio, J., MacDonald, L. H. (2005) - "Measurement and prediction of post-fire erosion at the hillslope scale, Colorado Front Range". *International Journal of Wildland Fire*, 14, 457-474.
- Bento-Gonçalves, A. J. e Coelho, C. de O. A. (1995) - "Wildfire impacts on soil loss and runoff in dry mediterranean forest, Tejo basin, Portugal: preliminary results". *Proceedings of Course on Desertification in a European Context*. Physical and Socio-Economic Aspects; Bruxelles, p. 361-369.
- Bento-Gonçalves, A. J., Vieira, A., Ferreira, A. D. e Coelho, C. (2008) - "Caracterização geomorfológica e implementação de um sistema integrado de informação, em ambiente SIG, no âmbito do projecto RECOVER (Estratégias de remediação de solos imediatamente após incêndios florestais)". *Revista Geografia Ensino & Pesquisa*, V. 12, nº 1, Santa Maria, Rio Grande do Sul, Brasil, p.3721-3735.
- Bento-Gonçalves, A. J. e Lourenço, L. (2010) - "The study and measurement of overland flow and soil erosion on slopes affected by forest fires in Lousã mountain – main results". *Actas das Jornadas Internacionais – Investigación y gestión para la protección del suelo y restauración de los ecosistemas forestales afectados por incendios forestales – 6 a 8 de Outubro de 2010 – Santiago de Compostela.*, p. 107-110.
- Burch, G. J., Moore, I. D., Burns, J. (1989) - "Soil hydrophobic effects on infiltration and catchment runoff". *Hydrological Processes*, 3, 211-222.
- Cerdà, A., Lasanta, T. (2005) - "Long-term erosional responses after fire in the Central Spanish Pyrenees". 1. Water and sediment yield. *Catena*, 60, 59-80.
- Coelho, C. O. A., Shakesby, R. A., Walsh, R. P. D. (1995) - "Effects of forest fires and post-fire land management practice on soil erosion and stream dynamics, Águeda basin, Portugal". *Soil and groundwater research report V*, European Commission, 91p.
- Coelho, C. O. A., Shakesby, R. A., González, M., TERNAN, L., Walsh, R. P. D., Williams, A. G. (1995) - "IBERLIM: Land management and erosion limitation in the Iberian Peninsula". Final Report to the EC in fulfilment of Project EV5V-0041 Land management practice and erosion limitation in contrasting wildfire and gullied locations in the Iberian Peninsula (unpublished), 246 pp.
- Coelho, C. O. A., Ferreira, A. J. D., Boulet, A. K., Keizer, J. J. (2004) - "Overland flow generation processes, erosion yields and solute loss following different intensity fires". *Quarterly Journal of Engineering Geology and Hydrogeology*, 37, 3, 233-240.
- Ferreira-Leite, F. (2010) - "Caracterização dendrocaustológica do Noroeste Português – o caso dos grandes incêndios florestais". Tese de Mestrado, Universidade do Minho, Guimarães, 94 pp. + anexos.
- Ferreira-Leite, F.; Bento Gonçalves, A. J.; Vieira, A. (2011) - "The recurrence interval of forest fires in Cabeço da Vaca (Cabreira Mountain - Northwest of Portugal)". *Environmental Research* 111 (2011) 215-221, doi:10.1016/j.envres.2010.05.007.
- Imeson, A. C., Verstraten, J. M., Van Mullingen, E. J., Sevink, J. (1992) - "The effects of



- fire and water repellency on infiltration and runoff under Mediterranean type forests”. *Catena* 19, 345-361.
- Jungerius, P. D., DeJong, J. H. (1989) - “Variability of water repellency in the dunes along the Dutch coast”. *Catena*, 16, 491-497.
- Lourenço, L. (1989) — “Erosion of agro-forester soil in mountains affected by fire in Central Portugal”. *Pirineos. A journal on mountain ecology*, Jaca, 133, p. 55-76.
- Lourenço, L. and Bento-Gonçalves, A. (1990) — “The study and measurement of surface flow and soil erosion on slopes affected by forest fires in the Serra da Lousã” . *Proceedings*, International Conference on Forest Fire Research, Coimbra, p. C.05–1 a 13;
- Lourenço, L., Bento-Gonçalves, A. and MONTEIRO, R. (1991) — “Avaliação da erosão dos solos produzida na sequência de incêndios florestais”. *Comunicações*, II Congresso Florestal Nacional, Porto, II vol, p. 834-844;
- Pierson, F. B., Carlson, D. H., Spaeth, K. E. (2002) - “Impacts of wildfire on soil hydrological properties of steep sagebrush-steppe rangeland”. *International Journal of Wildland Fire*, 11, 145-151
- Ritsema, C. J., Dekker, L. W. (1994) - “How water moves in a water-repellent sandy soil”. 2. Dynamics of fingered flow. *Water Resources Research*, 30, 2519-2531.
- Ruiz, J., Luque, I. (2010) - “Actuaciones de emergencia para la defense del suelo tras un gran incendio forestal em Andalucia”. *Actas das Jornadas Internacionais – Investigación y gestión para la proteccion del suelo y restauración de los ecosistemas forestales afectados por incêndios forestales – 6 a 8 de Outubro de 2010 – Santiago de Compostela.*, p. 49-64.
- Scott, D. F., Schulze, R. E. (1992) - “The hydrological effects of a wildfire in a eucalypt afforested catchment”. *S.A. Forestry Journal*, 160, 67-74.
- Scott, D. F. (1993) - “The hydrological effects of fire in South African mountain catchments”. *Journal of Hydrology*, 150, 409-432.
- Shakesby, R. A., Boakes, D. J., Coelho, C. de O. A., Bento Gonçalves, A. J., Walsh, R. P. D. (1993) - “Limiting the erosional effect of forest fires: background to the IBERLIM research programme in Águeda and Tejo basins, Portugal”. *Swansea Geographer*, 30; Swansea, p. 132 - 154.
- Shakesby, R. A., Boakes, D. J., Coelho, C. de O. A., Bento Gonçalves, A. J. and Walsh, R. P. D. (1996) - “Limiting the soil degradation impacts of wildfire in pine and eucalyptus forests, Portugal: comparison of alternative post-fire management practices”. *Applied Geography*, Vol. 16, Nº. 4, Elsevier Science, Ltd, p. 337-355.
- Shakesby, R., Ferreira, A., Ferreira, C., Stoof, C. R., Urbanek, E., Walsh, R. P. D. (2009) - “Wildfires in Portugal: characteristics, soil degradational impacts and mitigation measures”. *Desire*. (<http://www.slideshare.net/medesdesire/wildfire-2009>)
- Vega, J. A., Serradab, R., Hernandoc, C., Rincónd, A., Ocaña, L., Madrigalc, J., Fontúrbela, M. T., Pueyo, J., Aguilar, V., Guijarroc, M., Carrillo, A., Fernández, C., Marinoc, E. (2010) - “Actuaciones técnicas post-incendio y severidad del fuego:Proyecto Rodenal”. *Actas das Jornadas Internacionais – Investigación y gestión para la proteccion del suelo y restauración de los ecosistemas forestales afectados por incêndios forestales – 6 a 8 de Outubro de 2010 – Santiago de Compostela.*, p. 305-308.
- Walsh, R. P. D., Coelho, C. de O. A., Elmes, A., Ferreira, A. J. D., Bento Gonçalves, A. J., Shakesby, R. A., Ternan, J. L. and Williams, A. G. (1998) – “Rainfall simulation plot experiments as a tool in overland flow and soil erosion assessment, North-Central Portugal”. *Geokodynamik*, Band XIX, 3-4, Bensheim, p. 139-152.



Geographical Information Technology to support research on forest fires and soil erosion

A. Vieira^{1*}, A. Bento Gonçalves², C. Martins³, F. Leite⁴, Luis Mendes⁵

¹ Centro de Estudos em Geografia e Ordenamento do Território (CEGOT)/Núcleo de Investigação em Geografia e Planeamento (NIGP), Universidade do Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.

² Centro de Estudos em Geografia e Ordenamento do Território (CEGOT)/Núcleo de Investigação em Geografia e Planeamento (NIGP), Universidade do Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.

³ Núcleo de Investigação em Geografia e Planeamento (NIGP), Universidade do Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.

⁴ Núcleo de Investigação em Geografia e Planeamento (NIGP), Universidade do Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.

⁵ Master Student in Geography, Department of Geography, University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal.

* vieira@geografia.uminho.pt

Key-words: Forest fires, soil degradation and recovery, SDI, GIS database, GIS modeling

Introduction

The RECOVER (Immediate Soil Management Strategy for Recovery after Forest Fires) project aims to develop mitigation techniques and strategies to reduce soil and water degradation immediately after forest fires. Forest fires are becoming increasingly frequent as a result of climate variability, socio-economic change, and unsuitable forest planning, with adverse impacts on soil fertility and structure. One of the most important is the erosion of the top soil layers, where the 'nutrient pool' of the majority of Portuguese soils is located (Bento Gonçalves *et al.*, 2008). This nutrient mobilization happens during the first autumn rainfall events, and therefore sediment and nutrient exportation typically occurs in the first 4/6 months after a fire. The speed at which nutrient loss occurs and the extension of forest fires, tend to limit, in terms of costs and logistics, the solutions that can be taken to reduce soil and water degradation.

RECOVER presents an innovative approach based on field surveys of soil and vegetation properties following forest fires, which will be used to create a GIS database from which the critical spots will be identified.

The implementation of an integrated information system (integrating a spatial database, a map server and GIS software) will allow us to store the data collected in the field as well as the information produced through the spatial analysis. This information will be available in a web-GIS portal, accompanied by information for producers and all other agents involved in forest management.

Objectives

The aim of this work is to present the methodology applied in the implementation of an integrated information system (a Spatial Data Infrastructure) with GIS technology which can support the research on soil erosion mitigation techniques after forest fires.

The main objective is to produce a tool, based on Geographical Information Technology that is able to store all the data gathered throughout the project which is necessary to develop and implement spatial analysis processes that allow us to identify the critical spots where erosion mitigation techniques should be applied. The ultimate goal is to allow those with responsibilities in managing scorched areas to identify the critical areas where

interventions must be made to obtain the best conservation results at the lowest price. This will have a significant impact on soil conservation, vegetation recover, and, therefore, on the functioning of the ecosystem.

Methodology

Since the start of the project (2007) and during the years of 2007 and 2008, there were no large or high intensity forest fires in central Portugal. These were a necessary condition for the normal development of this project. To overcome this problem, the solution was to choose an area monitorized for a long time: Vale Torto catchment (Penedos de Góis) in Açor Mountain. It's a small (8,9 ha) schist and quartzite catchment, covered by shrubs and located in the municipality of Góis, Coimbra.

The project includes an initial phase of collecting and processing information related to the variables identified for the study and defining the data model to implement and organize the spatial database.

The survey of the study area (Fig. 1) allowed for the three-dimensional modeling of the area and the establishment of a surface runoff/flow modeling.

Also the characterization of land use and soil components (structure, texture, moisture, porosity, etc.), at the slope scale, as well as the analysis of the forest fires factors (intensity, recurrence...), will be used and integrated in the geographic database, allowing for the definition of the variables required in an erosion risk model.

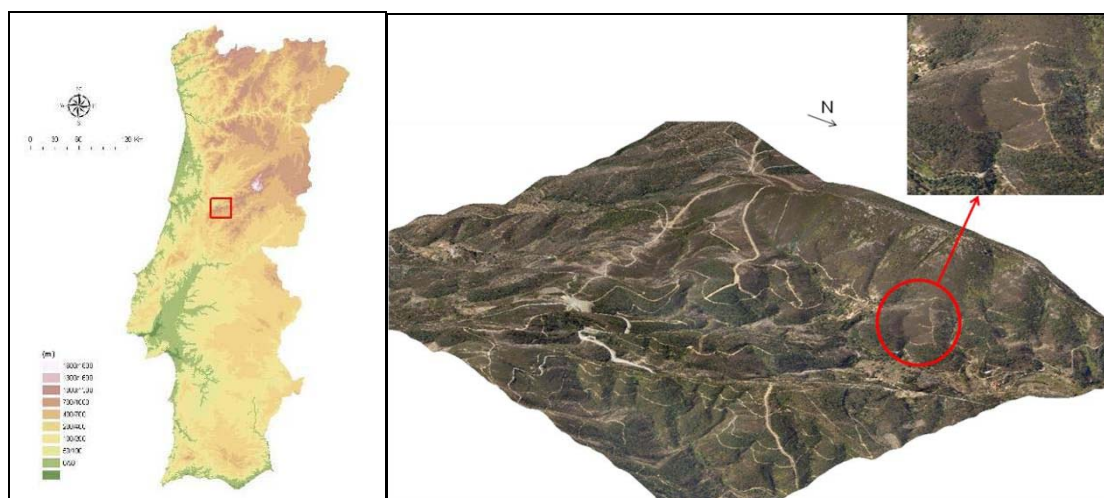


Figure 1. Study area – Vale Torto (Penedos de Góis) in Açor Mountain

Results

The modeling process of the environmental variables has been developed following the need to make explicit its spatial component. Thus, the integration of GIS technology was preferred due to its ability to integrate such models, as well as its efficiency in managing and analyzing large amounts of information and, above all, for its capacity to relate the information based on their spatial expression.

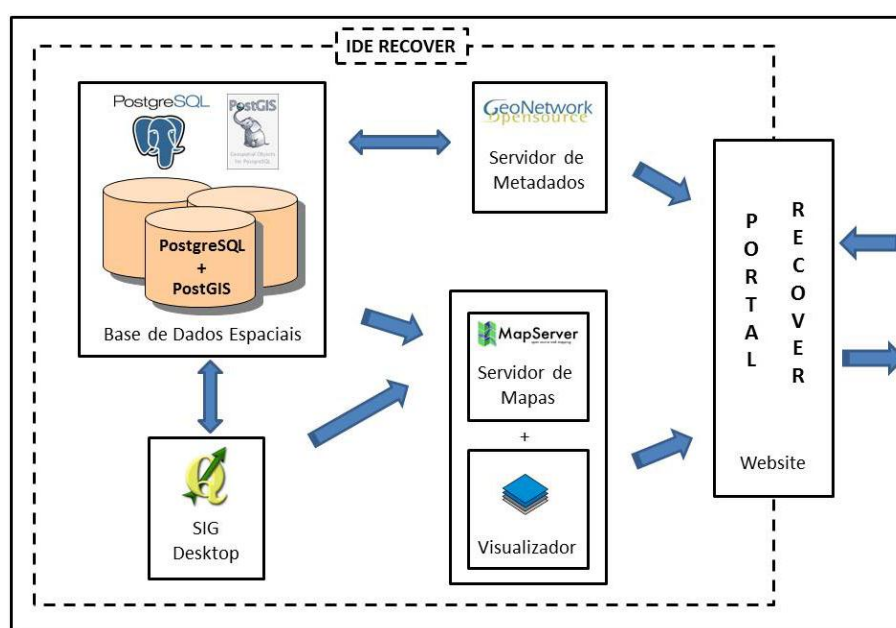
Given the intimate relationship between geomorphological processes and the area in which they are triggered, we consider it appropriate to apply the methodologies of modeling provided by GIS spatial analysis of erosion processes operated in the aftermath of forest fires.

Thus, following the installation and monitoring of erosion plots in various sectors of the slope in the mountain areas occupied with production forest in central Portugal, a wide

range of information concerning several parameters which combine to the genesis of the erosive geomorphological dynamic was produced.

The organization and analysis of the collected data was made based on the implementation of an SDI.

The implementation of an SDI (fig. 2) on such a subject implies the involvement of several components of GIT (Geographic Information Technologies). First of all, it is fundamental to integrate a Spatial Database that allows the storage of a large volume of the spatial data and the alphanumeric data gathered in the field or information acquired from official institutions. This spatial database allows us to implement spatial analysis tools (within the GIS) and integrate and disseminate the outputs through Web GIS solutions. This SDI makes the delivery of project results and its dissemination to the general public easy.



Source: Vieira *et al.*, 2009

Figure 2. Structure of the SDI-RECOVER

Although complex, the structuring of the specific data collected in the spatial database (fig. 3) was essential for the adequate functioning and access by the GIS software. The need for correct integration of the several GIS technologies forced us to establish some SDI principles and components, based on international and national regulations and patterns, namely institutional and normative structure, technology, data policy, data and metadata structure, and web-services.

To implement these web-services the integration of a map server, that will make available the outputs produced through the project, was fundamental.

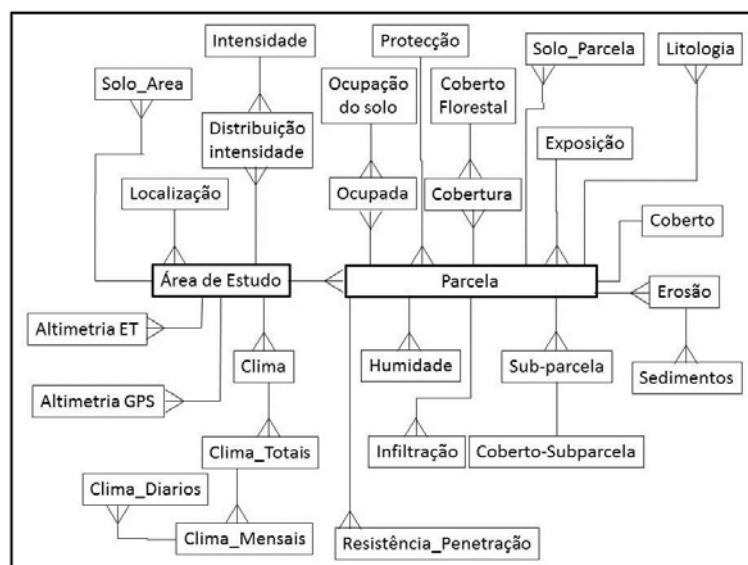


Figure 3. Database model (EAR)

But the key-feature of this SDI and the fundamental tool for the project success is the GIS software, in which we will integrate the modeling process to identify the critical areas for intervention.

In this sense, the development process of modeling the variables will allow for the measurement of possible interrelationships between them and the definition of behavior standards that can lead us to predict those processes in order to determine the validity and effectiveness of the mitigating techniques implemented during the project.

The implementation of the modeling process, conducted with the use of geographic information systems (GIS) technology, will be based on the information gathered, its validity, and reliability, which is stored and structured in a database integrated in the GIS. The results will be available through a web-GIS portal with available web-services (WMS, WFS, WCS, 'Gazetteer Service', CSW).

Conclusions

The information included in the geographic database will develop a variety of modeling operations, initially directed at the study plots, leading afterwards to the development of predictive scenarios. The modeling results will then be generalized to the shed in order to ascertain the validity of extrapolating data and the ability to produce useful indicators of general trends for the decisions on the proper techniques to mitigate erosion of scorched areas.

This spatial database will be a key component of the Integrated Information System, which, at a later stage, will be complemented with a component of spatial analysis (GIS desktop, to develop the processes of data modeling) and a spatial data server, allowing for the implementation of a Web-GIS that will provide the results obtained on the Internet.

Thus, one can draw a reliable structure to store, analyze, and disseminate spatial and alphanumeric data, which is available project RECOVER the web portal, and which integrates GIS technologies for the effective presentation of the spatial information produced.

IDE are valuable tools to numerous public and private institutions worldwide, allowing access to various and valuable information, and providing assistance in the decision-making process.



Aknowledgment

This research was funded by FCT – Fundação para a Ciência e Tecnologia (PTDC/AGR-AAM/73350/2006). The authors thank the LASSICS project (NIGP, ICS, University of Minho) for its support.

References

- Afonso, C. S. P. V. 2008. Infra-estruturas de Dados Espaciais nos Municípios – Contributo para a definição de um modelo de implementação. Dissertação de Mestrado em Ciência e Sistemas de Informação Geográfica, Instituto Superior de Estatística e Gestão de Informação da Universidade Nova de Lisboa, 125 p.
- Benavides-Solorio J, Macdonald LH, 2005. Measurement and prediction of post-fire erosion at the hillslope scale, Colorado Front Range. *International Journal of Wildland Fire*, 14, 457-474.
- Bento Gonçalves, A. J., Vieira, António A., Ferreira, A. D. e Coelho, C., 2008. Caracterização geomorfológica e implementação de um sistema integrado de informação, em ambiente SIG, no âmbito do projecto RECOVER (Estratégias de remediação de solos imediatamente após incêndios florestais”. *Revista Geografia Ensino & Pesquisa*, V. 12, nº 1, Santa Maria, Rio Grande do Sul, Brasil, p.3721-3735.
- Bento Gonçalves, A. J. e Vieira, A. e Ferreira Leite, F. – Mitigation of erosion after forest fires: a geomorphological approach based in GIS modeling. “Actas das Jornadas Internacionales – Investigación y gestión para la protección del suelo y restauración de los ecosistemas forestales afectados por incendios forestales”, 6 a 8 de Outubro de 2010, Santiago de Compostela, 2010, p. 111-114.
- Coelho COA, Ferreira AJD, Boulet AK, Keizer JJ, 2004. Overland flow generation processes, erosion yields and solute loss following different intensity fires. *Quarterly Journal of Engineering Geology and Hydrogeology*, 37, 3, 233-240.
- Goodchild M.F. et al. (Ed.), 1996. GIS and environment modeling. John Wiley & Sons, England. 504 p.
- Loenen, B. 2006. Developing geographic information infrastructures. The role of information policies. DUP Science, Delft University Press, 390 p.
- Longley, P., Goodchild, M., Maguire, D., Rhind, D. 2004. *Geographic Information Systems and Science*. Wiley, 519 p.
- Longley P, Batty M (Ed.), 1997. *Spatial analysis: modeling in a GIS environment*. John Wiley & Sons, England. 392 p.
- Moffet, Correy et al., 2007. Modeling soil erosion on steep sagebrush rangeland before and after prescribed fire. *Catena*, 71, 218-228.
- Shakesby R., Ferreira A.J.D., Ferreira C.S.S., Stoof C.R., Urbanek E., Walsh R.P.D.. Wildfires in Portugal: characteristics, soil degradational impacts and mitigation measures. *Desire*.
- Shekhar S & Chawla S, 2003. *Spatial databases. A tour*. Prentice Hall. 262 p.
- Thomas AD, Walsh RPD, Shakesby RA, 2000. Post-fire forestry management and nutrient losses in eucalyptus and pine plantations, northern Portugal. *Land Degradation & Development*, 11, 257-271.
- Vieira, A. A. B., Gonçalves, A. J. B., Martins, C. O., Loureiro, E. 2009. Sistema integrado de informação, em ambiente SIG, aplicado à erosão de solos na sequência de incêndios florestais. *Geo-Working Paper, Série de Investigação 2009/20, Núcleo de Investigação em Geografia e Planeamento, Universidade do Minho*.



Vieira, A., Bento Gonçalves, A. J., Martins, C e Ferreira Leite, F. – An integrated information system to support research on soil erosion mitigation techniques after forest fire. “Actas do V Congresso Nacional de Geomorfologia”, 8 a 11 de Dezembro de 2010, Apgeom, Porto, 2010,. CD-Rom.



IMMEDIATE POST-FIRE SOIL INTERVENTIONS IN FORESTED AREAS

Celeste Coelho^{a*}, Sérgio Prats^a, Teresa Carvalho^a, Alexandra Pinheiro^a, Anne-Karine Boulet^a, António Ferreira^b

^a Centro de Estudos do Ambiente e do Mar, Departamento de Ambiente e Ordenamento, Universidade de Aveiro, 3810-193 Aveiro (Portugal);

^b Centro de Estudos de Recursos Naturais, Ambiente e Sociedade, Escola Superior Agrária de Coimbra, Bencanta, 3040-316 Coimbra (Portugal).

* coelho@ua.pt

Key-words: Forest fires; Soil erosion; Water conservation; Treatments.

Introduction

The Burned Areas Restoration Project (RAA)², funded by the Permanent Forest Fund, has highlighted the i) state of the art on the characteristics of fires, forest types and tree species; ii) characterization of the relationship between fire and forest and iii) definition of the potential and limitations of the technical intervention options for the management of burned areas.

This project arose from the urgent need to intervene in the recovery of burned areas as a result of the fires of 2003 and 2004 in Portugal.

The recovery of burnt areas in Portugal traditionally involves three distinct phases: the intervention, rehabilitation and restoration/reforestation (Pinho, J. *et al.*, 2005).

The intervention phase follows immediately after the fires and aims to i) control erosion, ii) protect hydrologic network and iii) defense of infrastructure and sensitive habitats.

The rehabilitation phase is developed in the two following years after fire and involves the i) damage assessment and ecosystem response and ii) biophysical recovery actions which may include reforestation of sensitive areas.

The last phase corresponds to the planning and implementation of projects identified for restoration/reforestation, usually three years after the fire occurred.

In this sense, the University of Aveiro had contributed in this project, giving an important emphasis to the different techniques, or treatments, which may be included in the intervention phase. These treatments can be applied immediately after forest fires, to reduce soil erosion and, at the same time, contributing to water conservation.

The erosive processes are particularly concerning, especially during the first rainfall events after fires. These processes may lead to runoff and can initiate rills, sediment loss to water drainages, loss of soil fertility in the long term, and also, erosion of forest roads.

Treatments are applied in an attempt to minimize the constraints caused by fire in the ecosystems. Mitigation measures are essential to reduce ongoing degradation, which means, that the main goal is to reduce further degradation and to improve resources and their functions. The impacts caused by these interventions should become perceptible in short to medium term (WOCAT, 2007).

² Project 2004 09 002629 7 - Burned Areas Restoration - funded by the Specific Actions for the Applied Research, Experimentation and Demonstration under the Permanent Forest Fund. This project is coordinated by the Centro de Ecologia Aplicada "Prof. Baeta Neves" do Instituto Superior de Agronomia, in partnership with the University of Aveiro and the University of Trás-os-Montes e Alto Douro.



Objectives

The central objective is to create and disseminate scientific and technical intervention in the management of burned areas. Although post-fire treatment techniques are available, they are not so often known by the landowners or forest producers, so they cannot be put in practice. The specific objectives of this paper are: i) identify the techniques that can be used in a post-fire context; ii) their potentials and limitations; iii) cost/effectiveness of each technique and iv) distribute and disseminate the collected information.

Methodology

An extensive review of several techniques, which are applied worldwide, to minimize the effects of erosion, was conducted. Therefore, the selection and data collection was done based on research from i) entities that have vast experience in this subject such as the U.S. Forest Services, ii) projects of international scope such as the WOCAT Project - World Overview of Conservation Approaches and Technologies - and iii) the input from several international and national investigations.

The RAA Project also made very good progress using the available information from the synergies arising from several parallel research projects³ underway as a complement to the literature review. For selected treatments, a set of leaflets was produced describing i) the advantages and disadvantages, ii) the method of application, iii) the period of application, iv) the effectiveness and application ratio and v) the estimated cost for each treatment. A total of 26 techniques were selected to be applied on hillslopes (12), channels (4) and forest roads (10) (see Table 1).

The information was put together in leaflets, corresponding each one to one technique. A workshop to discuss the work done and to integrate suggestions from the participants: forest managers and researchers was realized during the RAA project. This workshop worked as an attempt to integrate the participant's views and an effort to disseminate the work done.

Table 1. Description of the selected techniques according to their location.

Hillslopes		Channels	Roads	
Mulch	Contour-Felled Log	Straw Bale Check Dams	Gravel on the running surface	Rubber Deflector
Hydro-Mulch	Straw Wattles	Log Check Dams	Outsloped/Insloped	Open Top culvert
Cords of Mulch	Tillage	Rock Check Dams	Broad Based Dips	Ditch
Seeding	Terraces	Sand, Soil or Gravel Bags	Rolling Dips	Culvert
Hydro-Seeding	Revegetation		Waterbars	
Vegetative Strips	Sediment Fences		Water turnouts	

Results and conclusions

Most of the techniques suitable for application after fire are not very well documented in Portugal. For this reason it was difficult to gather information about their effectiveness and costs. Nevertheless, the expertise of the participants in the mentioned workshop, and the parallel on-going projects, gave an important inside look of what is being done in the country. Most of the techniques are not known and put into practice by landowners (Ribeiro *et al.*, 2011 in this conference). It is interesting to note that even in countries, like U.S.A., most emergency post-fire efforts have been evaluated qualitatively, and in fact,

³ RECOVER Project - "Immediate soil management strategy for recovery after forest fires". Funded by FCT from 2007 to 2010.



only a few quantitative data have been collected (Robichaud *et al.*, 2000). This made it more difficult to obtain information regarding the two most important aspects of the techniques and specific goals purposed: their effectiveness and costs. Also, the existing literature on treatment effectiveness is limited, making treatment comparisons very difficult (Robichaud *et al.*, 2000). For this reason it was not possible to find information on effectiveness for some of the techniques, especially those concerning road mitigation problems. It was even harder to find data on costs for the most of them, even using the Commission for Monitoring of Forest Operations (CAOF) reference in Portugal, because most of the procedures needed for the techniques implementation were not described there. Even though, it was possible to collect a considerable amount of information into a manual with all the selected techniques to be published and made available on-line⁴ to all the key interested parties. 500 printed copies were distributed nationally to the i) National Forest Authority; ii) Municipalities; ii) forestry associations and iii) researchers.

The knowledge of the different available treatments is highly important to assist landowners and forest managers in the decision-making process: to treat or not to treat the burnt area and what type of treatment to apply? This was clearly perceptible by the positive reaction to the release of this manual from the entities who received them.

It is important to mention that all the post-fire rehabilitation efforts will not stop erosion from occurring, but they can reduce some of the undesirable effects such as the amount of runoff and soil loss (Robichaud and Brown, 2005). This is of a major relevance because this mitigation treatments, or techniques, may be used by the ones managing in forest.

Acknowledgment

The research described in this paper was developed under Recuperação de Áreas Ardidas Project, founded by the Permanent Forest Fund (IFAP-FFP) and RECOVER Project - “Estratégias de remediação de solos imediatamente após incêndios florestais” (PTDC/AGR-AAM/73350/2006), funded by the Foundation for Science and Technology (FCT) of Portugal.

References

- Pinho, J., Louro, G., Paulo, S. (2005). Recuperação das áreas ardidas em 2003. Orientações estratégicas. Actas das Comunicações do 5º Congresso Florestal Nacional, 16-19 de Maio, Viseu.
- Ribeiro, C., Coelho, C., Valente, S., Carvalho, T., Figueiredo, E. (2011). Do stakeholders know what happens to soil after forest fires? A case study in Central Portugal. Proceedings book of the International Meeting of Fire Effects on Soil Properties (*in prep.*). 15-19 March of 2011 - Guimarães, Portugal.
- Robichaud, Peter R.; Beyers, Jan L.; Neary, Daniel G. (2000). Evaluating the effectiveness of postfire rehabilitation treatments. Gen. Tech. Rep. RMRS-GTR-63. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.
- Robichaud, P. R.; Brown, R. E. (2005). Postfire Rehabilitation Treatments: Are We Learning What Works? Proceedings of the 2005 Watershed Management Conference. July 19-22, Williamsburg, VA. 13 p.
- WOCAT 2007: where the land is greener - case studies and analysis of soil and water conservation initiatives worldwide. Editors: Hanspeter Liniger and William Critchley.

⁴ http://www.phoenixefi.org/uploads/tecnicas_rel.pdf



Experimental design to model infiltration into a water repellent soil using a crust-type infiltration equation

Dennis Fox*, Cyriel Adnès, Jean Morschel, Frédéric Darboux

Faculty of Geographical Sciences, University of Nice Sophia Antipolis, France

* fox@unice.fr

Key-words: water repellency; hydrophobicity; layered soils; infiltration.

Introduction

The combustion of vegetation during forest fires can lead to the condensation of hydrophobic compounds on mineral matter near the soil surface. The resulting water repellent layer then inhibits water infiltration by altering soil hydraulic conductivity and the water content–soil matric suction relationship. This situation resembles that of a crust or seal capped soil, where a thin layer of reduced hydraulic conductivity overlays a more permeable soil. Although the physical processes leading to a surface seal or crusted layer are different from those of a water repellent layer, the infiltration modelling approach can theoretically be the same, as would be the case for all layered soils. The objective of this study was to test the use of a crust type infiltration equation ($IR = K_{wl}[(h_0 - \psi + Z_{wl})/Z_{wl}]$; where IR =Infiltration rate (cm h^{-1}), K_{wl} =hydraulic conductivity of the water repellent layer (cm h^{-1}), h_0 =depth of ponded water at surface (cm), ψ =sub-layer matric suction (-cm), Z_{wl} =thickness of the water repellent layer (cm)) for water repellent conditions. The study was carried out by applying simulated rainfall on a column of soil with the following dimensions: column diameter=13 cm, soil depth within the column=10 cm, and an underlying coarse sand layer for drainage=10 cm. Runoff from the surface of the column was collected in a beaker that was weighed continuously at 30 s intervals. Instantaneous infiltration was considered equal to the difference between the applied rainfall (about 40 mm h^{-1}) and runoff rates. The soil column was equipped with a tensiometer located near the centre of the column at a depth of 3 cm below the soil surface, and it measured soil matric suction at 30 s intervals. Before each simulation, a mass of oven dried pine needles was applied to the surface and burned in-situ. Different levels of water repellency were generated by varying the amount of pine needles burnt, and water drop penetration time (WDPT) measurements were carried out on all samples before rainfall application. Hence, a range of water repellent conditions was tested for which instantaneous infiltration and matric suction values were recorded. Water repellent layer depth was estimated using WDPT measurements at different depths on separate samples. These samples also served for aggregate stability samples. The infiltration model was then compared to measured values.



Modeling post-fire runoff and erosion at the micro-plot scale under simulated rainfall in eucalypt plantations in north-central Portugal

Diana Catarina Vieira*, Maruxa Malvar, João Pedro Nunes, Jan Jacob Keizer

Centro de Estudos do Ambiente e do Mar (CESAM), Departamento de Ambiente e Ordenamento, Portugal

* dianac.s.vieira@ua.pt

Key-words: wildfire, eucalypt, rainfall simulation experiments, erosion, modeling.

Introduction

Wildfires, through their effects on soil properties as well as on vegetation and litter cover, can lead to considerable changes in geomorphological and hydrological processes. Over the past decades, wildfires in Portugal have devastated on average around 100.000 ha each year, with dramatically higher figures for dry years like 2003 and 2005. The need for a model-based tool for assessing erosion risk following wildfire and, ultimately, guiding post-fire land management, like ERMiT for the Western U.S.A., is evident in the case of Portugal. Following the summer 2003, the EROSFIRE project set out to develop such an erosion prediction tool tailored to the specificities of post-fire conditions in Portugal's forests. Field rainfall simulation experiments (RSE's) were selected as principal method for gathering the data required for testing the suitability of especially the process-based model MEFIDIS for field-scale erosion predictions after wildfire and post-fire land management. In spite of the well-known limitations of RSE's, they have been widely used for studying hydrological and erosion processes in recently burnt woodland areas, especially at spatial scales of 1 m² and less. For as far Portugal is concerned, surprisingly few field RSE studies have been carried out in recently burnt eucalypt plantations. The proposed work will assess how well MEFIDIS can predict the overland flow and associated sediment losses that were produced by repeated RSE's. In total, some 125 RSE's were carried out in six intensive field campaigns during the first two years following wildfire. This was done in six eucalypt plantations on steep slopes that differed in pre-fire ground operations (unploughed, ploughed in downslope direction and along contour lines, terraced). All six study sites were burnt by moderate-severity wildfires, four during the summer of 2005 and the remaining two during the summer of 2006. The six sites were located at relatively close distance (< 10 km) in the municipalities of Albergaria-a-Velha, Águeda and Sever do Vouga, north-central Portugal. Initial MEFIDIS results were encouraging. For example, the marked seasonal variation in overland flow at two of the study sites could be reproduced in a satisfactory manner by calibrating MEFIDIS for severity of topsoil water repellency. This was done by mimicking the infiltration-reducing effect of water repellency, using the Ksat and Psi parameters of MEFIDIS' infiltration equation.



Initial stage of fungal succession in differently managed post-fire pinus mugo plantations on the baltic sea coast

Ernestas Kutorga^{ab*}, Gražina Adamonytė^a, Reda Iršėnaitė^a, Sigitas Juzėnas^b, Jonas Kasparavičius^a, Svetlana Markovskaja^a, Jurga Motiejūnaitė^a, Aušra Treigienė^a

^a Nature Research Centre, Institute of Botany, Laboratory of Mycology, Žaliųjų Ežerų Str. 49, LT-08406 Vilnius, Lithuania

^b Vilnius University, Department of Botany and Genetics, M. K. Čiurlionio Str. 21/27, LT-03101 Vilnius, Lithuania

* ernestas.kutorga@gf.vu.lt

Key-words: Fungi; Pinus mugo; crown-fire; management.

Introduction

High-intensity and severity forest fires strongly affect physical, chemical and biological environment. Post-fire fungal communities play an important ecological role in a recovery of devastated forest ecosystems, particularly in soil stabilization and formation. However, the patterns of fungal dynamics and functioning in variously shaped post-fire habitats of different geographical regions remain poorly documented. The aim of the present study was to investigate the initial stage of fungal succession in differently managed burnt and non-burnt sites of Mountain pine (*Pinus mugo*) plantations on the Baltic Sea coast in western part of Lithuania. The plantations of *P. mugo*, a non-native species in Lithuania, were established during the end of 19th century to minimize the erosion of sand dunes along Baltic Sea coast in the Curonian Spit. The devastating crown-fire in dense and almost pathless stands occurred in 2006 resulting in death of all trees and significant burn of rather thick litter cover on sandy soil in the territory of over 230 ha.

We studied the succession and functional community structure of fungi which inhabited burnt stands in the following 3 years (2007–2009). Anamorphic and teleomorphic ascomycetes, including lichens, as well as basidiomycetes, zygomycetes and myxomycetes were recorded in permanent study plots (500 m² in size), 9 of which were located in burnt and 3 on non-burnt (control) sites. Since forest management of the burnt sites was different, 3 study plots were established in each management variant (without clear-cutting and reforestation; clear-cutting without reforestation; clear-cutting with reforestation by Scots pine (*Pinus sylvestris*)).

Investigation results demonstrate the significant decrease of fungal species richness in the burnt sites and the rapid colonization during subsequent years after the wildfire. Nevertheless, in the third year after wildfire the species composition of different taxonomical fungal groups in burnt sites was still poorer than that of non-burnt sites. Different forest management methods influenced the species composition. In general, the higher species diversity was registered in uncut charred stands than in clear-cuts, probably because the removal of burned woody material diminished the quantity and quality of suitable substrates and microhabitats, especially for wood-rotting fungi. Reforestation by tree seedlings determined the establishment of some specific parasitic species. The phenomenon of abundant fruiting of several pyrophilic and wood-inhabiting species was observed during first two years after the fire. In all study plots saprotrophic species diversity was higher than that for parasitic, symbiotrophic mycorrhizal and lichenized species.

The frequency of fires and land degradation - Cabeço da Vessada do Monte, Serra da Cabreira

Flora Ferreira Leite^{a*}, António Bento Gonçalves^b, António Vieira^b, Luís da Vinha^c

^a Centro de Estudos em Geografia e Ordenamento do Território (CEGOT), Núcleo de Investigação em Geografia e Planeamento (NIGP), Departamento de Geografia (Pd.D. Student), Minho University, Campus de Azurém, 4800-058 Guimarães (Portugal),

^b Centro de Estudos em Geografia e Ordenamento do Território (CEGOT), Núcleo de Investigação em Geografia e Planeamento (NIGP), Departamento de Geografia, Minho University, Campus de Azurém, 4800-058 Guimarães (Portugal);

^c Núcleo de Investigação em Geografia e Planeamento (NIGP), Minho University, Campus de Azurém, 4800-058 Guimarães (Portugal)

* floraferreiraleite@gmail.com

Key-words: Cabreira mountain, forest fires, recurrence interval, soil degradation

Introduction

The mapping on the spatial distribution of scorched areas in the municipality of Vieira do Minho, in the period 1990-2007, unequivocally confirms the high vulnerability of this territory to forest fires (Bento-Gonçalves, A., 2006, Ferreira-Leite et al., 2010), especially in the area of the Serra da Cabreira.

The maximum recurrence of fires in this area, recorded over a period of 18 years (1970-2007) shows that in some situations certain areas were scorched by fire five times, as is the case of Cabeço da Vessada do Monte, which is located in the northern sector of Serra da Cabreira, in the Cabeço da Vaca (Ferreira-Leite, F. and Bento-Gonçalves, A., 2008) (Fig. 1).

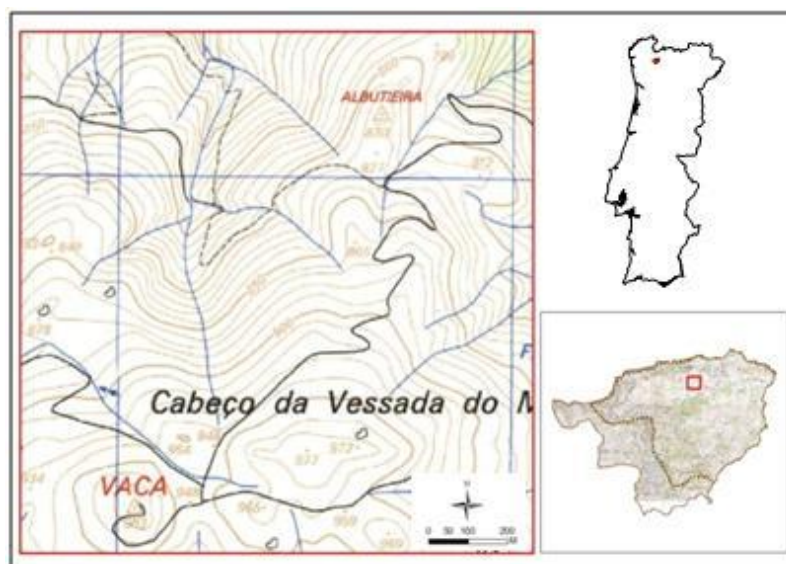


Figure 1. Location of the Cabeço da Vessada do Monte study area

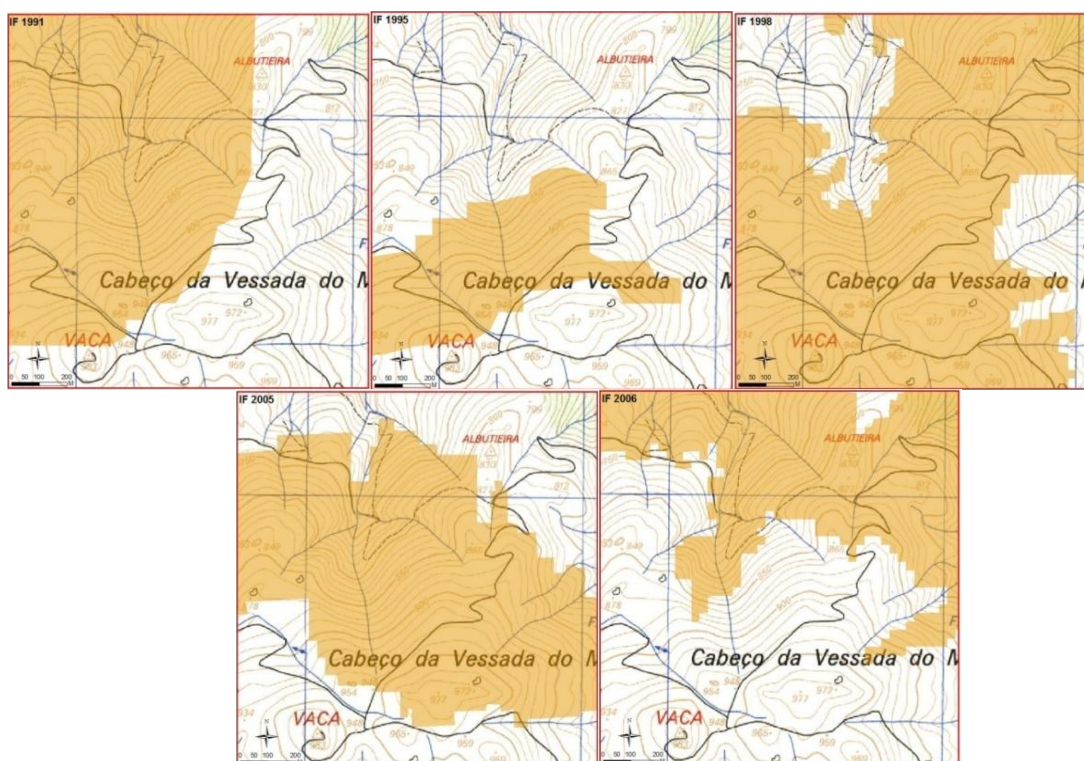


Figure. 3. Burnt areas in 1991, 1995, 1998, 2005 e 2006 - Cabeço da Vessada do Monte study area.

Similarly to what happened in much of the mountain, the area of Cabeço da Vessada do Monte was scorched by the great fires of 1975 and 1981. These scorched almost all the decades old forest (Bento Gonçalves, 2006), which accounted, as already mentioned, for the replacement of the woodlands by thickets.

Subsequently, many reforestation plans have been approved throughout the years, corresponding to the reforestation several dozen hectares. However, most plans did not make it off the paper. In the cases when they did, most of the times the young stands were scorched before they could ever develop into true forest areas.

This area has been particularly affected by the more recent forest fires, having been scorched by fire, between 1990 and 2007. It was scorched a maximum of 5 times (Fig. 2), in the years 1991, 1995, 1998, 2005 and 2006 (Fig. 3).

In the medium term, there seems to be a tendency for the time required for these same areas to be scorched again to be lessened, revealing that some portions of this territory are subject to frequent and sometimes large demonstrations of forest fire risk (Ferreira-Leite, F. et al., 2010).

Unlike the fires of the 1970s and early 1980s that were of high intensity due to the presence of adult forest tree populations, the fires more recent fires have occurred essentially in scrublands meaning that the fires are of medium and low intensity.

In this area, where soil is still present, weeds can reach 50 cm in height in about 2 years (photo 1), which makes for a high level of combustibility that allows fires to occur every two years. This is due, in large part, to the high levels of precipitation (Table I).

TABLE I. Udometeric Post located in the Cabreira Mountain, Municipality of Vieira do Minho (1961-1990).

Udometeric Post	Average Annual Precipitation (mm)	Altitude (m)
Guilhofrei	2705,7	350
Salamonde	2281,9	550
Zebral	3071,1	775

Source: INMG, 1961-1990

In effect, the precipitation concentrated in the autumn and winter months could help to dramatically accelerate the erosion process. However, despite this concentration, it occurs throughout the whole year, contributing primarily to a very fast recovery rate of vegetation, allowing for a high productivity of biomass that will be crucial in protecting the soil against physical erosion (fot. 2).



Photo 1 and 2. Scrublands in serra da Cabreira, municipality of Vieira do Minho.

In fact, the scrublands are the dominant trait in the regional landscape, mainly due to the fact that it represents about 50% of the total occupied area of the mountain (Smith, 2000, p. 46).

Inside the scrubland unit there are several types of species, namely the *Cytisus striatus*, *Genista cinerea*, *Erica arborea* L. There are also areas where other species, such as *Ulex* and various types of heathers, are predominant.

These species have pyrophytic characteristics, with flammability and calorific values of medium to high level (Table II), which can influence fire behaviour and facilitate the ignition and consequent spread of fires.

Table II. Inflammability and Calorific power - shrub species.

	Inflammability	Calorific power
<i>Erica</i>	medium	high
<i>Genista falcata</i>	medium	high
<i>Ulex parviflorus</i>	medium	high
<i>Cytisus multiflorus</i>	low	high

low medium high unknown

Source: Adapted from Vallette, 1990; Martin and Lara, 1989 in Silva e Páscoa, 2002.

Rather than consider the different species in isolation, it is especially important to characterize the vegetation formed by these species. Therefore, we are also interested in the combustibility of scrubland (Table III), since this landscape unit is the dominant type in the study area.

Table III – Combustibility of scrubland.

Underdeveloped Height <30 cm	low
Intermediate Height 30-50 cm	medium
Developed Height >50 cm	high

Source: Adapted from Ronde *in* Silva and Páscoa, 2002

By destroying or reducing, even if temporarily, the vegetation coverage and taking into account the dominant presence of steep slopes (Ferreira-Leite, F., 2008) and the high values of precipitation, the fire contribute significantly to degrading the soil and accelerating erosion. However, the severity of this degradation is a function of the frequency and the intensity patterns of the fires.

The low intensity of recent fires⁵, due to a high recurrence rate, can be verified in the field immediately after their occurrence. Also, the severity of the effect of the recurrence of the fires was evaluated using the vegetation as a bioindicator of the soil status (Calvo, 1996), and it was found that, on average, where there was soil (cambisols - 10-20 cm) it was dense to less dense and the roots were covered, thus indicating a low degree of physical erosion, a fact corroborated by the presence of small incisions and marks on the ground.

Concluding Remarks

In the international literature there are many studies on the effects of different intensities of fires on soil properties (Smith, A. et al. 2010; Jordán, A. et al. 2010; Lawrence, L., 2010). However, the frequency has been relatively under studied, which calls for promoting this kind of study.

This study, albeit in a very early stage, plans to launch the discussion on the relationship between the frequency of fires and physical erosion, showing that in particular situations, a high frequency does not always correspond to an accelerating loss of soil.

Indeed, in our sample area, which has a recurrence of up to 5 fires, the recovery rate of vegetation seems to go against the physical loss of soil. This is due to the high volume of precipitation, which contributes decisively to the high rate of vegetation growth which avoids that the soil is not unprotected for too long and subject to an accelerated erosion process.

References

- Bento Gonçalves, A. J. (2006) – *Geografia dos incêndios em espaços Silvestres de Montanha – o caso da serra da Cabreira*, Tese de Doutoramento, Instituto de Ciências Sociais da Universidade do Minho, Braga, 438 pp.
- Bento Gonçalves, A. J. (2006) – “A “construção” e a “desconstrução” do património florestal português no séc. XX – breve abordagem ao caso do concelho de Vieira do

⁵ Fires with an area of less than 10ha, maintenance of some green branches, partially or totally burned shrubs (Lampin et al., 2003).



- Minho”. GEO-Working Papers, Série de Investigação 2006/8, NIGP – Universidade do Minho, Guimarães.
- Calvo, D. A. (2002) – *Ciencias de la tierra y del médio ambiente*, 2.º Bachillerato, McGraw-Hill, Madrid, 333pp.
- Ferreira Leite, F. e Bento Gonçalves, A. J. (2008) – “Alterações no ciclo de fogo na serra da Cabreira”, *Actas XI Colóquio Ibérico de Geografia*, Universidad de Alcalá de Henares, Espanha.
- Ferreira Leite, F.; Bento Gonçalves, A.J.; Vieira, A. e Martins, C. (2010) – “A recorrência dos incêndios na serra da Cabreira como manifestação do risco de incêndio florestal”, *Territorium* 17, 2010, p. 93-98.
- Ferreiro, A., Fontúrbel, T., Fernández, C., Merino, A., Veja, J. A. (2010) – “Indicadores visuales de severidad del fuego y relaciones com câmbios en parâmetros químicos y microbiológicos después de incêndio”, *Jornadas Internacionales*, Diaz Raviña, M., Benito, E., Carballas, T., Fontúrbel, M. T., Veja, J. A. (eds.) - *Investigación y Gestión para la Protección del Suelo y Restauración de los Ecosistemas Forestales Afectados por Incendios Forestales*, FUEGORED 2010, Santiago de Compostela.
- Jordán, A., Zavala, L. M., Mataix-Solera, J. (2010) – “Impact of fire severity on soil structure and water repellency in the neo-volcanic axis range (Central Mexico)”, *Jornadas Internacionales*, Diaz Raviña, M., Benito, E., Carballas, T., Fontúrbel, M. T., Veja, J. A. (eds.) - *Investigación y Gestión para la Protección del Suelo y Restauración de los Ecosistemas Forestales Afectados por Incendios Forestales*, FUEGORED 2010, Santiago de Compostela.
- Lampin-Cabaret C., Jappiot, M., Alibert, N. e Manlay, R. (2003) – “Une échelle d'intensité pour le phénomène Incendie de forêts”, *SIRNAT – JPRN Orléans*.
- Lourenço, L., Bento Gonçalves, A. (2010) – “Erosión violenta post-incendios forestales en Portugal”, *Jornadas Internacionales*, Diaz Raviña, M., Benito, E., Carballas, T., Fontúrbel, M. T., Veja, J. A. (eds.) - *Investigación y Gestión para la Protección del Suelo y Restauración de los Ecosistemas Forestales Afectados por Incendios Forestales*, FUEGORED 2010, Santiago de Compostela.
- Pyne, S. J. *et al.* (1996) – *Introduction to Wildland Fire*, New York. John Wiley & Sons.
- Soares, A. (coord.) (2000) – *Atlas da fauna e flora da serra da Cabreira*, CIASC, p. 219.



Rainfall simulations and forest fires in the central sector of the Ebro basin

León, F.J.^{1*}, Álvarez, C.², Badía, D.³, Echeverría, M.¹, Martí, C.³ e Ibarra, P.¹

¹ Departamento de Geografía y Ordenación del Territorio. Universidad de Zaragoza. Pedro Cerbuna, 12, 50009 Zaragoza. España;

² Department of Environmental Sciences. Wageningen University. The Neetherlands;

³ Departamento de Agricultura y Economía Agraria. Escuela Politécnica Superior de Huesca. Universidad de Zaragoza. C^a de Zaragoza, s/n, 22071-Huesca. España.

* fcojleon@unizar.es

Key-words: Rainfall simulation, runoff and sediment production, mulching.

Introduction

Wildfire can be an important cause of hydrological and geomorphological change in fire-prone landscape because wildfires usually burn in mosaic patterns with portions of the area burned in low, moderate, and high severity conditions as defined by Ryan and Noste (1983) and DeBano *et al.* (1998). The loss of vegetation and litter cover represents the obvious changes in the burned landscape. Litter and plant canopies reduce the final drop impact energy, and the root system can act as a preferential flow path for infiltration. On the other hand, due to soil heating caused by fires of soils tend to alter their properties (Badía and Martí, 2003a, 2003b, 2008) including soil aggregate stability, infiltration, and water repellency (DeBano, 2000; Cerdà and Doerr, 2005; Doerr *et al.*, 2006). These changes often result in enhanced soil erosion and overland flow on sloping landscapes. The magnitude of these effects depends on an often complex interplay of factors including climate, plant, litter, terrain, post-fire rainfall patterns, type of cover (stones or ash) and, soil and fire characteristics (Cerdà and Doerr, 2005; Badía and Martí, 2008). Generally, fire-enhances water repellency and increases runoff and soil erosion (Shakersby *et al.*, 2007), but in some cases burned soils covered by ashes, are protected from soil erosion during the first year after being burned (Leighton-Boice *et al.*, 2007; Woods and Balfour, 2008; Cerdà and Doerr, 2008).

On the other hand, some practices proposed to improve soil physical characteristics and reduce soil erosion in semiarid land include herb or shrub sowing management (Vallejo *et al.*, 1993; Bautista and Bellot, 1994; Badía and Martí, 2000). Also in post-fire rehabilitation, mulches are intended to reduce rain impact and overland flow and keep the soil in place. Mulches are considered emergency hillslope measures, which are the first line of defence against post-fire erosion and off-site impacts of sediments and floods (Robichaud *et al.*, 2006; Bautista *et al.*, 2009). These rainfall simulation experiments give the opportunity to compare the soil erodibility in selected micro-plots with specific fire, terrain, and rainfall characteristics.

Objectives

A rainfall simulator was used to analyze the hydrogeomorphological behaviour of the soil after two fires. Those fires occurred in August 2008 and 2009 in the central sector of the Ebro Basin. Different spatial scenarios have been selected both in burnt (forest, shrub) and unburnt areas, on two different substrates, gypsum and limestone. In addition, rainfall simulation tests were conducted on plots covered with woodchip-mulching.

The objectives of the rainfall simulations were: (i) to quantify the different behaviour of post-fire erosion and runoff based on lithology and the type of burnt vegetation, and (ii) to

monitor the effectiveness of applying mulch on top of the plots of the simulation plots after the fire.

Material and methods

Study area:

The first area of study (Zuera) was affected by the fire of August 2008 that burned some 2,800 ha and is located in the Montes de Castejon (UTM 30N; 668427W, 4646689N), left bank of the Ebro River, about 50 km Northwest of the city of Zaragoza. The burnt vegetation is represented by irregular mosaics of Aleppo pine (*Pinus halepensis* Mill), Kermes oak (*Quercus coccifera*), and associations of Cervo-thymus-gorse on soils classified as *Haploxeroll pachic* at the top and bottom *Calcixeroll pachic* (NCRS: Soil Taxonomy System, 2006).

The second study area (Remolinos) is located close to the first one (UTM 658881W, 4638913N). This fire took place in August 2009, during some military manoeuvres, and affected 6,700 ha of scrub - gorse (*Genistascorpius*), broom (*Retamasphaerocarpa* L.), rosemary (*Rosmarinus officinalis*) as well as small forests of Aleppo pine (*Pinushalepensis* Mill) and Kermes oak (*Quercus coccifera*). This region has a semiarid Mediterranean climate, with an average annual rainfall ca 560 mm and a mean annual temperature of 12.5°C. The potential annual evaporative demand, estimated by Thornthwaite method is ca 950 mm. The relief consists of stepped slopes (200-748 masl) and the lithological substrate consists of limestones and gypsiferous marls, dated from the middle Miocene.

Rainfall simulation experiment:

The rainfall simulations were carried out, with a two stroke motor-pump (*Matabi*) and a cone-atomizing nozzle (*Lechler*) were used on a series of 12%-average-slope plots applying a rainfall intensity of about 60 mm/h for half an hour on a 0.21-m²-wide and ca 2.2-metre-high plot. The rainfall simulator was calibrated with a Laser Disdrometer (Thies) with the collaboration of Iserloh of Trier University. Rainfall characteristics were 97.8% of Christiansen Coefficient for the rainfall distribution at 52.5 mm h⁻¹, with a mean drop-size of 0.5·1 mm (D₅₀), and a Kinetic energy of 4.16 J m⁻² mm⁻¹. The plots' compositions were, shrub or tree. Also, the effect of mulching with Aleppo pinewoodchips was analyzed using the same plots, to see how it affected runoff. Finally the runoff was collected and the concentration of sediment yield determined the rate of erosion and water quality. The sediment samples were analyzed to determine pH, Electrical Conductivity and the concentration of Ca²⁺, Mg²⁺, K⁺ and Na⁺. In total 66 rainfall simulations were made (three replicates per treatment were carried out).

Results and conclusions

Runoff was different when comparing limestone and gypsum affected by wildfire (*Fig. 1, Table 1 and 2*), on limestone it was half as seen on other studies such as Badía and Martí (2000). On the other hand, runoff was lower in burnt limestone compared with unburnt, it was covered by ash, this has also been observed by other authors (Leighton-Boice *et al.*, 2007; Woods and Balfour, 2008; Cerdà and Doerr, 2008). The role of vegetation type was important, as it affected the runoff. Runoff was lower for calcareous soil than for gypsiferous soil, but it changed drastically according to the different vegetation types. On calcareous soils, runoff with shrubland was lower than with pine forest, as found by Cerdà (1998) in a Mediterranean shrubland. On gypsiferous soil it was the opposite, runoff on shrubland was higher than under pine forest. Finally the role of the wood chip-

mulching was more important for small amounts of runoff both on limestone and gypsum soils. Different types of mulching application have been seeing in studies of revegetation and post-fire rehabilitation (Vallejo et al., 1993; Bautista and Bellot, 1994; Badía and Martí, 2000; Robichaud et al., 2006; Bautista et al., 2009).

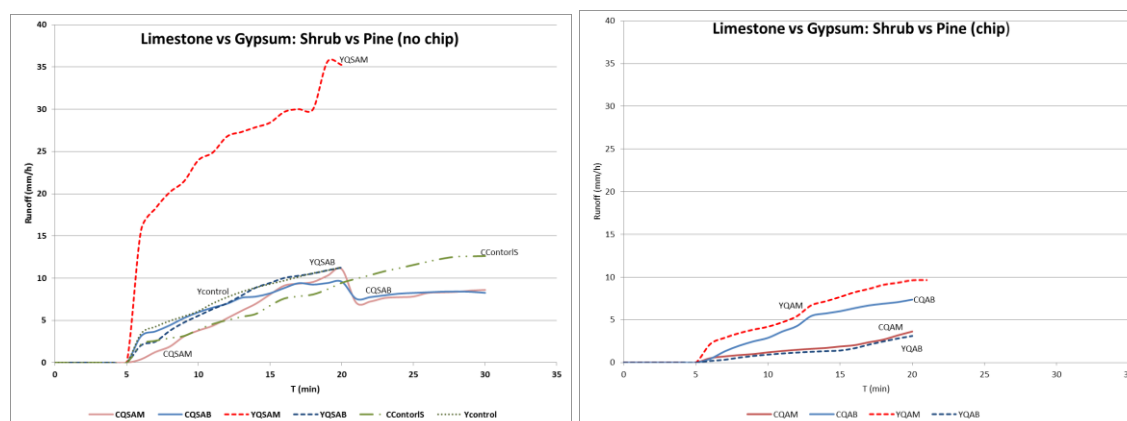


Figure 1. Mean runoff curves for the limestone and gypsum. (C) Limestone; (Y) Gypsum; (Q) burnt; (SA) no chip; (A) chip; (M) shrub; (B) pine.

Table 1. Field values. (T) type: (C) unburnt; (Q) burnt; (Ttm) treatment: (SA) no chip; (A) chip; (Tveg) vegetation type: (M) shrub; (B) pine.

LIMESTONE	Ponding time	Runoff Coef	Runoff Ratio	Sediment	Infiltration Coef
T Ttm Tveg	(min)	(%)	(mm/h)	($\text{gm}^{-2}\text{h}^{-1}$)	(%)
C SA M	3,28 $\pm$ 0,3	25,24 $\pm$ 22,5	12,62 $\pm$ 11,3	113,06 $\pm$ 124,3	74,76 $\pm$ 22,5
Q SA M	6,31 $\pm$ 2,7	24,42 $\pm$ 15,3	12,21 $\pm$ 7,69	51,75 $\pm$ 59,1	75,58 $\pm$ 15,3
Q SA B	3,77 $\pm$ 1,3	19,55 $\pm$ 3,7	9,78 $\pm$ 1,8	131,27 $\pm$ 112,4	80,45 $\pm$ 3,7
Q A M	5,83 $\pm$ 3,4	7,28 $\pm$ 3,5	3,64 $\pm$ 1,7	31,81 $\pm$ 15,1	92,72 $\pm$ 3,5
Q A B	5,18 $\pm$ 1,6	14,76 $\pm$ 12,2	7,38 $\pm$ 6,1	70,60 $\pm$ 40,7	85,24 $\pm$ 12,2

Table 2. Field values. (T) type: (C) unburnt; (Q) burnt; (Ttm) treatment: (SA) no chip; (A) chip; (Tveg) vegetation type: (M) shrub; (B) pine.

GYPSUM	Ponding time	Runoff Coef	Runoff Ratio	Sediment	Infiltration Coef
T Ttm Tveg	(min)	(%)	(mm/h)	($\text{gm}^{-2}\text{h}^{-1}$)	(%)
C SA M	3,87 $\pm$ 0,6	21,77 $\pm$ 6,1	10,89 $\pm$ 3,0	149,22 $\pm$ 284,9	78,23 $\pm$ 6,1
Q SA M	3,31 $\pm$ 1,0	59,73 $\pm$ 18,6	29,87 $\pm$ 9,3	911,72 $\pm$ 394,6	40,27 $\pm$ 18,6
Q SA B	4,62 $\pm$ 1,6	21,16 $\pm$ 5,2	10,58 $\pm$ 2,6	137,69 $\pm$ 21,3	78,84 $\pm$ 5,2
Q A M	5,65 $\pm$ 1,1	19,49 $\pm$ 13,5	9,75 $\pm$ 6,7	128,89 $\pm$ 116,3	80,51 $\pm$ 13,5
Q A B	6,36 $\pm$ 1,6	6,24 $\pm$ 0,8	3,12 $\pm$ 0,4	51,02 $\pm$ 4,8	93,76 $\pm$ 0,8

The laboratory analyses are shown on the Fig. 2 and Table 3 and 4. The pH was higher for calcareous and gypsiferous burnt soils, than for unburnt. And the EC was lower for calcareous and gypsiferous burnt soils than for unburnt. The amount of Ca^{2+} , decreases with the effect of fire, this is higher on gypsiferous soils than on limestone. But the amount of K^{+} increases with the effect of fire, finding higher concentrations on gypsiferous soils.

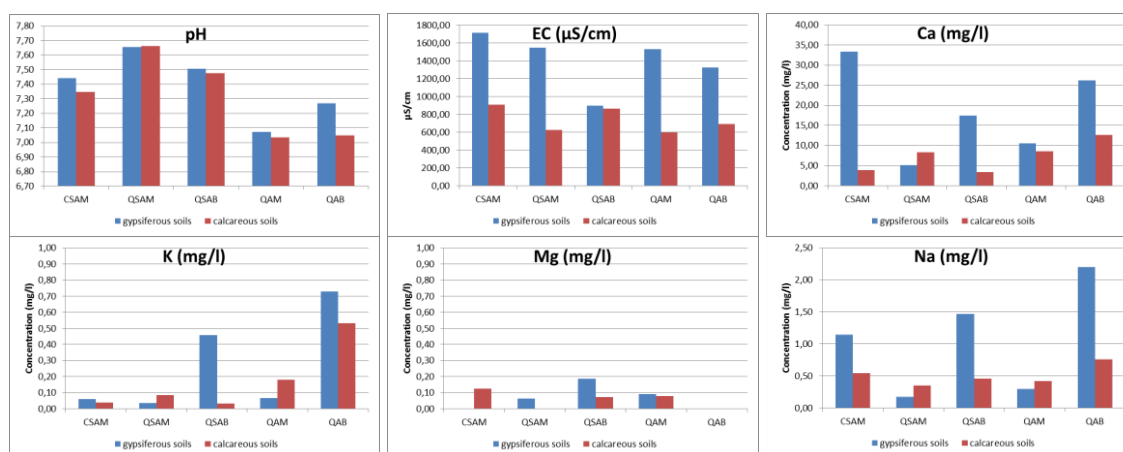


Figure 2. Laboratory parameters measure on runoff. (C) unburnt; (Q) burnt; (SA) no chip; (A) chip; (M) shrub; (B) pine.

The concentrations of Mg^{2+} have no significant changes when comparing the gypsiferous and limestone soils. These results show a similar pattern showed in calcareous soils in the work of Outeiro et al. (2008). On burned areas when the wood-chips mulching were used, the concentration of Na^+ , K^+ , Mg^{2+} are lower than when no wood-chips were used.

Table 3. Laboratory values. (T) type: (C) unburnt; (Q) burnt; (Ttm) treatment: (SA) no chip; (A) chip; (Tveg) vegetation type: (M) shrub; (B) pine.

LIMESTONE			pH	Ce ($\mu S/cm$)	Na^+ (mg/l)	Mg^{2+} (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)
T	Ttm	Tveg						
C	SA	M	7,35 $\pm$ 0,15	907,61 $\pm$ 639,5	0,55 $\pm$ 0,7	0,13 $\pm$ 0,18	0,04 $\pm$ 0,06	3,88 $\pm$ 5,4
Q	SA	M	7,66 $\pm$ 0,43	624,83 $\pm$ 26,1	0,35 $\pm$ 0,6	0,00 $\pm$ 0,00	0,08 $\pm$ 0,15	8,33 $\pm$ 14,4
Q	SA	B	7,47 $\pm$ 0,44	864,94 $\pm$ 278,2	0,46 $\pm$ 0,9	0,07 $\pm$ 0,15	0,03 $\pm$ 0,07	3,45 $\pm$ 6,9
Q	A	M	7,03 $\pm$ 0,03	595,22 $\pm$ 59,5	0,42 $\pm$ 0,3	0,08 $\pm$ 0,14	0,18 $\pm$ 0,16	8,53 $\pm$ 7,4
Q	A	B	7,05 $\pm$ 0,03	690,39 $\pm$ 24,1	0,76 $\pm$ 1,0	0,00 $\pm$ 0,00	0,53 $\pm$ 0,75	12,65 $\pm$ 17,8

Table 4. Laboratory values. (T) type: (C) unburnt; (Q) burnt; (Ttm) treatment: (SA) no chip; (A) chip; (Tveg) vegetation type: (M) shrub; (B) pine.

GYPSUM			pH	Ce ($\mu S/cm$)	Na^+ (mg/l)	Mg^{2+} (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)
T	Ttm	Tveg						
C	SA	M	7,44 $\pm$ 0,26	1713,49 $\pm$ 228,7	1,15 $\pm$ 1,9	0,00 $\pm$ 0,0	0,06 $\pm$ 0,1	33,34 $\pm$ 57,7
Q	SA	M	7,65 $\pm$ 0,06	1544,58 $\pm$ 182,5	0,17 $\pm$ 0,3	0,06 $\pm$ 0,1	0,03 $\pm$ 0,06	5,08 $\pm$ 8,7
Q	SA	B	7,51 $\pm$ 0,11	899,15 $\pm$ 129,8	1,47 $\pm$ 1,2	0,19 $\pm$ 0,3	0,46 $\pm$ 0,5	17,46 $\pm$ 13,5
Q	A	M	7,07 $\pm$ 0,15	1528,88 $\pm$ 110,6	0,30 $\pm$ 0,5	0,09 $\pm$ 0,1	0,07 $\pm$ 0,1	10,54 $\pm$ 18,2
Q	A	B	7,27 $\pm$ 0,05	1323,50 $\pm$ 195,8	2,20 $\pm$ 3,1	0,00 $\pm$ 0,0	0,73 $\pm$ 1,0	26,15 $\pm$ 36,9

The results show that the infiltration rates and the runoff and sediment production are strongly affected by the lithology substrate and the remains of vegetation cover after the fire. Higher infiltration rates were obtained on burned forest areas compared to burned shrub ones, and on limestone compared to gypsum areas. The application of mulching is an effective measure to reduce runoff.

References

- Badía, D., Martí, C., 2000. Seeding and mulching treatments as conservation measures of two burned soils in the Central Ebro Valley, NE Spain. *Arid Soil Research and Rehabilitation* 13, 219-232.
- Badía, D., Martí, C., 2003a. Plant and heat intensity effects on chemical and physical properties of two contrasting soils. *Arid Land Research and Management* 17, 23-44.



- Badía, D., Martí, C., 2003b. Effect of simulated fire on organic matter and selected microbiological properties of two contrasting soils. *Arid Land Research and Management* 17, 55-69.
- Badía, D., Martí, C., 2008. Fire and rainfall Energy effects on soil erosion and runoff generation in semi-arid forested lands. *Arid Land Research and Management* 22, 93-108.
- Bautista, S., Bellot, J., 1994. Evaluación de la siembra de herbáceas como tratamiento de control de los procesos erosivos post-incendio en una zona semiárida. *Studia Oecologica* 10-11, 129-136.
- Bautista, S. et al. (2009): "Post-fire mulching". *Land Reconstruction and Management*, Vol. 5, Oxford, 353-371 pp.
- Cerda, A. (1998a). Changes in overland flow and infiltration after a rangeland fire in a Mediterranean scrubland. *Hydrological Processes* 12, 1031-1042.
- Cerda, A. (1998b). Post-fire dynamics of erosional processes under Mediterranean climatic conditions. *Zeitschrift fur Geomorphologie* 42, 373-398.
- Cerdá, A., Doerr, S.H., 2005. Influence of vegetation recovery on soil hydrology and erodibility following fire: An 11-any investigation. *International Journal of Wildland Fire* 14, 423-437.
- Cerda, A., Doerr, S.H. (2008). The effect of ash and needle cover on surface runoff and erosion in the immediate post-fire period. *Catena* 74, 256-263.
- DeBano, L.F. (2000). The role of fire and soil heating on water repellence in wildland environments: a review. *Journal of Hydrology* 231, 195-206.
- Doerr, S.H., Shakesby, R.A., Walsh, R.P.D. (2000). Soil water repellency: its causes, characteristics and hydro-geomorphological significance. *Earth-Science Reviews* 51, 33-65.
- Doerr, S.H., Shakesby, R.A., Decker, L.W., Rittsema, C.J., (2006b). Occurrence, prediction and hydrological effects of water repellency amongst major soil and land-use types in a humid temperature climate. *European Journal of Soil Science* 57, 741-754.
- Horton, R. I. (1938). The interpretation and application of runoff plot experiments with reference to soil erosion problems. *Soil Science Society of America Proceedings* 3: 340-349.
- Mishra, S.K., Tyagi, J.V., Singh, V.P. (2003). Comparison of infiltration models. *Hydrological processes*. 17, 2629-2652.
- Moriasi, D.N., Arnold, J.G., Van Liew, Bingner, R.L., Harmel, R.D., Veith, T.L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, volume 50 (3): 885-900.
- Outeiro L., Asperó F., Úbeda X. (2008). Geostatistical methods to study spatial variability of soil cations after a prescribed fire and rainfall. *Catena* 74, 310-320.
- Shakesby, R.A., Doerr, S.H. (2006). Wildfire as a hydrological and geomorphological agent. *Earth-Science Reviews* 74, 269-307
- Vallejo, V.R., Bellot, J., Ferran, A. (Eds), 1993. *Revegetación de áreas quemadas en la Comunidad Valenciana*. *Ecosistemas* 4, 41-43.
- Woods, S.W., Balfour, V.N. (2008). The effect of ash on runoff and erosion after a severe forest wildfire, Montana, USA. *International Journal of Wildland Fire* 17(5), 535-548.



The effect of recurrent rainfall events on the hydrological changes of soil surfaces covered by ash.

León, F. J.^{1*}, Bodí, M.B.^{2,3}, Cerdà, A.², Mataix-Solera, J.³, Echeverría, M.¹

¹ Dpto. de Geografía y Ordenación del Territorio, Universidad de Zaragoza, Pedro Cerbuna 12, 50009, Zaragoza, Spain.

² Departamento de Geografía, Universitat de València, BlascoIbañez, 28, 46010, Valencia, Spain.

³ Departamento de agroquímica y Medio Ambiente, Universidad Miguel Hernández, Edificio Alcudia, Avda de la Universidad s/n. 03202 Elche, Spain.

* fcojleon@unizar.es

Key-words: White ash, black ash, rainfall simulation, water quality.

Introduction

The magnitude of the post-fire hydrogeomorphic response depends of the loss of surface litter, duff and other organic ground cover (Cerdà, 1998a; Woods et al., 2008), the soil water repellency (DeBano, 2000; Doerr et al., 2000, 2006; Shakesby et al. 2000) and the effects of heating on the soil structure (Mataix-Solera and Doerr, 2004). Some factors affecting hillslope responses, however, can change substantially within the first days or weeks following burning (Cerdà and Doerr, 2008).

The scientific community is being aware that ash is a key factor has critical importance in determining rates of overland flow and soil erosion (Woods and Balfour, 2008; Cerdà and Doerr, 2008). The highest levels of nutrients and suspended sediments in the streams have been measured during after the wildfire and during the first storms. One of the main responsible of this increase in the sediment and solute yield from slopes to channels and then to the watercourses is a new rich-nutrient material product that we can find after fire. The ash however, it has been reported a variability in its effects, from increasing runoff rates and soil erosion to reduce them. This variability is due to the ash physical characteristics (porosity, particle size or hydraulic conductivity) depending on the temperature of combustion and plant (Ulery et al., 1993; Neary et al., 2005; Woods and Balfour, 2008).

Ash is considered to increase post-fire erosion rates, because they are erodible fine material (Shakesby and Doerr, 2006). But in recent studies have been demonstrated that ash can reduce the runoff rate and protecting the soil surface from rainsplash impacts (Leighton-Boyce et al., 2007; Cerdà and Doerr, 2008; Woods and Balfour, 2008). Then, if ash temporarily reduces runoff and erosion from burned areas, then the highest risk of damaging runoff and erosion events may be delayed until after the ash layer is removed by dissolution or erosion (Cerdà and Doerr, 2008; Woods and Balfour, 2008).

The chemical composition of the ash has been mostly studied using a leaching test, which informs about the potential nutrients that can be dissolved. However, the effects of ash characteristics on the chemical constituents of overland flow from burned areas are not quantified as well as its effects on soil water quality (Smith et al., 2009; Pereira et al., 2009).

Objectives

This experiment shows the hydrological and erosional changes of ash affected by different rainfall events. Because for logistical reasons, it has often not been possible to follow the evolution of burnt terrain from immediately following a wildfire and data collection has typically begun some weeks or months after a burn (DeBano, 2000;



Shakesby and Doerr, 2006; Cerdà and Doerr, 2008). This paper is focused on the immediately post-fire period. The objective of this experiment is twofold: (i) to quantify the effects of ash characteristics and the thickness of the ash layer on overland flow and soil erosion and (ii) assess the effects of ash characteristics on the chemical constituents of overland flow.

Material and methods

Study area

A 30-yr abandoned rainfed orchard located in the Sierra de Enguera (38°50'N; 0°42'W) was selected as representative of mountainous rangeland of eastern Spain for the installation of the El Teularet Soil Erosion Experimental Station (TESEES), in Valencia province (east of Spain). The parent material is Cretaceous Marls, the soil is a Typic Xerorthent (Soil Survey Staff, 1998), the agricultural terrace had a slope gradient of 5 to 8% and the previous land management was almond and wheat crop farming. Intense ploughing has been applied at the site for centuries. Climate is typical Mediterranean with 3 - 5 months of summer drought, usually from late June–September. Mean annual rainfall at the study area range from 479 mm at the Enguera - Las Arenas meteorological station to 590 mm at the Enguera Confederación Hidrográfica del Júcar (CHJ) meteorological station. The mean annual days of rainfall at the study area is 37.9 (Las Arenas meteorological station) and 40.7 (CHJ meteorological station). Rainfall is distributed homogenously amongst spring, autumn and winter, while the summer is extremely dry due to high temperatures and lack of rainfall. Mean annual temperature ranges from 12.7°C to 14.2°C within the La Matea and Las Arenas meteorological stations. The hottest month is August with an average monthly temperature of 23 °C, while the coldest is January with an average monthly temperature of 7.3 °C.

Rainfall simulation experiments

Forty one rainfall simulation experiments were carried out in July-August 2010 under dry conditions in order to determine the soil and water losses. Thirty experiments with black ash (three depth of ash: 0.5 – 1.5 - 3 cm × 3 repetitions) and eleven experiments in control plots, were conducted during the summer drought period when soil moisture is low. The black ash from *Pinus halepensis* were collected of a fire in Teruel (Spain) in august 2009, of low intensity. The rainfall simulation runs were carried out after the ash was carefully deposited on the plot, and fifteen days later. Deionised water was applied from a height of two meters onto a 1 m² sub-plot, and runoff was collected from a bordered circular 0,24 m² area in the center of the sub-plot. Simulated rainfall duration was 1 h at a rate of 55 mm h⁻¹, simulating the rainfall from a thunderstorm, which in these study areas would occur once every 5 years. Rainfall characteristics were 93,24% of Christiansen Coefficient for the rainfall distribution at 55 mm h⁻¹, with a mean drop-size of 2,53 mm (D₅₀), mean drop velocity of 3,4 m s⁻¹, and a Kinetic energy of 7,1 J m⁻² mm⁻¹. Detailed information on the distribution of those parameters can be found in Cerdà et al. (1997).

Overland flow from the circular collection area was measured at 1-min intervals. Every tenth 1-min runoff sample was collected for laboratory analysis in order to determine sediment concentration. Runoff rates and sediment concentration were used to calculate the sediment yield, total runoff, runoff coefficient, infiltration, and erosion rates (Cerdà, 1999). Water samples were analysed for pH, EC, Ca²⁺, Mg²⁺, K⁺, Na⁺ and Cl⁻. Vegetation, litter and rock fragment cover were measured in the field as % of the soil surface covered by plants.

For the presentation of data was used adjusting curves using the equation of Horton (1938), where f_c is the steady state value of f , f_0 is the value of f at $t = 0$, and k is the infiltration decay factor. Equation is derived from the simple assumption that the reduction in the infiltration capacity during rain is directly proportional to the rate of infiltration and is applicable only when the effective rainfall intensity is greater than f_c . This model is considered a good election for semiarid lands (Kumar et al., 2003). To evaluate the values obtained with Horton equation and compare them to corresponding measured values, we selected the following three statistical parameters, RMSD (the root mean squared deviation, it gives the mean difference between measured and calculated values), NSE (the Nash Sutcliffe efficiency was also used (Moriassi, 2007) to compared measured and calculated values), and RSR (ratio of the mean squared error to the standard deviation of measured data). The parameters measured on the field are shown in Table 1 (means by treatment):

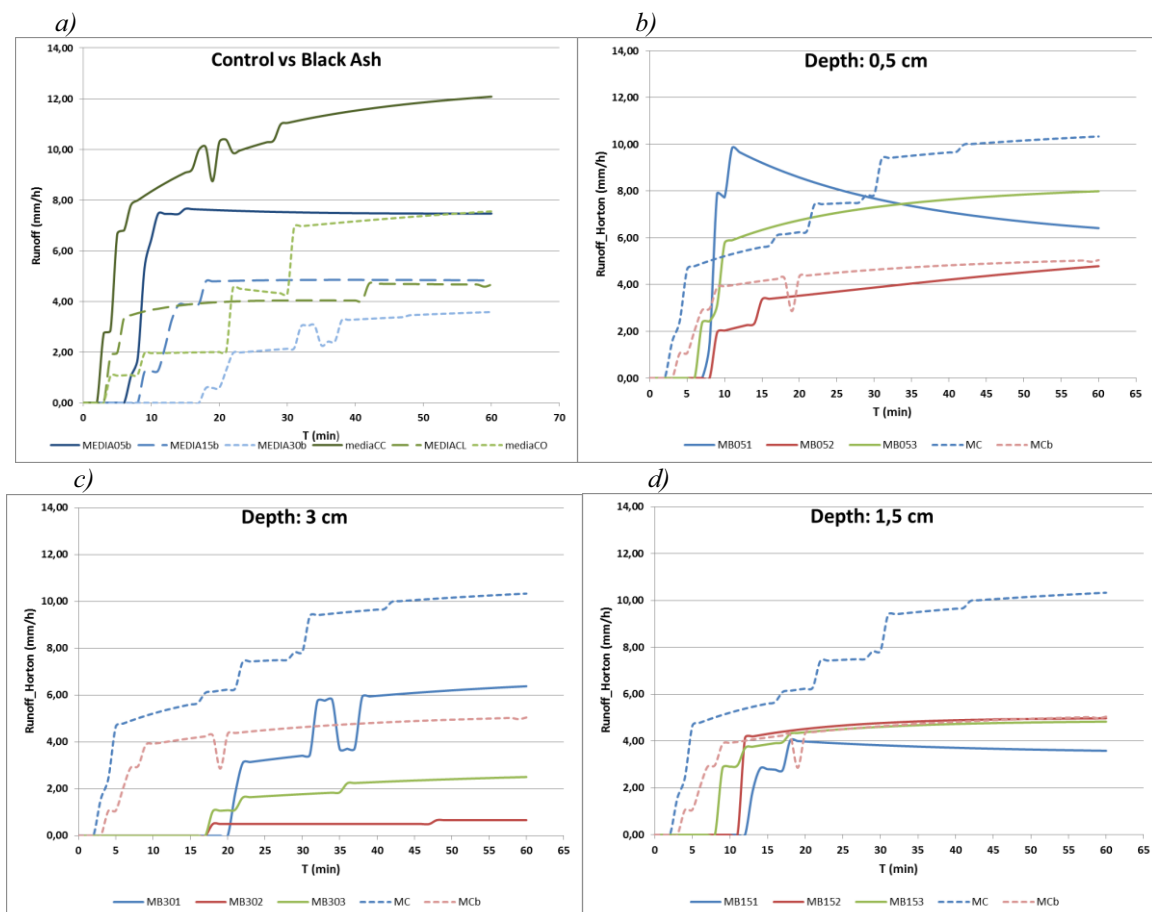


Figure1. (a) Mean runoff curves for the control and black ash (mean of runoff); Black ash to 0.5 cm (b), 1.5 cm (d) and 3 cm (c) of depth by event. Curves fitted to the Horton model.

Table 1. Parameters measured in rainfall simulation. (BA) Black ash; (C) Control; (05, 15, 30) Ash depth in mm; (a, b, c) 1st, 2nd, and 3rd rainfall event.

	Ponding time (min)	Runoff (mm/h)	Coef Runoff (%)	Coef Infiltration (%)	k (min ⁻¹)	f ₀ (mm/h)	f _c (mm/h)
BA 05 a	4,00 ±2,8	5,58 ±9,3	11,16 ±18,6	63,84 ±45,8	0,05 ±0,03	12,38 ±11,4	5,69 ±8,0
BA 05 b	7,43 ±7,0	2,19 ±3,2	4,38 ±6,5	62,28 ±54,2	0,02 ±0,03	2,00 ±1,8	4,08 ±6,8
BA 05 c	5,89 ±4,1	6,51 ±6,8	13,02 ±13,7	61,98 ±42,6	0,04 ±0,04	3,67 ±3,6	6,17 ±9,8
BA 15 a	7,33 ±1,4	2,72 ±3,3	5,45 ±6,7	61,22 ±6,7	0,02 ±0,02	5,75 ±0,7	2,25 ±2,4
BA 15 b	5,71	1,98	3,95	46,05	0,04 ±0,05	1,46 ±2,0	2,50 ±3,5
BA 15 c	9,22 ±4,3	2,91 ±4,7	5,82 ±9,3	69,18 ±9,3	0,05 ±0,04	2,32 ±2,7	3,65 ±4
BA 30 a	13,67 ±0,7	2,37 ±0,8	4,73 ±1,7	61,93 ±1,7	0,14 ±0,20	2,58 ±0,1	7,00 ±0,9
BA 30 b	21,33 ±21,2	0,41 ±0,7	0,83 ±1,4	65,84 ±1,4	0,03 ±0,03	0,67 ±0,7	0,67 ±0,7
BA 30 c	18,35 ±9,3	1,11 ±1,3	2,22 ±2,6	72,78 ±2,6	0,02 ±0,03	0,98 ±0,7	2,0 ±2,6
C a	15,97 ±14,6	10,26 ±11,4	20,52 ±22,8	79,48 ±22,8	0,04 ±0,05	7,18 ±6,6	11,40 ±9,4
C b	5,25 ±2,2	4,05 ±1,6	8,09 ±3,3	91,91 ±3,3	0,03 ±0,01	3,92 ±0,1	4,25 ±2,8

Results and conclusions

On the *Figure 1a* show the behaviour of the runoff under different treatments. Runoff decreased when increases the depth of ash. The runoff in the control plots was higher than the runoff with black ash. This is due to effect of the hydrophilic black on a hydrophobic soil. On *Figure 1 b,c,d* control is the mean of the three. In the plot with an ash layer with a depth of 0.5 cm can be seen that the runoff was high during the first minutes of runoff, decrease with the second storm and increase after the last storm. This was similar to the behavior of the plot with 3 cm of ash layer. The plots with an ash layer depth 1.5 cm did not contribute with runoff yields. Then, when decreased the ashes depth increased the runoff. And, that the runoff is lower when the ashes cover the soil, which was the case of the first thunderstorm.

Table 2. Laboratory parameters measure on runoff. (BA) Black ash; (C) Control; (05, 15, 30) Ash depth in mm; (a, b, c) 1st, 2nd, and 3rd rainfall event..

	PH	CE(μS/cm)	Ca ²⁺ (mg/l)	Mg ²⁺ (mg/l)	K ⁺ (mg/l)	Na ⁺ (mg/l)	Cl ⁻ (mg/l)
BA 05 a	5,95 ±3,9	357,81 ±256,2	33,28 ±29,7	8,34 ±5,8	10,21 ±6,9	2,22 ±1,4	40,09 ±27,0
BA 05 b	4,14 ±5,8	91,81 ±129,8	2,94 ±4,1	0,21 ±0,2	0,19 ±0,2	0,55 ±0,7	8,37 ±11,8
BA 05 c	6,37 ±4,2	96,84 ±80,6	1,81 ±1,3	0,32 ±0,3	0,43 ±0,6	0,52 ±0,4	10,78 ±9,3
BA 15 a	5,40 ±0,1	204,15 ±119,3	16,89 ±17,4	5,77 ±2,5	4,27 ±2,8	2,02 ±0,8	27,78 ±0,5
BA 15 b	5,19 ±0,4	137,07 ±115,2	6,63 ±7,6	2,86 ±5,6	3,34 ±6,6	1,42 ±1,5	32,36 ±48,0
BA 15 c	6,21 ±0,2	97,89 ±40,1	3,30 ±1,3	0,23 ±0,07	0,29 ±0,3	0,41 ±0,3	16,31 ±21,5
BA 30 a	5,27 ±0,2	280,04 ±271,0	20,11 ±15,3	6,23 ±6,3	12,03 ±18,2	1,48 ±0,2	42,79 ±29,8
BA 30 b	5,26 ±0,1	130,38 ±89,7	8,20 ±9,5	5,09 ±6,9	4,56 ±6,8	2,37 ±0,2	26,59 ±23,9
BA 30 c	5,97 ±0,3	101,51 ±11,6	3,13 ±2,5	0,22 ±0,04	0,19 ±0,03	0,57 ±0,3	16,02 ±12,8
C a	7,78 ±0,5	150,24 ±58,79	8,00 ±5,7	2,66 ±1,6	8,92 ±11,1	2,00 ±1,2	40,52 ±24,0
C b	7,12 ±0,2	148,35 ±31,60	6,28 ±1,1	3,14 ±0,5	9,20 ±2,9	3,85 ±0,3	61,95 ±19,1

The pH values (*Table 2*) show lower values than on the ash covered than on the control plots. Then the electric conductivity was higher on the ash than control plots, and the EC values decreased when the ash depth increased. Furthermore, the EC decreased with following runs and on the last storm the values were similar. The K⁺ and Na⁺ were found to be lower on the ash covered plots than on the control ones, and they were also lower on the ash covered plots with the lower ash doses. Meanwhile K⁺, Na⁺ and Cl⁻, show greater values in the control plots were than on the ash covered plots. The K⁺, Na⁺ and Cl⁻ values decreased when the ash depth. Then the changes on the ash depth are relevant to understand the changes in water quality after forest fires.~



References

- Cerda, A. (1998a). Changes in overland flow and infiltration after a rangeland fire in a Mediterranean scrubland. *Hydrological Processes* 12, 1031-1042.
- Cerda, A. (1998b). Post-fire dynamics of erosional processes under Mediterranean climatic conditions. *Zeitschrift für Geomorphologie* 42, 373-398.
- Cerda, A., Doerr, S.H. (2008). The effect of ash and needle cover on surface runoff and erosion in the immediate post-fire period. *Catena* 74, 256-263.
- DeBano, L.F. (2000). The role of fire and soil heating on water repellence in wildland environments: a review. *Journal of Hydrology* 231, 195-206.
- Doerr, S.H., Shakesby, R.A., Walsh, R.P.D. (2000). Soil water repellency: its causes, characteristics and hydro-geomorphological significance. *Earth-Science Reviews* 51, 33-65.
- Horton, R. I. (1938). The interpretation and application of runoff plot experiments with reference to soil erosion problems. *Soil Science Society of America Proceedings* 3: 340-349
- Leighton-Boyce, G., Doerr, S.H., Shakesby, R. A., Walsh, R.P.D. (2007). Quantifying the impact of soil water repellency on overland flow generation and erosion: a new approach using rainfall simulation and wetting agent on in situ soil. *Hydrological Process* 21, 2337-2345.
- Mataix-Solera, J., Doerr, S.H. (2004). Hydrophobicity and aggregate stability in calcareous topsoils from fire-affected pine forests in south-eastern Spain. *Geoderma* 118, 77-88.
- Mishra, S.K., Tyagi, J.V., Singh, V.P. (2003). Comparison of infiltration models. *Hydrological processes*. 17, 2629-2652.
- Moriasi, D.N., Arnold, J.G., Van Liew, Bingner, R.L., Harmel, R.D., Veith, T.L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, volume 50 (3): 885-900
- Neary, D.G., Ryan, K.C., DeBano, L.F. (Eds) (2005). *Wildland fire in ecosystems: effects of fire on soil and water*. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42-Volume 4. (Ogden, UT).
- Pereira, P., Úbeda, X., Outeiro, L., Martin, D.A. (2009). Factor analysis applied to fire temperature effects on water quality, In: E. Gomez and K. Alvarez (Eds) *Forest Fires: Detection, Suppression and Prevention*.
- Shakesby, R.A., Doerr, S.H. (2006). Wildfire as a hydrological and geomorphological agent. *Earth-Science Reviews* 74, 269-307
- Smith, H.G.; Sheridan, G.J.; Lane, P.N.J.; Nyman, P.; Haydon, S. (2009). Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology*, v. 396, iss. 1-2, p. 170-192.
- Ulery, A.L, Graham, R.C., Amrhein, C. (1993). Wood-ash composition and soil pH following intense burning. *Soil Science* 156, 358-364.
- Woods, S.W., Balfour, V.N. (2008). The effect of ash on runoff and erosion after a severe forest wildfire, Montana, USA. *International Journal of Wildland Fire* 17(5), 535–548.



Aging of black carbon in the protected marshland of the Guadalquivir delta, Southern Spain

Heike Knicker*, Francisco Javier González Vila, Luis Clemente Salas

CSIC-IRNAS

* knicker@irnase.csic.es

Key-words: Donana National Park; C-cycling; charcoal stability.

Abstract

The Doñana National Park is located at the mouth of the river Guadalquivir in Southern Spain and represents one of the largest marshlands reserves of Europe. Although vegetation fires are now prevented as far as possible, some of the areas were formerly subjected to frequent prescribed fires since 1628 (approximately every 25-30 years). The so formed pyrogenic organic matter (PyOM) is supposed to compose a major proportion of the slow-cycling carbon pools in soils and as such it is expected to affect quality and quantity of the soil organic matter (SOM) in the present reclaimed soils. In order to test this, the SOM of three profiles (Humaquepts) within the protected center region were analyzed by solid state ¹³C NMR spectroscopy. The respective pyrogenic organic carbon (PyOC) content was elucidated, using the chemical oxidation method. Two of the selected profiles had experienced no fire since installation of the park in 1969. Here, no major quantities of PyOC were recovered in the O layer, but an increase of aromaticity correlating with PyOC contents was revealed with soil depth. At both sites, PyOC accounted for more than 15% of the C_{tot} in the A/C horizon (> 50 cm). This clearly evidences a downward translocation of charcoal within the soil profile. The third profile suffered a severe fire in 1985. The fire combusted all of the O layer (0-20 cm), but after 19 years, it recovered to approximately 15 cm, although only minor contributions of PyOC were revealed. Whereas directly after the fire, the soil at a depths of 55 cm contained only 3 mg g⁻¹ organic C without any evidence of PyOC, 16 and 19 years a clear increase of C_{tot} (10-15 mg g⁻¹) with a considerable contribution of PyOC (12% of C_{tot}) was revealed. Although the absolute concentration of PyOC did not decrease in the lower depths, its relative contribution to C_{tot} declined. This may be explained by the constant input of fresh litter, which on a long term masks the presence of char. Alternatively, a more efficient downwards transport and subsequent stabilization of PyOC may have occurred. In summary, the studied profiles clearly indicate that limiting the quantification of charcoal to the upper horizon is likely to result in its underestimation. With respect to modern agriculture, the possible transport and stabilization of PyOC residues has also to be considered if one intends to apply artificially produced biochars as possible soil amendments.



Cation's washing in burned soil: a rainfall simulation study

Javier Cancelo-González^{a*}, María E. Rial-Rivas^b, Francisco Díaz-Fierros^a

^a Departamento de Edafología e Química Agrícola, Universidade de Santiago de Compostela, Campus Vida, CP. 15782 Santiago de Compostela-A Coruña (Spain);

^b CESAM, Centro de Estudos do Ambiente e do Mar, Campus Universitário de Santiago, 3810-193 Aveiro (Portugal)

* javier.cancelo@usc.es

Key-words: Thermal shock, unaltered soil samples, rainfall simulator, washing of cations, laboratory test.

Introduction

Cation content of water in burnt catchments is one of the key factors controlling the pH in water. Obviously, anions have influence in the ionic balance but as, in many cases, its concentration depends on atmospheric inputs (Martin and Lavabre, 2000) its relationship with the effect of fire in the pH is lower. Hydrochemical balances at catchment scale, allows to determine the cations export and are also a good indicator of losses of soil fertility experimented in the burnt areas (Tiedemann et al. 1978).

These studies can be done in natural conditions at two levels: *in situ*, determining changes in the content and status of soil cations after fire or *ex situ* analyzing the exportation by drainage water. Other types of studies can be conducted under different experimental conditions: a) experimental plots using rainfall simulations (Cerdà et al. 2010), b) with field lysimeters to determine the runoff water (Martin and Lavabre, 2000) and c) in the laboratory by subjecting the soil to thermal shock simulating fire conditions and then monitoring the changes in the composition of the soil water (Soto and Díaz-Fierros, 1993).

This study used an experimental device of 45x20x12cm lysimeter boxes under rainfall simulations to determine the composition of surface water and subsurface water, as well as the changes in the soil composition after being subjected to temperatures of 200 and 400°C during time periods similar to forest fires.

Objectives

Study the changes experimented by surface and subsurface runoff from soils subjected to thermal shocks and laboratory rainfall simulations.

Methodology

The studied soil is a regosol umbric, rich in organic matter (10%). The soil was directly sampled in the field with the lysimeter boxes (45 long, 20 wide and 12 high), respecting its natural structure. A total of 6 samples were taken, two of them as control samples, two were exposed to a moderate intensity fire (200°C at 1 cm depth) and two exposed to a fire with more intensity (400°C at 1 cm depth). The heat shock simulations were carried out with eight Philips infrared lamps IR375CH with 375 Watts each, located at 10cm height from the samples. Once the soil reached the target temperature was move out and left to cool, resulting in heating curves to close to those observed during a forest fire (De Bano et al 1998).

Lysimeter boxes, arranged with an inclination of 20% were subjected to simulated rain with a swinging nozzle (water jet system) generating a fan-shaped rainfall with a mean intensity of 45mm.h⁻¹. Two consecutive rainfall simulations were made, with 90 mm of rain each, separated by an interval of 15 days.

The composition from the surface runoff water and the infiltrated water from each soil sample during the rainfall simulation was analyzed each time that the water sample reach 375 ml, and the soils were analyzed before and after the heating and after each rainfall simulation. All results are expressed as means of replicates of each experience.

Results and conclusions

The concentrations measured in the water at the end of the first rainfall simulation shown minimal differences with the in initial concentrations in the second rainfall simulation, so the two can represent a single washing process and as such will be discussed (Figure 1). In comparison with the control samples, the soil samples heated at 200°C have higher exportation ratios of calcium and magnesium, but there are no changes in sodium and potassium that even in the surface runoff present lower values than the control samples. All the soil samples heated at 400°C increased the washing for all the cations, and this washing process is always greater in subsurface runoff than in surface runoff. The analyzed parameters in surface and subsurface runoff, experiment an exponential decrease with the time of the rainfall simulation, considering that, at the end of the washing process (180mm), the cation losses, due the heating, are complete.

Table I. Exchangeable basic cations, sum of exchangeable cations (S), cation exchangeable capacity (CEC), % base saturation (V).

	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	S	CEC	V
	(cmol(+)/Kg)	(cmol(+)/Kg)	(cmol(+)/Kg)	(cmol(+)/Kg)	(cmol(+)/Kg)	(cmol(+)/Kg)	%
Control	0.37	0.79	2.07	0.74	3.97	25.50	15.24
200°C	0.26	0.68	1.78	0.55	3.27	17.50	18.80
400°C	0.20	0.65	1.55	0.37	2.76	14.00	20.69

The soil warming causes a decrease in the CEC generating an increase in the base saturation (V) of exchangeable basic cations (Table I). Anyway, the final balance of cations in the soil results in losses of Na, K, Ca and Mg as can be seen in the table II. In the samples heated at 200°C, the monovalent cations decreased, this can be considered as an anomalous behaviour, in comparison with literature results. Anyway similar results were reported by Soto and Díaz-Fierros (1993) explaining this behaviour due to interlayer processes that happen in illites in which the interlayer water was replaced by the monovalent cations at high temperatures.

The cation washing in the burnt soils is an important process in relation to water quality due it is the first responsible for the changes in the pH of these waters and nutritive value.

Table II. Cation losses from soil.

Runoff		Na	K	Ca	Mg
		(Kg/Ha)	(Kg/Ha)	(Kg/Ha)	(Kg/Ha)
Control	Surface	5.97	7.33	1.22	0.95
	Subsurface	6.30	7.88	0.90	0.89
200°C	Surface	12.04	10.06	19.76	5.15
	Subsurface	5.36	7.56	5.60	1.77
400°C	Surface	8.34	12.45	31.60	5.32
	Subsurface	8.72	13.44	15.11	3.94

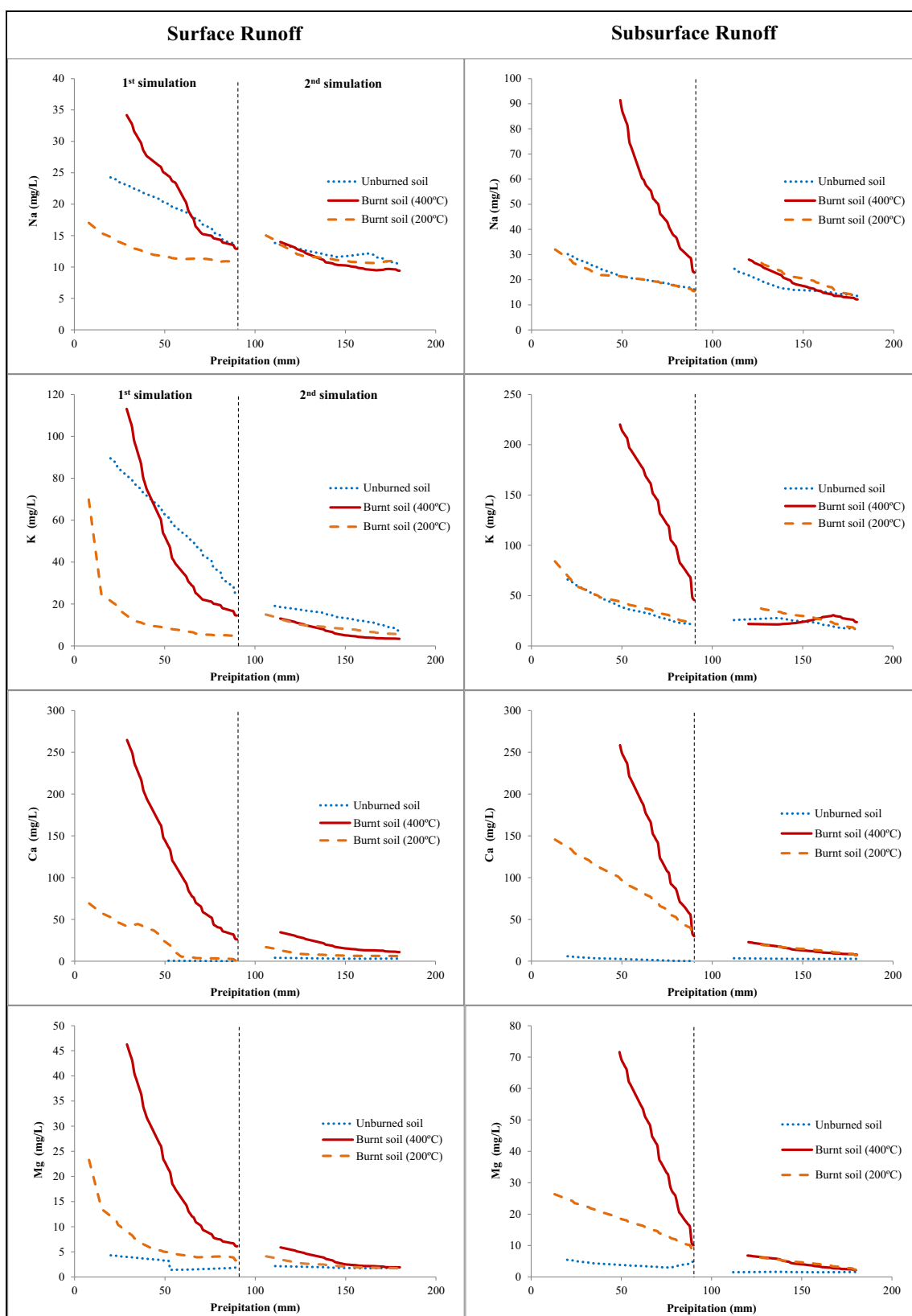


Figure 1. Cation concentrations in water measured during the rainfall simulations



References

- Cerdà, A., Marcos, E., Llovet, J., Benito, E., Pérez-Cabello, F., Úbeda, X., Jordán, A., Zavala, L.M., Ruiz-Sinoga, J.D. (2010). La lluvia simulada como herramienta para la investigación del efecto de los incendios forestales sobre los suelos. In A. Cerdà, Jordán, A. (Ed.) Actualización en métodos y técnicas para el estudio de los suelos afectados por incendios forestales (pp. 45-83) Valencia: 978-84-370-7887-8.
- De Bano, L. F., Neary, D.G., Ffolliott, P.F. (1998). Fire's effects on ecosystems. New York, NY: John Wiley and Sons.
- Martin, C., Lavabre, J. (2000). In Conséquences d'un incendie de forêt dans le bassin versant du Rimbaut.
- Soto, B., Díaz-Fierros, F. (1993). Interactions between plants ash leachates and soil. *International Journal of Wildland Fire*, **3**, 207-216.
- Tiedemann, A. R., Conrad, C.E., Dieterich, J.H., Hornbeck, J.W., Megahan, W.F., Viereck, L.A., Wade, D.D. (1979). Effects of fire on water. (p. 28) Washington: USDA Forest Service.



Fast characterization of wildfire effects on soil organic matter by analytical pyrolysis

José María de la Rosa^{a*}, María Eufemia Varela^b, Silvia R. Faria^b, Francisco Javier Gonzalez-Vila^c, Heike Knicker^c, M. Fátima Araújo^a, José Antonio González-Pérez^c, J. Jakob Keizer^b

^a Instituto Tecnológico e Nuclear (ITN), Estrada Nacional 10, 2686-953, Sacavém, Portugal;

^b Centro de Estudos do Ambiente e do Mar (CESAM), Dept. Ambiente, U. de Aveiro, 3810-193 Aveiro, Portugal;

^c Instituto de Recursos Naturales y Agrobiología de Sevilla, Av. Reina Mercedes 10, 41012, Sevilla, Spain.

* jmrosa@itn.pt

Key-words: Wildfires; central Portugal; soil organic matter; C-sequestration.

Introduction

Forest fires are a frequent phenomenon in Mediterranean ecosystems, and are widely considered to be the main factor of disturbance in the Mediterranean basin. The Iberian Peninsula has the highest risk of wildfire occurrence of Europe. During the period 1980-2003 approximately 29% of continental Portugal was affected by wildfires.

Wildfires can affect wide range of physical, chemical, mineralogical and biological soil properties (e.g. González Pérez et al., 2004). The extent of these changes depends to a large degree on the temperature ranges reached at different soil depths (severity) and on the degree of heating that the different soil components can withstand before being altered (resilience).

Therefore, the present work aims a fast characterization of the chemical changes in the topsoil of two distinct forest types on Leptosols-Cambisols in the Colmeal area (central Portugal), where a wildfire occurred in August 2008. The fire effects on the organic matter quality of these soils are studied through analytical pyrolysis (Py-GC/MS). The Py-GC/MS results for neighboring burnt and unburnt sites are compared to identify typical patterns of fire-induced alterations and, thereby, improve the knowledge basis for soil restoration efforts.

Analytical pyrolysis is a fast technique, which provides information concerning the structure of organic molecules, including N species, which cannot be released by hydrolysis. Pyrolysis involves thermolytic degradation of macromolecules into small fragments that are analyzed by gas chromatography-mass spectrometry (GC/MS). It is assumed that the fragments are representative of the original larger macromolecules. The interpretation of pyrolysis data, however, requires a detailed knowledge of the pyrolysis behaviour of the compounds under study. It has been recently used for the characterization of fire effects on different soils (De la Rosa et al., 2008; Tinoco et al., 2006; Knicker et al., 2005).

For this study, a double-shot pyrolysis programme has been used, carrying out a GC-MS analysis of gases evolved at 300 °C and 500 °C. The double-shot pyrolyzer allows thermal desorption of samples (at sub-pyrolysis temperature) prior to pyrolysis, and so allows the sequential examination of the products released by thermal desorption and by thermal cracking from the same sample. This permits observing the alterations caused by fire in the molecular composition of the SOM for two different compartments in terms of thermal stability. A desorption step is applied to look specifically for molecular markers of fire-induced changes in the thermolabile OM. Previous studies employing thermal



analysis have shown a loss of thermolabile organic constituents in fire-affected soils (Knicker et al., 2005). Analysis at sub-pyrolysis temperatures (up to 350 °C) permits to discern changes in thermolabile units, whilst analysis at pyrolysis temperatures addresses changes in compounds with higher thermal stability (Quenée et al., 2005).

Objectives

The main objective here is to assess the suitability of pyrolysis–gas chromatography/mass spectrometry (Py–GC/MS) as a rapid analytical technique for discerning changes and molecular alterations in the soil organic matter of Mediterranean forests.

Methodology

Area of Study and soil sampling

The area of study is located in the Lousã Mountains in central Portugal, and was burned by a wildfire in August 2008. Within the burnt area of about 70 ha, two slopes were selected with a Maritime Pine (*Pinus pinaster*) and a eucalypt (*Eucalyptus globulus*) plantation. In addition, two comparable, unburnt slopes in the immediate surroundings were selected as control sites. Soil samples were mechanically de-ashed, dried and sieved (< 2mm) before analysis.

Analytical pyrolysis (Py-GC/MS)

Py-GC/MS was performed in a double-shot pyrolyzer (model 2020, Frontier Laboratories) directly connected to an Agilent 6890 GC-MS system. Between 0.5 to 1 mg of soil sample was placed in small platinum capsules. A thermal desorption step at 300 °C (first shot) was achieved before the pyrolysis at 500 °C (second shot). During desorption the sample capsule was introduced in the furnace preheated at 100 °C and the temperature was raised to 300 °C at a rate of 20 °C min⁻¹ and held at 300 °C for 1 min. Subsequent pyrolysis was carried out at 500 °C. The GC/MS conditions were the same for all samples; oven temperature was held at 40 °C for 1 min and then increased up to 100 °C at 30 °C min⁻¹, from 100 to 500 °C at 20 °C min⁻¹ and isothermal at 500 °C for 2 min. The identification of individual compounds was achieved by single ion monitoring for different homologous series, low-resolution mass spectrometry and comparison with published and stored data (NIST and Wiley libraries).

Results and conclusions

The analysis of the released compounds of the pyrolysates showed conspicuous differences in the composition between the first and the second shot.

First Shot (300 °C)

Thermal desorption of the samples at 300 °C was dominated by furfural, furan-methanol and other compounds with carbohydrate origin. They are considerate thermally labile OM, which agreed with their greater relative abundance in the unburnt soils. In addition, a series of *n*-alkane/enes (C₁₀-C₂₉), aromatic compounds derived from methyl-benzene and naphthalene and N-containing products from peptides were also detected in most samples. On the other hand, long chain *n*-alkanes, substituted-naphthalenes and some of peptides-derived products (mainly indoles and indenenes) were detected in the unburnt samples but not in the fire-affected samples. This clearly suggested a heat-induced alteration of the SOM composition.

Second Shot (500 °C)

Pyrolysis at 500 °C presented minor differences between the burnt and unburnt soils. The TIC of the samples was characterized by the presence of a complex mixture of *n*-alkanes/enes (pattern C₁₀-C₃₃), aromatic structures; mainly benzenes and naphthalenes, polysaccharides-derived compounds; mostly furanes, and some N-containing products from peptides. All these compounds are typical pyrolytic products of SOM. In addition, fatty acids methyl esters (FAMES), *n*-alkyl ketones, *n*-alkane nitriles, lignin derived products, and some triterpenoids and sterols were present, albeit with a limited contribution. Due to the unique and known source of most of these compounds, they can be used as “fingerprints” for detecting differences in SOM composition (Almendros et al., 1997). *n*-alkanes, *n*-alkenes, and FAs have been used as molecular markers for detecting environmental changes in soils and sediments, including by fire, and will be discussed in detail underneath.

Phenol and methyl-phenols were amongst the most abundant compounds in all the programs. They are often recognized in pyrolysates of lignin-containing tissues as indicating demethylated units formed from microbial degradation of lignin or representing secondary reaction products in thermal degradation during lignin pyrolysis (Saiz-Jimenez and de Leeuw, 1986). Lignin-derived compounds were also detected in all pyrograms. Polysaccharides, ubiquitous in pyrolysis of plant material or SOM, are labile compounds easily altered thermally or biodegraded during the initial phases of diagenesis. The presence of both lignin compounds and polysaccharides in the pyrolysates of all samples, including the burnt ones, suggested the incorporation of fresh OM and/or a low-to-moderate fire intensity.

The burnt samples presented a slightly higher relative abundance of highly condensed aromatic structures. They are usually released in incomplete combustion processes as occur commonly in wildfires, and indicate the presence of black carbon or thermally altered refractory OM (Tinoco et al., 2006).

The N-containing compounds were dominated by indanes and *n*-alkanenitriles. Indanes probably have protein origin (microbial input) but indole and methyl-pyridine can also be present in fresh plant material. *n*-alkanenitriles could have resulted from the reaction of carboxylic acids and ammonia liberated from minerals during the pyrolysis process.

The *n*-alkanones were also present in the pyrolysates. They are usually present in plant material but they may also derive from thermal alteration processes and bacterial degradation of alcohols and aldehydes.

Steroids are difficult to identify by pyrolysis. Nonetheless, the triterpenoid compound Neoursa-3,12-diene was identified in all pyrograms. Triterpenes are major biomarker components of gums and mucilages from angiosperms and gramineae, and are also typical marker of ryegrass wax. β -Sitosterol and substituted sterols, were identified in all samples, with a greater relative abundance in the un-burnt samples soils. They are constituents of plant lipid membranes and waxes, and are also significant components of OM from vascular plants. However, they can also originate from soil algae and fungi.

Fig. 1 shows the distributions of the series of *n*-alkanes, *n*-alkenes and *n*-fatty acids. *N*-alkanes series ranged C₁₀-C₃₃, having a bimodal distribution with maximums at C₁₃ and C₂₁, and C₁₅ and C₂₂ in the case of the eucalypt and pine forest, respectively. Odd/even carbon number predominance was not observed (CPI= 0.7). A series of *n*-alkenes primarily as terminal olefins (*n*-alk-1-enes) were present in the TIC of the soils, and showed a C range C₁₀-C₃₂ with maximum at C₂₂.

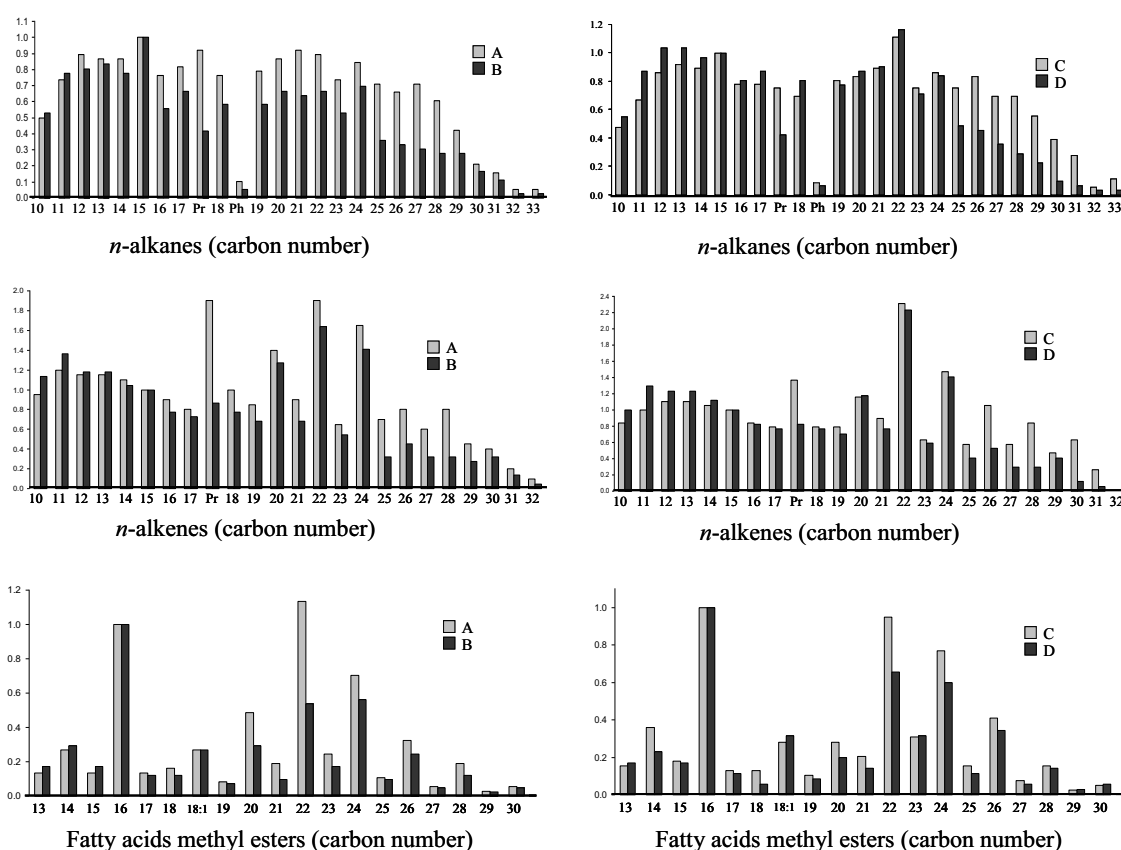


Figure 1. Relative abundance (vertical) vs. carbon distribution (horizontal) of *n*-alkanes, *n*-alkenes and fatty acids (as methyl esters) after pyrolysis at 500 °C of bulk soils. Abundances of *n*-alkanes and *n*-alkenes are normalized to C₁₅. Abundances of fatty acids are normalized to Palmitic acid (C₁₆). Axis numeral indicates the carbon number). Pr, pristane; Ph, phytane

n-fatty acids were also identified in the range C₁₃-C₃₀. Analytical pyrolysis presents major limitations in the detection of FAs, (Dignac et al., 2006). It is therefore hardly surprising that *n*-fatty acids occurred with markedly lower relative abundance than *n*-alkanes/enes. FAs with an even number of C were more profuse, with palmitic acid (C₁₆) and behenic acid (C₂₂) being the most abundant. Table 1 shows several parameters regarding the distributions of *n*-alkanes, *n*-alkenes and *n*-fatty acids. Previously studies have used these parameters to detect fire-induced changes in SOM and as markers of post-fire soil recovery (Almendros et al., 1988).

A decrease in the average chain length (ACL) of *n*-alkanes and *n*-alkenes in burnt soils (samples B and D; Table 1), has been identified as resulting from heat-induced breakdown (Almendros et al., 1988). In the case of the eucalypt forest, the ratio of short/long *n*-alkanes was 2.6 for the unburnt sample and 3.7 for the burnt sample; in the case of the pine forest, the respective values were 2.2 and 4.3. Furthermore, the ratio of short/total *n*-alkanes and *n*-alkenes was 0.3 for the unburnt soils vs. 0.4 for the burnt soils. This accumulation of low molecular weight homologues suggested the cracking of long chain components, and agreed with the difference in the ratio of long/total *n*-alkanes and *n*-alkenes (0.3 vs. 0.2). Similar trends were observed for *n*-alkenes and fatty acids. In addition, the relative abundance of pristane and phytane was significantly reduced in the burnt samples. They correspond to isoprenoid hydrocarbons that are diagenetic products of the phytol side chain of chlorophyll. Pristane/phytane ratios have been used as a measure of the sediment oxicity. In this case, the greater abundance of pristane could

suggest that the diagenesis occurred in oxic depositional environments. The fatty acid (FA) distribution has been also employed as indicator of soil status and post-fire recovery (Gonzalez Vila et al., 2001). Fig. 1. shows a decrease in the relative abundance of FA in the burnt (B and D) compared to unbunrt soils (A and C). Furthermore, the observed differences in the ratio of short-/long-chain FAMES between burnt and control soils (Table 1) confirmed the occurrence of oxidative scission of long chain homologues in the fire-affected.

The results presented here are preliminary, and other analytical tools are currently being explored for a better characterization of the fire-induced changes in the SOM at the study sites

The main conclusions obtained so far may be summarized as follows:

- the distribution and relative abundances of homologous compound series as determined by analytical pyrolysis provided a good indicator of the occurrence of the wildfire o and its intensity;
- the desorption step revealed that the wildfire produced a significant reduction of the thermally labile molecular structures of the SOM, , whereas pyrolysis at 500 °C evidenced an accumulation of low molecular weight homologues, suggesting the occurrence of thermal breakdown and cracking of long chain components;
- various markers like polysaccharides, lignin-derived compounds and triterpenes pointed to a fast recovery of SOM following the wildfire and/or a moderate fire intensity

Table 1. Comparison of parameters calculated from *n*-alkyl biomarkers released by analytical Pyrolysis at 500 °C

Sample	<i>n</i> -alkanes							<i>n</i> -alkenes					<i>n</i> -fatty acids				
	ΣC ₁₀ - C ₂₃ /	ΣC ₁₀ - C ₁₅ /	ΣC ₂₄ - C ₃₃ /	Pr/C ₁₇	Ph/C ₁₈	Pr/Ph	AC	ΣC ₁₀ - C ₂₃ /	ΣC ₁₀ - C ₁₅ /	ΣC ₂₄ - C ₃₃ /	Pr/C ₁₇	ΣC ₁₃ - C ₁₈ /	ΣC ₁₀ - C ₁₈ /	ΣC ₁₉ - C ₃₀ /	Pr/C ₁₇	ΣC ₁₃ - C ₃₀ /	ΣC ₁₉ - C ₃₀ /
	short/long	short/total	long/total					short/long	short/total	long/total		short/long	short/total	long/total		short/long	short/total
A (control)	19.5	2.6	0.3	0.3	1.1	0.14	8.8	19.3	2.6	0.3	0.3	2.4	0.6			0.4	0.6
B (burnt)	18.4	3.7	0.4	0.2	0.6	0.10	7.5	18.2	3.9	0.4	0.2	1.2	0.9			0.5	0.5
C (control)	20.0	2.2	0.3	0.3	1.0	0.12	9.0	19.7	2.4	0.3	0.3	1.7	0.6			0.3	0.6
D (burnt)	18.4	4.3	0.4	0.2	0.5	0.08	6.5	18.3	4.2	0.4	0.2	1.1	0.8			0.4	0.5

ACL; Average chain length is the weighted average number of C atoms. Pr; Pristane/ene. Ph; Phytane. Values were calculated from normalized abundances shown in Fig 1..

References

- Almendros, G., González-Vila, F.J., Martín, F. Sanz, C, Álvarez-Ramis, C. 1998. *Appraisal of pyrolytic techniques on different forms of organic matter from a Cretaceous basement in Central Spain*. Org. Geochem. 28: 613-623.
- De la Rosa, J.M., González-Pérez, J.A., González-Vázquez, R., Knicker, H., López-Capel, E., Manning, D.A.C., González-Vila, F.J. 2008. *Usefulness of thermal analysis to monitor fire induced changes in forest soils*. CATENA, 74: 296-303.



- Dignac, M.F., Houot, S., Derenne, S., 2006. *How the polarity of the separation column may influence the characterization of compost organic matter by pyrolysis-GC/MS*. J. of Anal. and Appl. Pyrol. 75: 128-139.
- González-Pérez, J.A., González-Vila, F.J., Almendros, G., Knicker, H. 2004. *The effect of fire on soil organic matter—a review*. Env. Int. 30: 855-870.
- González-Vila, F.J., Tinoco, P., Almendros, G., Martin, F. 2001. *Pyrolysis-GC-MS analysis of the formation and degradation stages of charred residues from lignocellulosic biomass*. J. Agr. & Food Chem. 49: 1128-1131.
- Knicker, H., Gonzalez-Vila, F.J., Polvillo, O., Gonzalez, J.A., Almendros, G. 2005. *Fire-induced transformation of C- and N-forms in different organic soil fractions from a Dystric Cambisol under a Mediterranean pine forest (Pinus pinaster)*. Soil Biol. Biochem. 37: 701-718.
- Quénéa, K., S. Derenne, C. Largeau, C. Rumpel and A. Mariotti. 2005. *Spectroscopic and pyrolytic features and abundance of the macromolecular refractory fraction in a sandy acid forest soil (Landes de Gascogne, France)*. Org. Geochem. 36: 349-362.
- Saiz-Jimenez, C., de Leeuw, J.W., 1986. *Chemical characterization of soil organic matter fractions by analytical pyrolysis-gas chromatography-mass spectrometry*. J. of Anal. and Appl. Pyrol. 9: 99-119.
- Tinoco, P., Almendros, G., Sanz, J., González-Vázquez, R., González-Vila, F., 2006. *Molecular descriptors of the effect of fire on soils under pine forest in two continental Mediterranean soils*. Org. Geochem. 37: 1995-2018.



Effects of prescribed fire on carbon storage and loss in degraded pine forest and pine-oak forest at nam nao national park, Thailand

Chinnawong, K.¹, Wanthongchai, K.^{2*}, Tarusadamrongdet, V.¹, Rugsamane, S.³,
Kongdetadisak, P.⁴

¹Graduate school, Faculty of Forestry, Kasetsart University, Chatuchak Bangkok 10900

²Department of Silviculture, Faculty of Forestry, Kasetsart University, Chatuchak Bangkok 10900

³National Park Office, Department of National Park, Wildlife and Plant Conservation, Bangkok 10900

⁴Office of Conservation Administration 11, Department of National Park, Wildlife and Plant Conservation, Bangkok 10900

* fforksw@ku.ac.th

Introduction

Wildfires play an important role in the carbon cycle in forest ecosystems and environmental impacts. Biomass burning is a significant global source of atmospheric gases such as carbon dioxide (CO₂) and methane (CH₄), which are green-house gases contributing to global warming. During wildfires large amounts of CO₂ are released to the atmosphere (Flannigan *et al.*, 2000). After the fire, forest ecosystems become a carbon sink, which atmospheric CO₂ is again absorbed from photosynthesis and incorporated into the new vegetative growth. Therefore, ecosystem recovery to pre-fire levels of carbon storage and fuel loading are carbon balance in forest ecosystem (Conard and Solomon, 2009). However, fire regime (frequency, size, seasonality, and fire severity) and characteristics of forest ecosystem are an important factor in the recovery of carbon in ecosystem. The high fire severity, which typically kills all or most of the living vegetation, releases a great deal of carbon, and ecosystem recovery to pre-fire levels is generally slow. By Contrast, low fire severity may burn only surface fuels and understory vegetation. These surface fires release relatively small amounts of carbon but, they are likely to occur more frequently, with the result that cumulative carbon release over time may be similar to that where fires are less frequent (Johnson *et al.*, 2009).

Pine forest in Thailand, consists of three sub-communities, including pine forest, pine-oak forest and pine-dipterocarp forest (Marod and Kutintara, 2009). Although pine forests are a fire-dependent ecosystem, but too frequent fires may lead to forest ecosystem and nutrient depletion, and may affect long term ecosystem carbon dynamic. Pine forests will become a carbon source during each fire event, while the ability of this forest to be a carbon sink will be eventually reduced. Therefore, numbers of degraded pine forest have been observed, especially at Phu Kum Khao, Nam Nao national park. Therefore, the fundamental knowledge about carbon storage and loss in the fire event in this forest ecosystem is a very important for the mitigation strategy on climate change and the recommendation for forest fire management to reduce carbon loss from the fire in this ecosystem.

Objective

This study aimed to investigate effects of prescribed fire on aboveground and belowground carbon storage and loss in degraded pine forest (PF) and pine-oak forest (O-PF) at Nam Nao National Park, Thailand.

Methodology

The study was conducted in the pine forest, which consists of two sub-communities, including pine forest (PF) and pine-oak forest (O-PF), located at Nam Nao National Park, Thailand (Fig. 1). Prior to burning three 50×50 m plots were set up for each sub-community, thereafter fuel loads (including seedling, litter, herb, shrub, grass and twig) and its pre-fire aboveground carbon (AGC) were estimated from four 2×2 m subplots located systematically within the plot (Fig. 1). Post-fire belowground carbon (BGC) at 0-15 cm soil depth, including carbon stored in the soil and fine root biomass, was also estimated at the center of each fuel subplot. An experimental fire was ignited at the center of the plot to allow free burning. Immediately after the fire, four 50×50 cm subplots were set up to determine post-fire BGC and AGC residues (i.e. ash, charcoal and unburned material). The AGC, BGC and total carbon loss from wildfire were calculated as the differences between pre- and post-fire carbon.

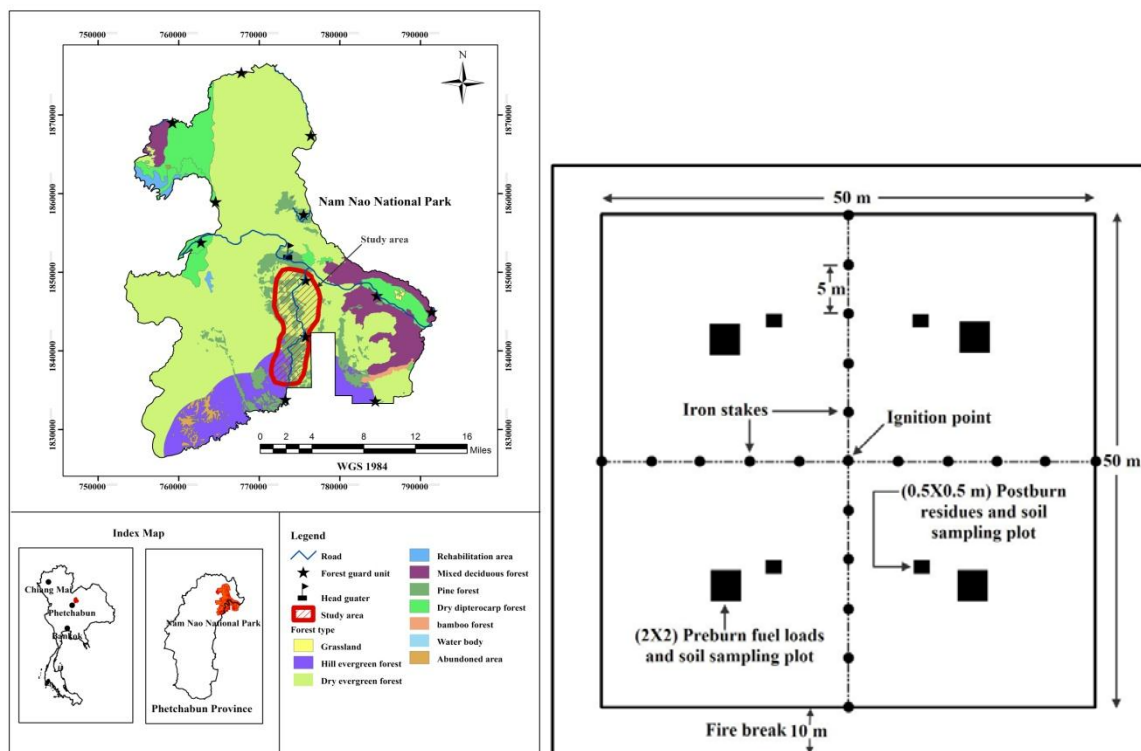


Figure 1. Location of Nam Nao National Park and plot layout for fuel, residue and soil determination.

Results and conclusions

Aboveground fuel load, C stock and C loss

The study revealed that pre-fire aboveground fuel load for PF and O-PF were 12.9 and 8.7 t/ha, respectively, whereas pre-fire AGC pool in PF and O-PF were 5.96 t C/ha and 3.98 t C/ha, respectively (Table 1). Post-fire AGC pool in residues for PF and O-PF were 0.87 t C/ha and 1.85 t C/ha, respectively. Therefore, total AGC loss from vegetation fire in PF and O-PF represented 85% (5.09 t C/ha), and 54% (2.13 t C/ha), respectively (Table 2). According to Cheney (1994), the burn was classified as a low-intensity fire for the O-PF (47.9 kW/m), while burning in PF was classified as medium-intensity fire (626.7 kW/m). The greater AGC loss at PF may come from the abundance and homogeneity of the grass fuel that allow for more complete burning. In addition, fire behavior, in particular fire intensity may also influence the loss of AGC.

Table 1. Pre-fire aboveground carbon in each fine fuel type

Site	Pre-fire Aboveground Carbon (t/ha)						
	grass	shrub	herb	seedling	litter	twig	total
PF	2.64 ^a	0.02 ^a	0.06 ^a	0.35 ^a	2.33 ^a	0.22 ^a	5.63 ^a
O-PF	0.64 ^b	0.14 ^a	0.05 ^a	0.27 ^a	2.19 ^a	0.68 ^a	3.98 ^b

Remark: Different small letters in column denote a significant difference ($P < 0.05$) in pre-fire AGC in each fine fuel type between PF and O-PF.

Table 2. Post-fire aboveground carbon in residues and carbon loss

Site	Pre-fire AGC (t/ha)	Post-fire carbon in residues (t/ha)				Total carbon loss (t/ha)	% Carbon consumed
		Ash	Charcoal	Unburned material	Total		
PF	5.63 ^a	0.19 ^a	0.25 ^a	0.43 ^a	0.87 ^a	4.76 ^a	85
O-PF	3.98 ^b	0.15 ^a	0.28 ^a	1.42 ^b	1.85 ^b	2.13 ^b	54

Remark: Different small letters in column denote a significant difference ($P < 0.05$) in post-fire AGC and total carbon loss between PF and O-PF.

Belowground C stock and C loss

The pre-fire BGC pool at 0-5 cm soil depth for PF and O-PF were 9.99 t C/ha and 11.05 t C/ha, respectively, while post-fire BGC in PF and O-PF were 9.78 t C/ha and 10.47 t C/ha, respectively (Table 3). These changes in BGC were not significant ($P > 0.05$). Likewise, BGC between 5-15 cm soil depth for all sites were not significantly ($P > 0.05$) affected by fire, because heat did not penetrate to the deeper soil layer. The changing in soil temperature and hence soil carbon losses depends on other factors such as the magnitude and duration of energy transferred from the fire to the soil, soil composition (e.g. moisture), structure (porosity), etc (De Bano *et al.*, 1998).

Table 3. Pre-and Post-burning belowground carbon in each site

Soil depth (cm)		Belowground Carbon pool (t/ha)	
		PF	O-PF
0-5	pre-burning	9.99 ^a	11.05 ^a
	post-burning	9.78 ^a	10.47 ^a
5-15	pre-burning	12.25 ^a	13.45 ^a
	post-burning	11.75 ^a	13.35 ^a

Remark: Different small letters in column denote a significant difference ($P < 0.05$) in belowground Carbon pool between Pre-and Post-burning at each site.

Total C loss in PF and O-PF

Total carbon loss to the atmosphere as a result of fire in PF and O-PF represented 21% (5.47 t C/ha) and 10% (2.81 t C/ha) of pre-fire C pool (Fig. 2), that stored in above-and below-ground, respectively. These results may indicate that C losses are mainly from AGC, whereas BGC does not contribute significantly to C loss from forest fire in these forest types. As long as fire-free interval for these forest types is appropriated, the AGC may recover back to the pre-fire levels before the next successive fire begins.

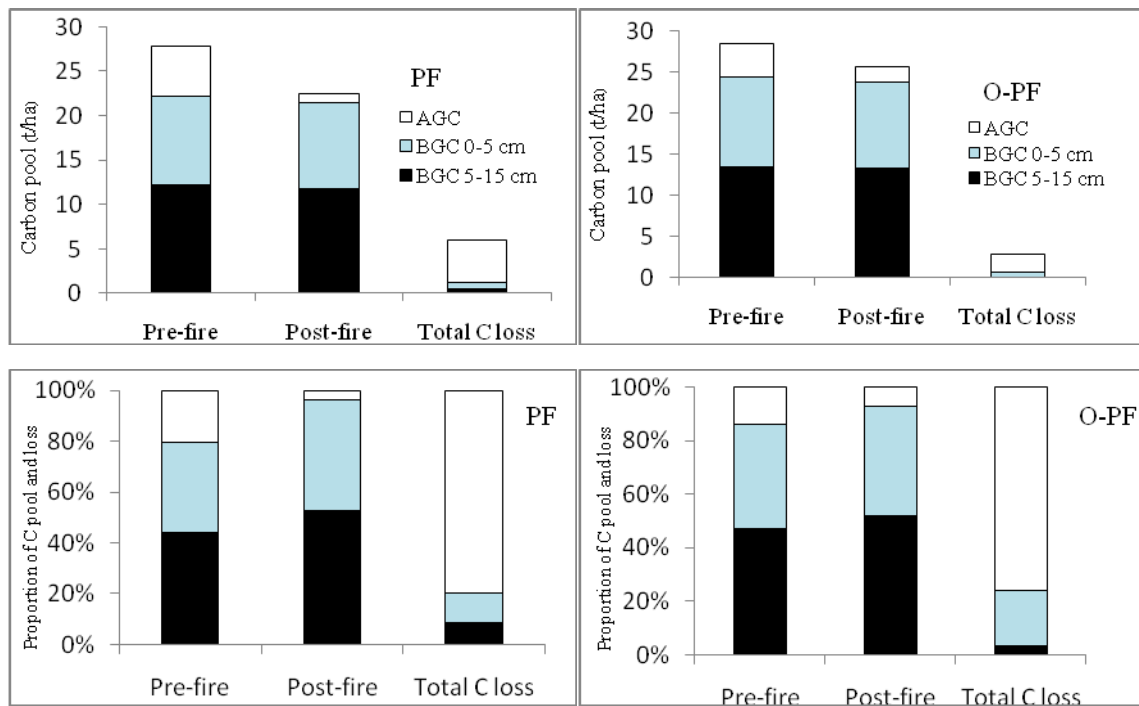


Figure 2. Proportion of C pool and loss in pine forest (PF) and pine-oak forest (O-PF).

References

- Conard, S.G. and A.M. Solomon. 2009. Effects of wildland fire on regional and global carbon stock in a changing environment, pp. 109-138. In A. Bytnerowicz, M.J. Arbaugh, A.R. Riebau and C. Anderson, eds. *Wildland Fires And Air Pollution*. Elsevier, Hungary
- DeBano, L.F., D.G. Neary and P.F. Ffolliott. 1998. *Fire, s Effect on Ecosystem*. John Wiley and Son, New York.
- Flannigan, M.D., B.J. Stock and B.M. Wotton. 2000. Climate change and forest fire. *The Science of the Total Environmental* 262: 221-229.
- Johnson, D.W., M.E. Fenn, W.W. Miller and C.F. Hunsaker. 2009. Fire effect on carbon and nitrogen cycling in forests of The Sierra Nevada, pp. 405-423. In A. Bytnerowicz, M.J. Arbaugh, A.R. Riebau and C. Anderson, eds. *Wildland Fires And Air Pollution*. Elsevier, Hungary
- Marod, D. and U. Kutintara. 2009. *Forest Ecology*. Forest Biology Department, Faculty of Forestry, Kasetsart University, Thailand
- Cheney, P., 1994. The effectiveness of fuel reduction burning for fire management, pp. 9-16. In, *Proceedings of fire and biodiversity: The effect and effectiveness of the management*. Dept. of the Environment, Sport and Territories, Canberra, Footscray, Melbourne



Joint effects of fire and drought on the seasonal patterns of soil nutrient availability and microbial activity

M Belén Hinojosa, Antonio Parra, David Antonio Ramírez, José Antonio Carreira,
Roberto García-Ruiz, José Manuel Moreno

Centro de Investigaciones del Fuego, Spain.

* MariaBelen.Hinojosa@uclm.es

Key-words: fire; drought; soil nutrients availability; mineralization rates; enzyme activities.

Introduction

Less rainfall projected for some Mediterranean regions, as a consequence of climate change, are likely to exacerbate drought conditions, and therefore fire frequency and extent. However, in spite of the importance of soil resource on plant community regeneration after fire, there is still much to be learned and understood in terms of soil nutrient availability and microbial activity of burned soils under a climate change scenario.

Although there are many studies about the effect of fire on soil N and P availability, C and N mineralization rates and enzyme activities, in our knowledge they never has been studied in burned soils under different drought treatments.

The aim of this study was to assess the effect of fire on seasonal patterns of soil N and P availability and their mineralization rates in a Mediterranean shrubland subjected to different drought scenarios.

The study was carried out on a natural Mediterranean Cistus-Erica shrubland located in Montes de Toledo (Spain). In April 2009, an automated manipulative experiment was setup with the implementation of plots (6×6 m²) with four different treatments where annual precipitation was controlled by changing spring-summer rainfall, resulting in: environmental control (EC), long-term historical average precipitation (HC), 25% reduction of HC (D1) and 50% reduction of HC (D2). In September 2009, the plots were burned to evaluate the joint effects of drought and fire. In order to compare burned and non burned scenarios a set of non burned plots was kept without rainfall manipulation (EC-). Finally, each treatment (EC-, EC+, HC+, D1+ and D2+) was replicated four times in the experimental setup.

Soil samples were collected after fire on spring, summer, autumn and winter in order to evaluate seasonal pattern of the assayed variables. Field-moist soil samples were analysed for soil N and P labile fractions, potential C mineralization rate, net potential nitrification rate and enzyme activities (phosphatase activity, β -glucosidase activity and arylsulfatase activity).

Our results show that, in general, the effects of drought on burned soils were expressed in a slower nutrient turn-over (potential mineralization rates and enzyme activities). However, although drought caused a decrease on inorganic P soil, an accumulation of inorganic N forms was observed after rainfall exclusion.



Short-term changes in soil physical and chemical properties after wildfires in NW Spain

María Eufemia Varela^{a*}, Elena Benito^b, María Rodríguez-Alleres^b, Jan Jacob Keizer^a

^a Centro de Estudos do Ambiente e do Mar (CESAM), Departamento de Ambiente e Ordenamento, Universidade de Aveiro, 3810-193 Aveiro, Portugal

^b Departamento de Biología Vegetal y Ciencias del Suelo. Facultad de Biología. Universidad de Vigo. Campus Lagoas-Marcosende, 36310 Vigo, Spain

* eteijeiro@gmail.com

Key-words: wildfires; post-fire evolution; aggregate stability; water repellency; organic carbon.

Introduction

The passage of a fire does not only affect soil properties directly, through heating, but also indirectly, through the fire-induced changes in vegetation and litter cover as well as in the soil properties themselves. For example, the removal of vegetation cover increases the exposition of the soil surface to fluctuations in weather conditions, and will lead to changes in the topsoil's temperature and moisture regimes. In spite the importance of the indirect wildfire effects is widely recognized, they have received less research attention than the immediate effects.

The present study addresses both the direct and indirect wildfire effects on the properties of several forest soils in Galicia, north-west Spain. At a total of nine sites, neighboring burnt and unburnt soils were compared immediately after fire and then monitored at regular intervals during the subsequent two years. The focus of this study is on the fire-induced changes in soil aggregation (size distribution and stability) and soil water repellency but also organic carbon content and microbial biomass were compared. The evolution of the soil properties during the first two years after fire varied markedly between the different study sites. This seemed to reflect to a large extent the magnitude of the direct fire-induced changes. When changes immediately after the passage of the fire were minor, pre-fire values were generally restored during the first few months afterwards. Marked direct changes, however, required recovery periods longer than the two year of this study. The carbon content seemed to be a critical factor in the recovery of the other soil properties.



Effects of wildfire on soil water repellency and their implications for soil erosion

Maria Rodriguez Alleres^{a*}, María Eufemia Varela Teijeiro^b, Elena Benito Rueda^a

^a Departamento de Biología Vegetal y Ciencias del Suelo. Facultad de Biología. Universidad de Vigo.
Campus Lagoas-Marcosende, 36310 Vigo, Spain

^b Centro de Estudos do Ambiente e do Mar (CESAM), Departamento de Ambiente e Ordenamento,
Universidade de Aveiro, 3810-193 Aveiro, Portugal

* malleres@uvigo.es

Key-words: wildfire, water repellency, surface runoff, soil erosion.

Introduction

Soil water repellency is a naturally occurring phenomenon that can be strengthened by heating. Soil water repellency induced or enhanced by fire, in combination with reduced vegetation and litter cover, is widely regarded as one of the main causes of increased surface runoff and accelerated soil erosion in burnt areas.

In Galicia (NW Spain), forest soils usually exhibit water repellency that is ascribed to the regional climate and, specifically, to its warm, dry summers, the prevalence of soils with coarse textures and high organic matter contents, and the high incidence of forest fires over the past decades.

In this work, we examined the effects of a wildfire of medium–high intensity on soil water repellency and its consequences on surface runoff and soil erosion. To this end, the water repellency of the burnt area was compared, immediately after the fire, with that of a nearby unburnt area using the water drop penetration time (WDPT) test. The unburnt soil exhibited extreme water repellency (WDPT > 6 h) down to 10 cm, strong repellency (WDPT 60–600 s) from 10 to 20 cm and no repellency below 20 cm. On the other hand, the burnt soil exhibited considerably decreased water repellency in its surface layer (0–2 cm); its repellency, however, increased with increasing depth in relation to the unburnt soil and was extreme in the 2–20 cm layer but slight (WDPT 5–60 s) in the 20–40 cm layer.

Such strong repellency reduced water infiltration in the burnt area and resulted in runoff coefficients of 50% as determined by simulating rainfall in 1 m² plots. At this scale, however, runoff resulted in modest soil erosion only. At the slope scale, the strong precipitation in the area two months after the fire, the loss of the protective plant cover and the extreme water repellency to subsurface water, facilitated strong erosion that was studied in terms of changes in soil texture and colour, as well as by morphological analysis of the soil surface.



Wildfire effects on hydrogeochemistry of Marão river watershed

Maria Rosário Costa^{a*}, José Aranha^b

^a Centro de Investigação da Universidade de Aveiro (GeoBioTec); Departamento de Geologia da UTAD, 5001-801 Vila Real (Portugal);

^b Departamento de Engenharia Florestal da UTAD, 5001-801 Vila Real (Portugal).

* rosario.costa@utad.pt

Key-words: Wildfire, ashes, soils, surface water, hydrochemistry.

Introduction

The conditions offered after a wildfire increases the transport of sediment and ash into the watercourses, with direct influence on their quality. Published studies on the effects of forest fires on water quality of rivers indicate that variations may occur at the level of pH, turbidity and nutrient loading (nitrate, sulfate, calcium, magnesium, heavy metals and others), dissolved or in suspension (Raison e McGarity, 1980; Binkley e Brown, 1993; Ranalli, 2004; Wallbrink et al., 2004).

A wildfire, triggered by a fallen aircraft, in June 2006 burnt about 255 hectares in the Marão River watershed (approximately 16% of the basin area), which has humic cambisols soils with a underlying bedrock of schists, greywacks and some granites. The area was dominated by *Pinus pinaster* and various shrubs such as brume and genista. The fire incinerated the thin layer of organic matter in soil, the vegetation and the trees, killing all vegetation in its length. The study site is located in the Marão Mountain (centroide: 41° 15' 16''; 7° 53' 40'', NE Portugal) with altitude varying between 1344m and 400m. The region has a sub-atlantic clima with mean annual temperatures between 10°C and 12.5°C and a mean precipitation ranging 1400 to 2000mm/year. Samples of ash, soil and water, from within and outside the burnt area, were collected about 5 months and one year after the fire for chemical analysis. All sampling sites were located using a Differential Global Positioning System.

Objectives

The purpose of this study was to assess changes in quality of river water by comparing post-wildfire hydrogeochemical data with pre-fire data and to analyze the recovery capacity of water composition trough time.

Methodology

Samples of ash, soil and groundwater were collected at locations, inside and outside the burnt area at different periods of time in order to perform chemical analysis.

Three samples of ash and the soil underlying the ashes were collected, as well as 9 soil samples, outside the burnt area, to serve as reference of soil characteristics prior to the fire. The collection of ashes was made in November 2006 (5 months after fire) and the soils were collected also in November 2006 and in May 2007 (11 months after the fire). The methodology for the collection of ash and soil was to devise a square with 30cm side, and with the help of a plastic spoon, remove the ash and then the soil, which were placed in separate plastic bags previously identified. Laboratory analysis was performed at the Soils Laboratory of UTAD. Deteminations of pH was made by potentiometry, carbon by combustion at 1100 °C and detection by infra-red in an elemental analyzer, the concentration in organic matter (OM) by calculation ($OM = C * 1.724$), P_2O_5 and K_2O

were measured by the Egner-Riehm method, cations (Ca, Mg, K, Na) with ammonia acetate, metals (Zn, Cu, Mn and Fe) by the method of Lakanen, the total nitrogen by sulfuric digestion and determination by spectrophotometry of molecular absorption in segmented flow analyzer, the nitrate-nitrogen and Ammonia by extraction with saline solution (KCl-2M) and determination by spectrophotometry of molecular absorption in segmented flow analyzer.

The collection of water samples was carried out in three campaigns and was held in November 2006 and February and July 2007. There were still available hydrochemical data of water samples collected in the region in July 2002, which allowed to characterize pre-fire water quality. The methodology for water sampling was to collect a bottle of 200ml (acidified with nitric acid 1%) for determination of cations and trace elements and a 500ml bottle for determination of alkalinity and anions. Determinations of some physical and chemical parameters including pH, electrical conductivity, total dissolved solids and temperature were performed in the field. Chemical analysis of water samples were performed at the Laboratory of Chemistry of UTAD where determinations of Iron and Silica were made by Molecular Absorption Spectrometry, Na and K by Atomic Emission Spectrometry, Ca, Mg and Zn by Atomic Absorption Spectrometry (AAS), Mn and Cu by AAS (Graphite Furnace).

Results and conclusions

The results of the chemical analysis of ash and underlying soils samples, harvested 5 months after the fire presented in Table 1 put on evidence that the pH of the ashes is always higher than the underlying soil, which may be associated with increased concentrations of carbonates and oxides and hydroxides in the ash resulting from burning of vegetation (Soto and Diaz-Fierroz, 1993 and Khanna et al., 1994). The percentage of carbon is also higher in the ash which reflects the conversion of OM in ash caused by burning. The organic phosphorus is combusted resulting in ashes with very high concentrations of phosphate. For base cations there is a general increase in concentration in the ash, which is highlighted in particular by the highest concentration of Ca and Mg. For metal ions there is a high concentration of Mn in the ash, that reaches up to 5 times the content of the underlying soil (as is the case of sample B). In other studies, were found high concentrations of Mn in pine needles (Kabata-Pendias and Pendias, 1984) and the resulting ash (Someswar, 1996). In the study region it could be seen that the pine needles were burnt, but the arms were largely intact, suggesting that the needles were the main source of ash.

Table 1. Chemical analysis of ash and underlying soils, 5 months after the fire.

	pH	C	O.M.	P ₂ O ₅	K ₂ O	Ca	Mg	K	Na	Zn	Cu	Mn	Fe	Nitrogen		
Sample	H ₂ O	%	%	E.R.(mg/kg)		Ammonia Acetate (cmol+/kg)				Lakanen (mg/kg)				Total (g/kg)	Nitr. (mg/kg)	Amon. (mg/kg)
Ash A	6	35.4	61	305	180	13.2	4.67	1.44	0.53	52.8	3.2	248.6	190.3	19.8	50.2	343.3
Soil A	5.1	17.4	29.9	38	64	4	1.47	0.38	0.14	17.6	1.3	57.2	448.8	9.3	19.4	179
Ash B	6.1	17.2	29.6	573	144	21.36	5.73	0.85	0.24	68.2	4.3	418	121	15.7	82.4	74.4
Soil B	5.4	8.2	14.1	171	136	5.47	1.04	0.35	0.04	6.2	2.8	82.5	188.1	6.8	70.8	265.2
Ash C	6.1	29.9	51.5	190	156	7.79	3.2	0.95	0.22	31.9	3.1	291.5	106.7	19.1	13.3	225.9
Soil C	5.5	15.5	26.8	113	140	1.52	0.72	0.57	0.04	5.9	0.9	106.7	171.6	10.1	24.1	231.5

Results of the soils composition about one year after the wildfire show a recovery of pH values (Fig. 1), close to the reference value (obtained from soil samples collected outside the burnt area, which is consistent with the decrease in content of base cations, that approached the reference values (Fig. 2). The loss of base cations, especially Ca and Mg is due to transport of particles by rain. Sodium tends to increase slightly, which may be related to their attachment to the soil through ion exchange. For the metal ions examined (Fig. 3), there is a tendency to increase the content of Fe and Cu and a decrease in Zn and Mn. While Fe and Cu tend to linger in the soil in the form of oxides and hydroxides, Zn and Mn elements are more soluble and are easily leached by rain water.

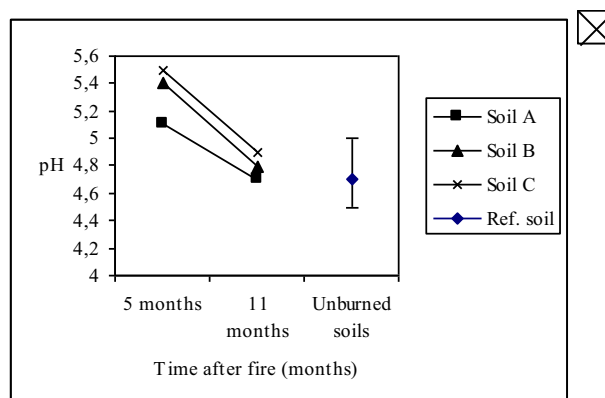


Figure 1. Temporal variation of pH in soil samples of the burnt area and comparison with pH of unburnt soils.

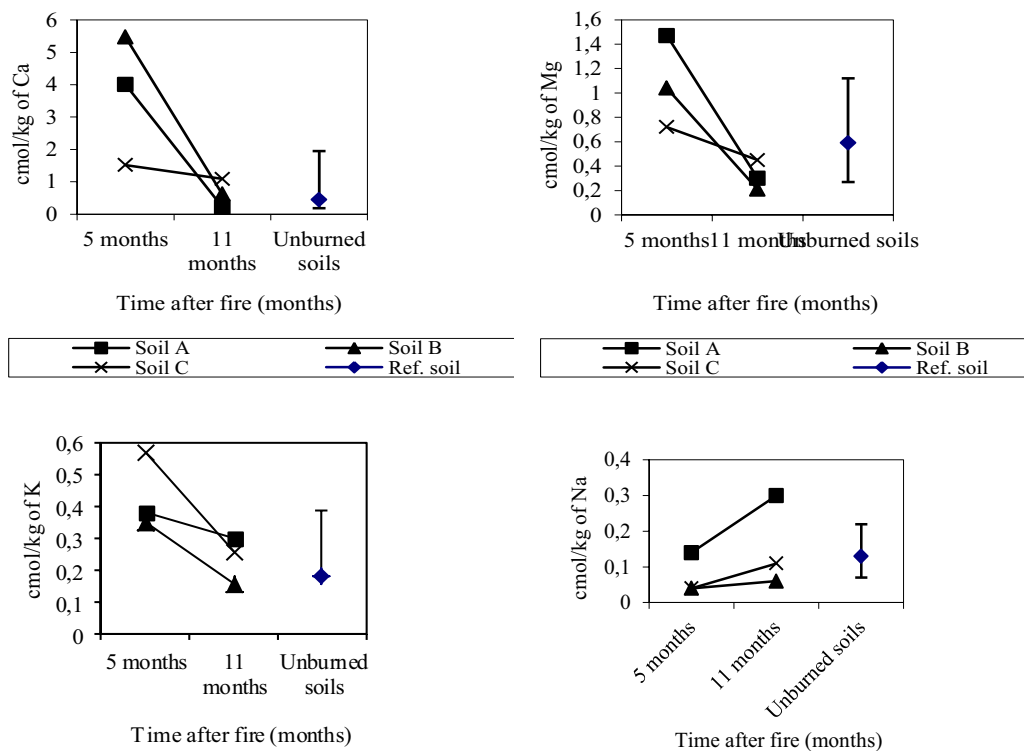


Figure 2. Temporal variation of cations (Ca, Mg, K and Na) in soil samples of the burnt area and comparison with values of unburnt soils.

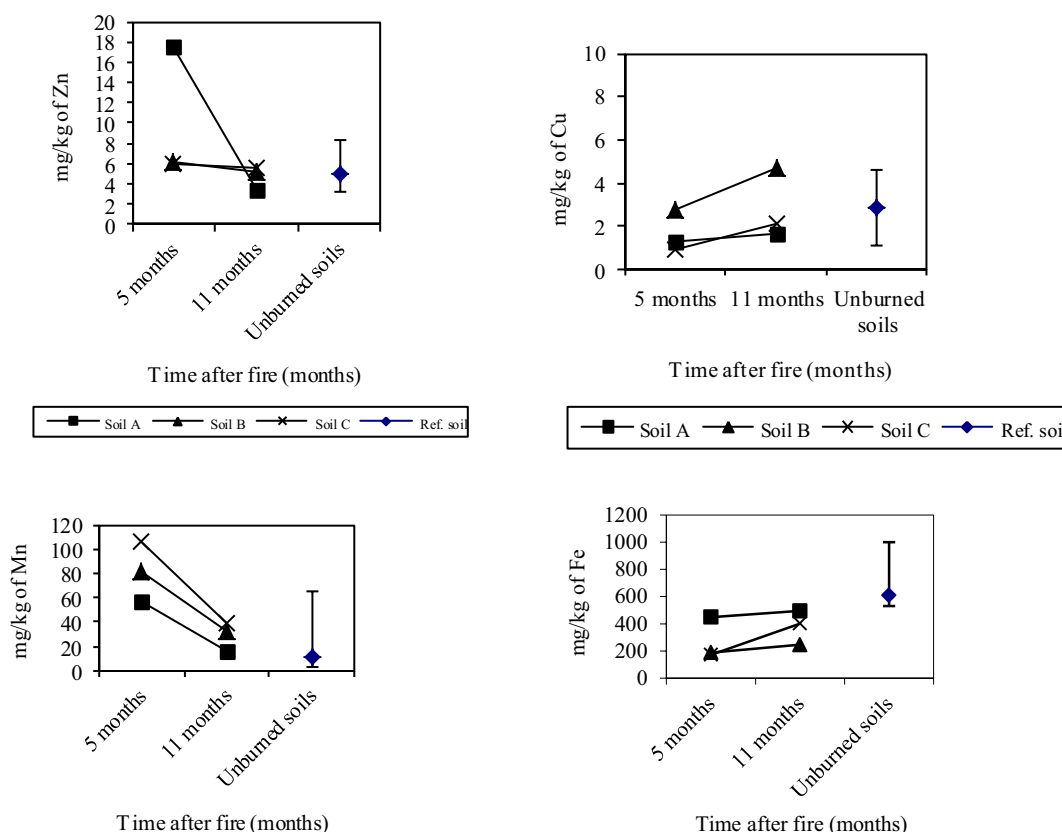


Figure 3. Temporal variation of metal ions (Zn, Mn, Cu and Fe) in soil samples of the burnt area and comparison with values of unburnt soils.

The wildfire effects on the Marão River water quality resulted in an increase in the total mineralization of water. Water electrical conductivity (EC) was about twice pre-fire values 5 months after the wildfire (EC increased from 15 to 37 $\mu\text{S}/\text{cm}$) and 1.5 times higher one year after the wildfire.

Cations of Ca, Na, Mg and Mn showed the greatest increase. This increase was probably triggered by the movement of ash to the watercourses which was found to be especially rich in Ca, Mg and Mn. This increase had already attenuated one year after wildfire to values closer to pre-fire data except for manganese (Fig. 4).

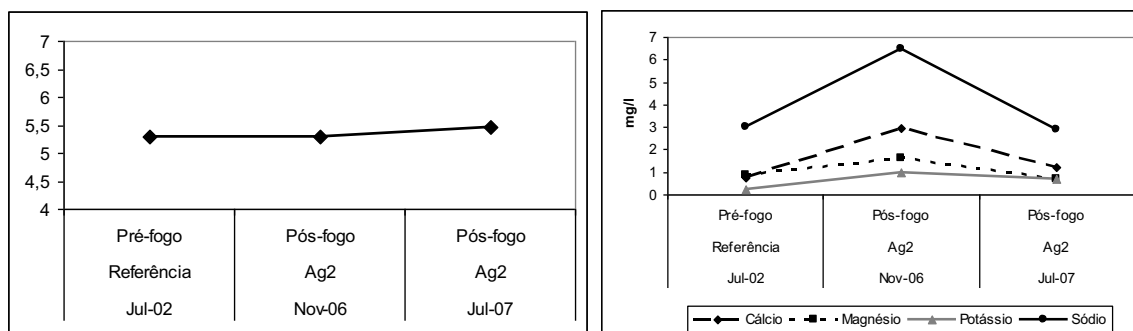


Figure 4. Variation on pH and cations concentration in water river samples in the burnt area.

Manganese had anomalous concentration in the water within the burnt area (Fig. 5). The concentration of manganese in ash samples reached values up to 5 times more than values found in underlying soils. This result probably stemmed from the combustion of pine needles, which was transported as part of the ash to the stream and thus may explain the high concentration in stream water. Another aspect that may explain why the Mn concentration in water was higher and remain in solution more time than the other cations is related to the occurrence of a little rainy spring and summer with an unusually abundant rainfall in 2007, what may have delay the ash transport to the river. There was also a substantial increase in the concentration of dissolved silica and values of pH in the river water downstream from the wildfire between 5 months and 1 year after the wildfire. This seems to indicate an increase in the rate of dissolution of the silicate minerals from the bedrock (mainly granites and metasedimentary rocks) caused by the removal of the overlying ash and soil.

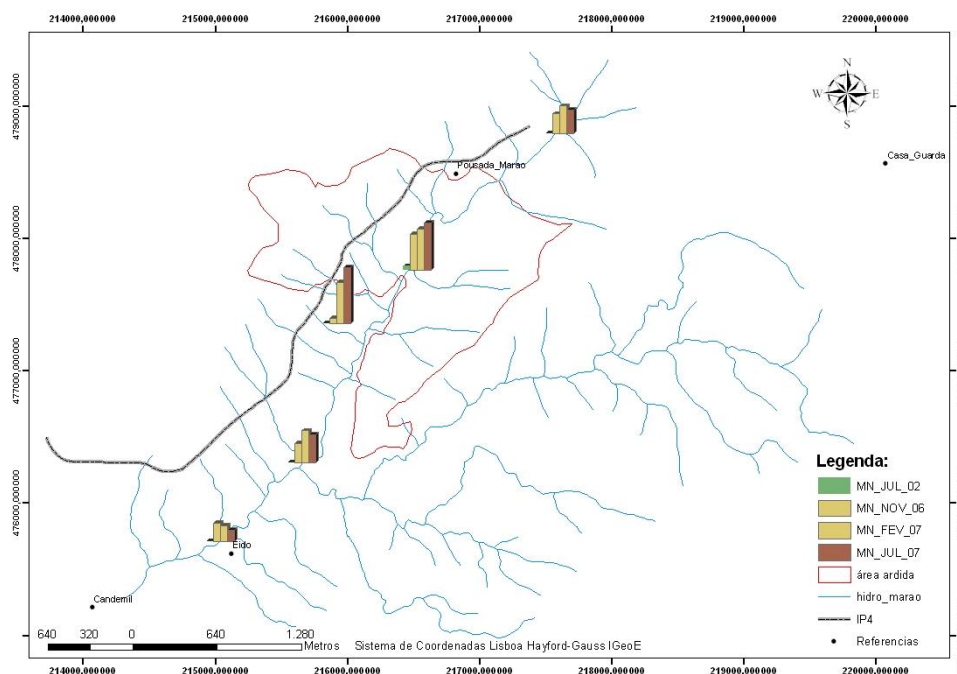


Figure 5. Variation on Mn concentration in the water along the Marão river.

References

- Binkley, D. and Brown, T.C. 1993. Management impacts on water quality of forests and rangelands. USDA Forest Service General Technical Report RM.
- Kabata-Pendias, A. Pendias H. 1984. Trace elements in soils and plants. CRC Press. Florida.
- Raison, R.J. & McGarity, J.W. 1980. Effects of ash, heat and the ash-heat interaction on biological activities in two contrasting soils. I. Respiration rate. Plant and Soil. 55:363–376.
- Ranalli, A.J. 2004. A Summary of the Scientific Literature on the Effects of Fire on the Concentration of Nutrients in Surface Waters. U.S. Geological Survey. Reston. Virginia.
- Someshwar, A.V. (1996). Wood and combination wood-fired boiler ash characterization. Journal of Environmental Quality. 25: 962–972.



- Soto, B. & Diaz-Fierros, F. 1993. Interactions between plant ash leachates and soil. *International Journal of Wildland Fire*, v.3. 4:207-216.
- Wallbrink P., English P., Chafer C., Humphreys G., Shakesby R., Blake W. and Doerr S. 2004. Impacts on water quality by sediments and nutrients released during extreme bushfires. Sydney Catchment Authority - CSIRO Land & Water Collaborative Research Project.



Evolution of soil organic matter after prescribed fire: a 20-year chronosequence

M. A. Alexis^{*1}, H. Knicker², C. Anquetil¹, C. Rumpel³

¹ Bioemco Laboratory, 4 place Jussieu -75252 PARIS Cedex 05, FRANCE

² Lehrstuhl für Bodenkunde, Technische Universität München, D85350-Weihenstephan, GERMANY

³ Bioemco Laboratory, Centre INRA Versailles-Grignon, 78850 Thiverval-Grignon, FRANCE

* marie.alexis@upmc.fr

Key-words: soil chronosequence, prescribed fire, chemical composition, solid-state ¹³C NMR, carbon stock

Introduction

Numerous studies highlighted the strong instantaneous effect of fire on soil organic matter quality: colour, hydrophobicity, aromaticity and stability are modified (Certini, 2005 and references therein; Eckmeier et al., 2010; Malkinson and Wittenberg, 2011). As charred OM is considered slowly degraded not to say inert, the impact of fire on the soil properties is supposed to be long-lasting. However charcoal degradation studies did not necessarily reflect high stability of pyrogenic carbon (Ascough et al., 2011). The objective of this work was to assess the influence of charcoal produced by moderate-intensity fire on the medium-term evolution of total soil organic carbon quality and quantity.

Methodology

The study site was in Florida, on the *Merritt Island Wildlife Refuge*. Ecosystem is an oak shrub managed by prescribed fires (moderate intensity). We used a chronosequence of soils collected in plots protected from fire for 1, 4, 11 and 20 years. Climate is subtropical and soil highly sandy, potentially favouring C decomposition. Three soil depths were sampled: 0-5 cm, 5-15 cm and 15-25 cm. C and N contents were measured and the soil organic matter stocks calculated. After the demineralisation of samples, solid-state ¹³C nuclear magnetic resonance (¹³C-CP/MAS-NMR) was used to characterize the organic matter from depth 0-5 cm and 5-15 cm. Moreover the characterization of surface samples were supplemented by the application of the Curie Point pyrolysis coupled to mass spectrometry (CuPy-GC-MS) and the quantification of oxidation (K₂Cr₂O₇/H₂SO₄, 80°C) resistant elemental carbon (OREC).

Results and conclusion

The C stock proved to decrease from 38 to 26 mg OC cm⁻³ soil in the 0-5 cm depth after the first year. In contrary it remained stable in the 5-15 cm and the 15-25 cm depths with mean values of 13±4 mg OC cm⁻³ soil and 7±2 mg OC cm⁻³ soil, respectively. The C/N ratio was between 38 and 44 for the different depths 1 year after the fire. This ratio decreased with time, ranging between 22 and 26, 20 years after the fire.

One year after the fire in the 0-5 cm depth sample (Fig.1), the NMR spectrum was dominated by the alkyl C (30 ppm) that might be assigned to the lipid compound. In the O-alkyl C region, a high peak at 72 ppm was detected, as well as a lower peak at 105 ppm, probably reflecting the contribution of carbohydrates and ligno-cellulosic compounds. The aromatic-C chemical region (110-160 ppm) presented a main peak at 130 ppm that may be related to a lignin and/or charcoal origin of C. A small contribution in the carbonyl-C region (172 ppm) was also observed. In the 0-5 cm depth, a relative

decrease of the O-alkyl C occurred between 1 and 4 years after the fire, followed by the decrease of the aromatic-C contribution between 4 and 11 years after the fire. 20 years after the fire, the alkyl-C contribution became lower. In the 5-15 cm depth, no change occurred between 1 and 4 years, whereas all compounds decreased compared to alkyl-C between 4 and 20 years.

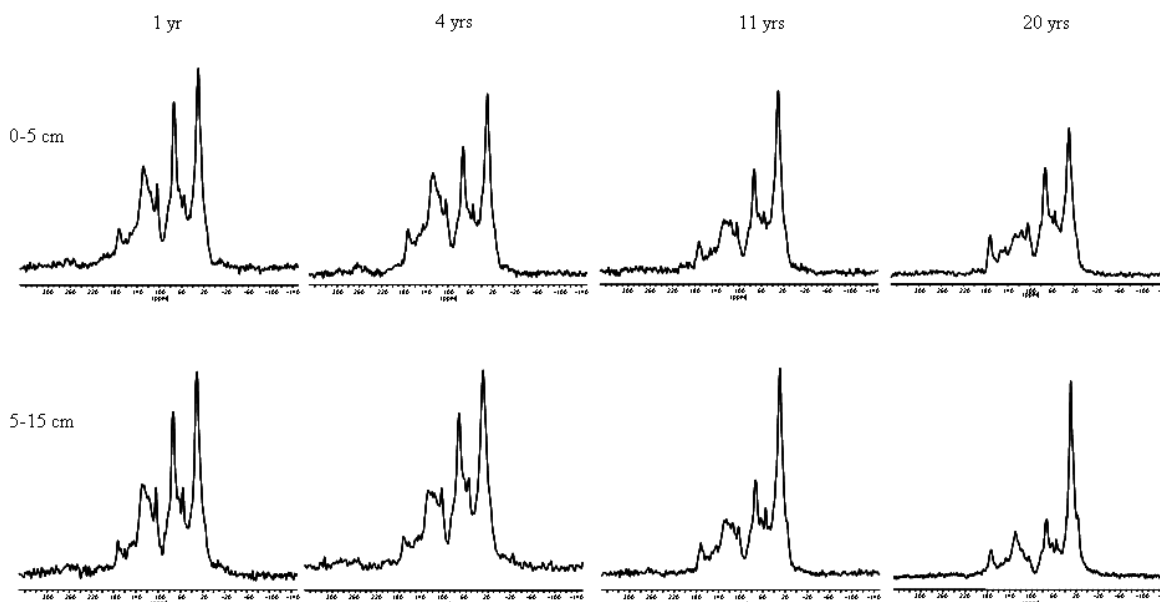


Figure 1. soil organic matter spectra obtained by ¹³C-CP/MAS-NMR for the depths 0-5 cm and 5-15 cm in the plots sampled 1, 4, 11 and 20 years after the last fire.

The spectra obtained by Cu-Py-GC-MS reflected the contribution of mainly three classes of compounds: phenols, polysaccharides and lipids (Fig.2). Pyrochromatograms obtained at different dates did not reflect different organic matter quality, but the evolution was consistent with results obtained by ¹³C-CP/MAS-NMR. The detected aromatic molecules were scarce and this can be related to the low content of OREC measured in the samples. These results showed that the aromatic carbon degraded between 4 and 11 years most likely originated from lignin and not from charcoal.

The evolution of the organic matter might be divided into three steps: at first, the degradation affected a labile C pool, which probably originated from the high input of uncharred organic matter during the fire; secondly, the phenolic part of lignins appeared the most affected by the degradation, and thirdly, the degradation seemed to affect the alkyl-C. The soils of this 20-year chronosequence contained only small quantity of pyrogenic carbon. These data illustrate that after moderate-intensity fires, the degradation of the pyrogenic material can be relatively fast once added to soil. These results have consequence for the long-term C storage potential of charcoal and for the duration of soil property modification.

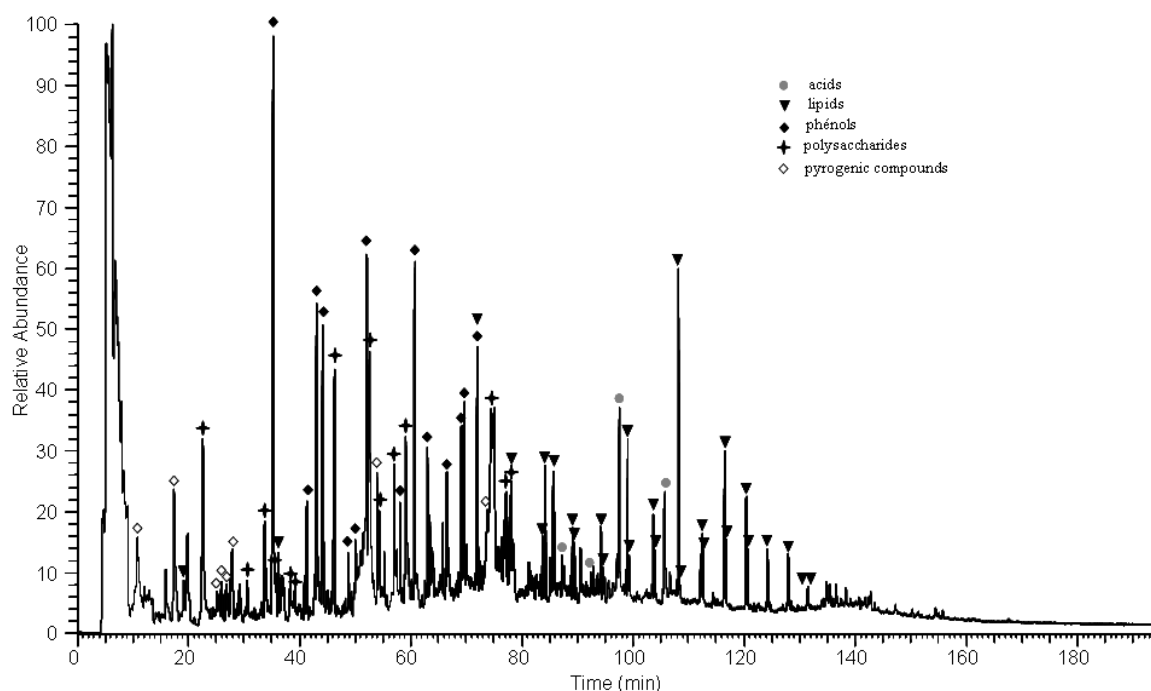


Figure 2. Pyrochromatogram obtained by CuPy-GC-MS for the depth 0-5 cm in the plot sampled 1 year after the fire.

References:

- Ascough PL, Bird MI, Francis SM, Lebl T (2011) Alkali extraction of archaeological and geological charcoal: evidence for diagenetic degradation and formation of humic acids. *Journal of Archaeological Science*, 38 (1)
- Certini G (2005) Effects of fire on properties of forest soils: a review. *Oecologia*, 143 (1)
- Eckmeier E, Egli m, Schmidt MWI, Schlumpf N, Notzli M, Minikus-Stary N, Hagedorn F (2010) Preservation of fire-derived carbon compounds and sorptive stabilisation promote the accumulation of organic matter in black soils of the Southern Alps. *Geoderma*, 159 (1-2)
- Malkinson D, Wittenberg L (2011) Post fire induced soil water repellency-Modeling short and long-term processes. *Geomorphology*, 125 (1)



Overland flow and soil erosion at micro-plot scale in six recently burnt eucalypt stands in North-central Portugal

Maruxa Malvar Cortizo*

CESAM-Universidade de Aveiro, Portugal

* maruxa@ua.pt

Key-words: runoff; erosion; micro-plot; eucalypt; wildfire.

Abstract

In the EROSFIRE project, micro-scale runoff plots were employed to assess how representative the results of field rainfall simulation experiments (RSE's) were for runoff and erosion response under natural rainfall conditions. This was done at six sites where RSEs were carried out at several occasions during the first one or two years following fire. The six study sites are located in the Vouga River basin in north-central Portugal and the six sites are Eucalyptus globulus plantations. The sites were selected for their contrasting pre-fire land management. Three slopes show no evidence of mechanical operations while the other three were subject to different types of ground operations prior to the plantation of the eucalypt trees, namely contour and down-slope ploughing and terracing. Within a month after fire, the sites were equipped with two pairs of micro-plots located on the slopes' lower and upper halves. The runoff of the plots was measured and sampled at 1-2 weekly intervals, and the sediment concentration of the runoff samples was analyzed in the laboratory using standard methods. Rainfall was measured using totaliser as well as automatic rainfall gauges. Selected soil conditions (e.g. water repellency, moisture content,) were monitored at mostly two-weekly intervals. The RSE's produce more runoff than natural rainfall plots which could be attributed to the highest intensity of the simulated rainfall. For both techniques the overall runoff generation by site shows minor differences between sites with the natural rainfall micro-plots having values ranking from 20-15%. The results suggested a temporal pattern of runoff generation that could be explained by soil water repellence. The initial monitoring period immediately following the fire is characterized by high runoff coefficients as well as pronounced soil water repellency. Both runoff generation and water repellency are basically non-existent during the ensuing wet winter and spring periods but reappear with the onset of the dry season of the second monitoring year. Sediment losses are lower than those reported in literature for similar studies. This could be attributed to the moderate-low intensity of the wildfire and/or sediment-limited erosion. In evaluating these losses, however, the shallowness of the soils must not be overlooked.



Potential and effective response to fire of the seed bank of a mediterranean heatland

Paula Maia*, Isabel Fernandes, Ana Vasques, Domingos Viegas, Juli Pausas, Jacob Keizer

CESAM-Universidade de Aveiro, Portugal

* paula.maia@ua.pt

Key-words: experimental fire; seed bank; *Erica* spp.; *Pterospartum tridentatum*.

Abstract

In recent years, prescribed burning is increasingly being used as a management tool of standing biomass and, thus, of wildfire hazard. This has raised the need to provide further insight into the consequences of prescribed fire in terms of environmental factors and processes like, for example, atmospheric emissions and soil erosion. The present study addresses this need by investigating the impact of an experimental burning on the seed bank of a Mediterranean heathland in central Portugal. The study area is located in Coentral, in the municipality of Castanheira de Pêra and involves a series of plots that are being managed by the Centre for Research on Forest Fires (CEIF) for experimental burning purposes. In the present case, the burning took place in May 2008. The soil seed bank was sampled immediately before and after the fire, using a metal cylinder of 6cm diameter, at a depth of 6 cm. Sampling was done at two locations within each plot, i.e. roughly halfway the plot's lower and upper halve, and under the nearest specimen of *Pterospartum tridentatum* and *Erica umbellata*. The collected soil samples were placed in a greenhouse to germinate, and seedling emergence was recorded for 1 year. Also, the germination in the field has been recorded for the same period of time to evaluate not only the potential germination response but also the effective establishment of the seedlings. To obtain supplementary insight into the role of fire in the germination of *Pterospartum tridentatum* and *Erica umbellata*, controlled heating experiments were carried out. This was done with seeds collected from the neighbouring areas in the summer 2009. This complementary experiment also included *Erica australis* seeds, since it was the third dominant species in the experimental plots and it was also found in the seed bank. The overall results from the seed bank germination under laboratory conditions showed similar seedling densities for the pre-fire and post-fire soil samples. Average densities of viable seed were 3362 and 3662 seeds per m² before and after the burning, respectively. The higher germination density was recorded on the soil samples collected under *Erica umbellata* shrubs, as opposite to samples collected under *Pterospartum tridentatum*. In addition, the most abundant taxon found in the seed bank was *Erica* spp. Further data analysis will integrate the results from germination in the greenhouse as well as the in the field with those from the controlled heating experiments.



Soil protection by ash after a wildfire

Paulo Pereira^{a*}, Artemi Cerdà^b, Xavier Úbeda^c, Jorge Mataix-Solera^d, Deborah Martin^e

^a Department of Environmental Protection Department, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius (Lithuania);

^b Departament de Geografia, Universitat de València, Blasco Ibañez, 28, 46010, València (Spain);

^c GRAM (Grup de Recerca Ambiental Mediterrànea), Departament de Geografia Física i Anàlisi Geogràfica Regional, Facultat de Geografia i Història, Universitat de Barcelona, C/ Montalegre, 6. 08001 Barcelona (Spain);

^d GEA (Grupo de Edafología Ambiental) Departamento de Agroquímica y Medio Ambiente, Universidad Miguel Hernández, Elche, Alicante (Spain);

^e USGS, 3215 Marine Street, Boulder, Colorado (USA).

* pereiraub@gmail.com

Key-words: White ash, black ash, rainfall simulation, water quality.

Introduction

Fires induce important reductions of soil cover, exposing it to erosion agents. This reduction depends essentially of fire severity. In the immediate period after the fire, soil is critically exposed to erosion process and the ash layer remained after the fire is the unique and valuable protection (Pereira et al., 2010a; Cerdà and Doerr, 2008). Despite of the importance of ash layer in soil protection after the fire few studies have been carried out about ash layer thickness after fire (Pereira et al., 2010a,b; Woods and Balfour, 2010), perhaps because it is ephemeral. High severity wildland fires have important impacts on soil cover and due the temperatures reached and convection mechanisms occurred during the fire soil protection is coercively reduced and the ash produced, especially the small particulates are (re)distributed. Thus, it is very likely that some areas can be without ash cover and directly exposed to erosion agents, especially in slope areas where they are more active. The aim of this work is work is assess the probability soil no cover by ash one day after a high severity wildland fire.

Methodology

Wildfire occurred in July, 26 of 2010 and affected an area of 100 ha near the urban area of Quinta do Conde, at 38° 57' N and 09° 05' W and 27 m a.s.l.. The geological substrate of study area is mainly composed by Plio- Pleistocene dunes with low cementation and soils are classified as *podzols* (FAO, 2006). Mean annual temperature is 14.8 °C and the precipitation of 639.2 mm. The forest was mainly composed by *Pinus pinaster* species. One day after the fire we designed a grid with 20x4 m in a south faced slope with 27% of inclination. Ash thickness measurements were carried out with an iron bar (Pereira et al., 2010b) every 50 cm in a total of 200 measurements over the entire grid.

Omnidirectional semi-variogram of ash thickness was performed in order to observe the spatial structure of the variable. Spatial dependence was observed calculating the nugget/sill ratio. If the ratio is greater than 75%, the variable shows weak spatial dependence, between 75% and 25%, the variable shows moderate spatial variability and nugget/sill ratio less than 25% shows that the variable had strong spatial dependency (Chien et al., 1997).

In order to observe soil with no cover we calculated the probability of ash thickness being 0. These analyses were carried out with probability maps according Kriging methods. To identify the most accurate probability map, we tested several Kriging methods, Ordinary

Kriging (OK), Simple Kriging (SK), Universal Kriging (UK), Indicative Kriging (IK), Probability Kriging (PK) and Disjunctive Kriging (DK). Details about these probability methods can be founded in Smith et al. (2009). Methods accuracy assessment was carried out with the cross-validation method and the analysis of the mean error (ME) and Root Mean Square Error (RMSE) of each method. For more explanations of these indexes see Pereira and Úbeda (2010). The probability method with the lower RMSE is the most appropriate to interpolate the variable. Accuracy of the probability methods was also assessed with a Pearson correlation coefficient, significant at a $p < 0.05$. Statistical analyses were carried out with Statistica 7.0 and spatial analysis with Surfer 9.0 and ArcGis 9.3 for windows.

Results and conclusions

The fire was of high severity according the ash colour observed (Figure 1a) and clearly illustrated in the figure 1b. The majority of the ash colour observed was light grey (30%), followed by dark grey (23.50%), white (16%) and black (0.5%). In some points we identified that no ash cover (30%) that is very likely to be due the inexistence of fuel previous to fire or high severity combustion that consume all the existent biomass. On average, ash thickness was of 4.97 mm (± 6.13 mm), ranging from a minimum of 0 mm and a maximum of 26 mm. The CV% is extremely high (124.14%), which means that the ash thickness and soil protection was highly variable across the studied plot. This is very likely to be a consequence of fuel type, distribution and conditions (moisture) previous to fire, degree of combustion, meteorological conditions, and smoke and air convection during the fire that can (re)distribute ash across the plot. Overall, the soil had little protection against erosion agents, especially because the light gray and white as is composed by small particles and easily removed by wind and water as observed elsewhere in the field (Pereira et al., 2010b) and in laboratory studies (Úbeda et al., 2009).

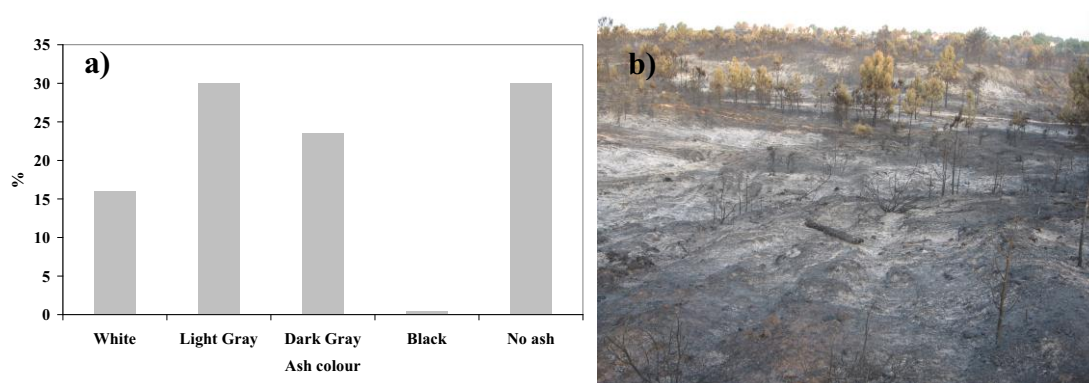


Figure 1. a) % of the identified ash colour ($N=200$) and b) foto taken 1 day after the fire (26-07-2010).

Table 1. Descriptive statistics of ash thickness. S.D (Standard deviation), Min (Minimum), Max (Maximum) and CV (Coefficient of variation in %). Data in mm. ($N=200$).

	Mean	Median	S.D	Min	Max	CV%
Ash cover	4.94	3.00	6.13	0	26	124.14

The figure 2 shown the punctual distribution of ash uncovered and covered points. We observed that one day after the fire the soil protection in the studied area did not showed any spatial pattern and is very heterogeneous and confirms the high CV% observed. From this punctual map it is visible that ash covered and uncovered areas are intercalated which means that soil protection is highly variable in very short distances. These differences are attributed to soil microtopography (Figure 1b). Ash accumulates in the lower areas and it is where it is thicker. In addition, during the fire is very likely that the convective air circulations contribute to the redistribution of ash across the plot. These small distance variation in ash accumulation will also produce variation in the impacts of ash on soil properties, during the period that ash remains in that place. Previous studies pointed out that ash is easily transportable in slope areas, especially after torrential rainfalls, distributing their impacts in the areas where they were not produced (Pereira et al., 2010a,b).

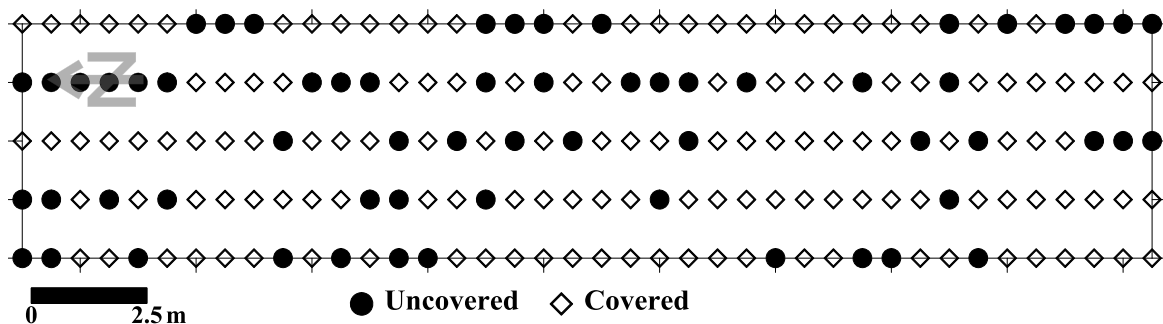


Figure 2. Spatial localization of not covered and non covered soil areas. ($N=200$).

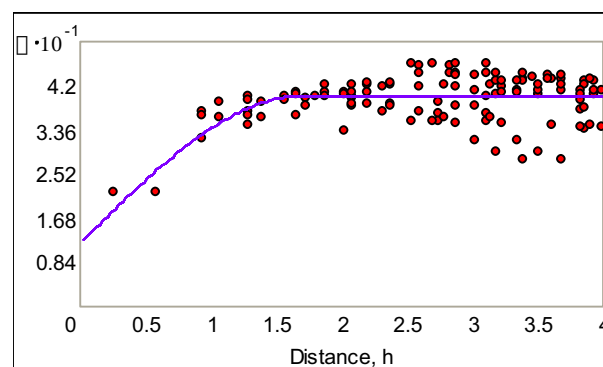


Figure 3. Omnidirectional semi-variogram calculated for ash thickness. Line represents the best fitted model. Range = 1.45; sill = 4.18 m; nugget effect = 1.22; nugget/Sill ratio = 26.84%. Distance, h in meters.

The calculated omnidirectional semi-variogram shows that ash thickness in the studied plot has a range of 1.6 m, a sill of 4.18 m, a nugget effect of 1.22 and a nugget/sill ratio of 26.84%, which means that the variable has a moderate spatial dependency. The omnidirectional semi-variogram shown a good structure and among all tested theoretical models, the gaussian model is the best fitted and shows that the variability of the variable increases in the first 1.6 m, reducing thereafter. The nugget effect is reduced, indicating that the spatial density of sampling points is sufficient to identify spatial structures. In addition the range (1.6 m) identified is larger than the sampling interval (0.5 m) which means that the grid designed is appropriated for this study. However, the range was considered small (1.6 m) and this suggests that the variation of the variable increase only

in until this distance. Beyond 1.6 m there is no spatial correlation that could be due some small scale variability observed in ash thickness. This small scale variation it is observed in the interpolated map (Figure 4).

Considering all methods, ME was in general unbiased (close to 0) and ranged from -0.305 to 0.1766. The RMSE varied between 0.4638 and 0.5523 (Table 2). Among all tested methods, the most accurate to interpolate the probability of ash thickness be 0 was SK and the less accurate IK. The correlation between observed and estimated values was higher in the high in the most accurate method and lower in the less precise interpolation method, which reflects the proximity between observed and estimated values (Table 2). The probability of ash being 0 varies between 0 and 77% and in the major part of the plot the probability of ash being 0 is higher than 50% (Figure 3). This means that this plot is very much vulnerable to soil erosion, until vegetation recover. We observed that there is no clear pattern of ash distribution after the fire and as we observed in the field this depends very much of plot topography. However some larger areas of thicker ash are evident in the map of the figure 4, and are located in the North and Southwest of the plot that are related with the plot large depressions.

Table 2. Summary statistics of the probability method accuracy. In bold the most precise. Minimum (Min) and Maximum (Max). r Correlation between observed and estimated values, significant at *** <0.001 and not significant (n.s) at a $p<0.05$.

Method	Min	Max	ME	RMSE	r
OK	-0.485	0.996	0.09282	0.4696	0.45***
SK	-0.567	0.983	0.09292	0.4638	0.49***
UK	-0.403	0.991	0.1365	0.4739	0.46***
IK	-0.400	0.822	-0.305	0.5523	0.04 ^{n.s}
PK	-0.403	0.802	0.005665	0.5007	0.05 ^{n.s}
DK	-0.336	1.000	0.1766	0.4863	0.37***



Figure 4. Probability map of ash being 0 calculated with the most accurate method ($N=200$).

References

- Cerdà, A.; Doerr, S. H. 2008. The effect of ash and needle cover on surface runoff and erosion in the immediate post-fire period, *Catena* 74(3): 256–263,
- Chien, Y.L., Lee, D.Y., Guo, H.Y., Houng, K.H. (1997) Geostatistical analysis of soil properties of mid-west Taiwan soils. *Soil Science*, 162, 291–297.
- FAO (2006) World reference base for soil resources 2006. *A framework for international classification and communication* 103 p.
- Pereira, P., Bodi, M., Úbeda, X., Cerdà, A., Mataix-Solera, J., Balfour, V., Woods, S. (2010a) Las cenizas y el ecosistema suelo, In: Cerdà, A. Jordan, A. (eds) Actualización en métodos y técnicas para el estudio de los suelos afectados por



- incendios forestales, 345-398. Càtedra de Divulgació de la Ciència. Universitat de Valencia.
- Pereira, P., Cerdà, A., Úbeda, X., Mataix-Solera, J., Martin, D.A. (2010b) Effects of fire in ash thickness in a Lithuanian grassland. Part I, Transect análisis. In: Diaz-Ravina, M., Benito, E., Carballas, T., Fontúrbel, M.T., Vega, J.A (Eds) *Research and Postfire Management: Soil protection and rehabilitation techniques for burnt forest ecosystems*, 265–268.
- Pereira, P., Úbeda, X. (2010) Spatial variation of heavy metals released from ashes after a wildfire, *Journal of Environmental Engineering and Landscape Management*, 18(1), 13-22.
- Smith, M. J., Goodchild, M. F., Longley, P. A. (2009) *Geospatial Analysis. A comprehensive guide to principles techniques and software tools*. Troubador Publishing. Leicester. 394 p.
- Úbeda, X., Pereira, P., Outeiro, L., Martin, D. (2009) Effects of fire temperature on the physical and chemical characteristics of the ash from two plots of cork oak (*Quercus suber*), *Land Degradation and Development*, 20(6), 589-608.
- Woods, S.W., Balfour, V. N. (2010) The effects of soil texture and ash thickness on the post-fire hydrological response from ash-covered soils. *Journal of Hydrology*, (In press) doi:10.1016/j.jhydrol.2010.08.025



Impact of a forest regeneration method used after fire on some soil properties

Piotr Sewerniak^{a*}, Sławomir S. Gonet^a, Marta Bożejewicz^a

^a Department of Soil Science, Nicolaus Copernicus University, 87-100 Toruń (Poland)

* sewern@umk.pl

Key-words: Forest fire; Forest management; Soil properties; Cambic Arenosol.

Introduction

Fire is a natural element that strongly influences plant associations so this agent is of a great importance for silviculture and forest management. In timber woods one of the most important purposes of foresters after fire is to restore forest stands in burnt areas. The methods of forest regeneration used in this exertion can be divided into two general groups: (i) with usage of natural succession and (ii) planting trees. Both main forest regeneration methods influence soil properties that result in e.g. differences in plant or seedling overcrowding. Moreover mentioned two main groups of forest regeneration are usually different as intensity of soil scarification is taking into account, that also effect soil properties.

The main tree species of Polish forests (about 70% of cover) is Scots pine (*Pinus sylvestris* L.). Although the species commonly seeds in burnt areas after forest fires (Obmiński 1970, Hille et al. 2004, Marozas et al. 2007) natural succession was not wide used in restoring such areas in the 20th century in Poland and planting method prevailed. In conformity with ‘close to nature’ forest management in last decade the natural method of forest regeneration in Polish silviculture has clearly increased. Yet, differences of regeneration method in aspect of effect on soil properties have not been well recognized. The aim of the research was to evaluate the impact of forest regeneration method used after fire on some soil properties in Central Poland. As the subject is connected to forest management the study was analysed in aspect of silviculture.

Methodology

The study was conducted in the Cierpiszewo fire area (52°57’N, 18°27’E; 50 m a.s.l.) in Central Poland (fig. 1), where almost 30 km² of pine forest was burnt in 1992. The fire has been one of the biggest of all forest fires in Poland in last hundred years. The mean yearly precipitation in the investigated area is 523 mm and the mean air temperature is 7,9°C (Wójcik, Marciniak 2006).

We investigated soil properties almost 20 years after fire in 3 study plots of different forest regeneration method used after fire: A. the pine thicket of a natural seeding origin, B. the two generation pine stand: the parent pine stand (burnt by surface fire of low severity only) of loose crown density (ca 30%) with underwood of young (post-fire) pine thicket of a natural seeding origin, C. the pine thicket of a planting origin. In the plot A and B soil was not intensive cultivated after fire, it was only partially surface scarified during removing burnt trees. In the plot C soil was prepared by a plough after fire and before tree planting. All the analyzed plots are characterized by the soil of Brunic Arenosol (IUSS Working Group WRB 2007).

In each investigated plot soil samples were collected for laboratory analysis. In the plot C samples were collected both from rows and interrows of post-ploughing micro-relief. Six samples of each O subhorizons (Oi and Obu – “old” litter, burned during the fire (Gonet

et al. 2007, Gonet 2010)) and the AE horizon were randomly collected in every pine stand. For these horizons the mean values of soil parameters are given in the paper. From each of deeper soil horizons (BwoBs, Bwo) one sample was collected from a soil pit dug in every plot. In soil horizon descriptions of the C plot, where soil was scarified by a plough, “au” index was added to autochthonous and “al” index to allochthonous soil horizons. The other horizon descriptions were given according to WRB (IUSS Working Group WRB 2007).

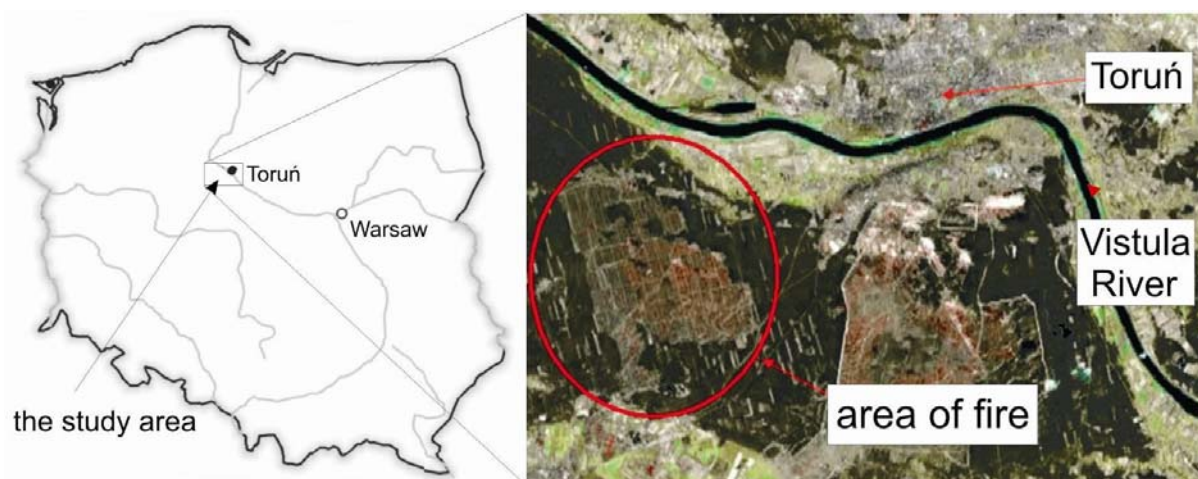


Figure 1. The location of the investigated area

In every collected soil sample the following parameters were determined (Bednarek et al. 2004):

- organic matter (OM) content – by the ignition method (3h in 550°C),
- organic carbon (OC) content – by sample oxidation in the mixture of $K_2Cr_2O_7$ and H_2SO_4 ,
- total nitrogen (Nt) content – by the Kjeldahl method.

Results and conclusions

The thickness of the forming after fire Oi subhorizon was significantly higher in both investigated thickets of a natural origin than in both analyzed positions (rows and interrows) in the greenwood of a planting origin (plot C, tab. 1). The main reason for the differences is probably dissimilar density of young pines in the investigated plots that is an important factor shaping organic biomass supply onto soil surface. The density was much more in the plot A (206 pines in $100 m^{-1}$) and B ($216 \cdot 100 m^{-1}$) than in the plot C ($75 \cdot 100 m^{-1}$, Sewerniak 2010). In the plot C the thickness of the Oi subhorizon was related to the location in a post-ploughing micro-relief. It was much higher in rows than in interrows (tab. 1).

In the investigated thickets of natural origin (plot A and B) the total soil organic matter stock was similar as in interrows in the plot C and significant higher than in rows of the planted thicket (plot A: $9,2 kg \cdot m^{-2}$; plot B: $10,1 kg \cdot m^{-2}$; plot C: rows – $5,6 kg \cdot m^{-2}$, interrows – $9,1 kg \cdot m^{-2}$). The differences between plots, concerning the total stocks of OC and Nt were similar to dissimilarities concerning OM stock. As it can be seen from table 1 the differences in total stocks result from altered stocks in surface soil horizons (O and AE) mainly. Particular distinct difference concerned total nitrogen stock in the Oi subhorizon. In the plot C it was clearly lower (rows – $11,4 g \cdot m^{-2}$, interrows – $2,77 g \cdot m^{-2}$) than in plot A ($27,2 g \cdot m^{-2}$) and B ($22,1 g \cdot m^{-2}$). The obtained C:N ratio values

proved distinct higher biological activity in the Oi subhorizon in thickets of natural origin than in the plot C (tab. 1).

Table 1. Properties of the investigated soils

Horizon	Thick-ness [cm]	OM [%]	OC [%]	Nt [%]	C:N	OM stock [kg·m ⁻²]	OC stock [kg·m ⁻²]	Nt stock [g·m ⁻²]
<i>Plot A</i>								
Oi	3,8	64,8	35,1	1,06	33	1,48	0,94	27,2
Obu	2,0	28,7	15,9	0,93	17	1,98	1,09	63,8
AE	3,0	3,1	1,9	0,08	24	0,80	0,55	22,3
AE2	8	2,3	1,2	0,05	24	2,37	1,28	51,6
BwoBs	6	0,8	0,40	0,02	20	0,73	0,36	18,0
Bwo	21	0,6	0,19	0,01	19	1,81	0,57	30,2
<i>Plot B</i>								
Oi	2,7	60,0	31,9	0,93	34	1,45	0,76	22,1
Obu	2,5	11,0	6,2	0,36	17	1,42	0,80	48,0
AE	2,2	3,1	1,7	0,07	24	0,71	0,41	17,7
AE2	8	2,3	1,37	0,05	27	2,22	1,19	48,2
BwoBs	7	1,5	0,69	0,03	23	1,44	0,66	28,8
Bwo	30	0,7	0,22	0,02	11	2,91	0,97	88,2
<i>Plot C – rows</i>								
Oi _{au}	2,1	69,4	37,7	0,91	41	0,85	0,47	11,4
AE _{au}	3,1	3,0	1,4	0,06	23	0,99	0,48	22,2
ABwoBs _{au}	13	1,9	0,83	0,04	21	3,20	1,40	67,5
Bwo _{au}	24	0,2	0,16	0,01	16	0,58	0,54	33,8
<i>Plot C- interrows</i>								
Oi _{au}	0,7	57,6	34,7	0,75	46	0,15	0,12	2,77
AE _{al}	5,3	6,0	3,3	0,12	27	3,16	1,75	62,2
Obu _{al + au}	3,5	20,2	11,4	0,42	27	3,00	1,68	63,6
AE _{au}	3,9	3,7	2,4	0,09	27	1,24	0,74	29,4
ABwoBs _{au}	4	1,8	0,79	0,04	20	0,94	0,41	21,0
Bwo _{au}	24	0,2	0,16	0,01	16	0,58	0,54	33,8

Except differ pine density in the investigated plots an important reason for the obtained differences of soil properties is dissimilar soil scarification intensity after fire. Ploughing usually increases the rate of organic matter mineralization, so intensive soil preparation in the plot C after fire and before planting can in part explain the results.

Fire results in serious losses of soil nutrients (Lewis 1974, Pritchett 1979, Brais et al. 2000). In restoring of fire areas should be used methods that do not increase the losses. In fresh sandy soils content of organic matter is a decisive factor that determines soil fertility and its moisture properties. Our results show that natural seeding should be more often use in forest regeneration in burned areas. In the Cierpieszewo fire area the pine thickets of the natural seeding origin are only about 5% of all greenwoods. The results suggest also that in regeneration of fire areas intensive method of soil preparation (e.g. ploughing) is not an advisable method, that it can increase organic matter mineralization. The method of only surface soil scarification in regeneration of fire areas should be rather applied.

References

Bednarek R., Dziadowiec H., Pokojka U., Prusinkiewicz Z. 2004. *Ecopedological studies*. Polish Scientific Publisher, Warsaw (in Polish).



- Brais S., David P., Ouimer R. 2000. *Impacts of wild fire severity and salvage harvesting on the nutrient balance of jack pine and black spruce boreal stands*. For. Ecol. a. Manage. 137: 231-243.
- Gonet S., S., Dziadowiec H., Bućko M., Kwiatkowska A. 2007. *Changes in morphology, organic matter stock and properties in pine forest soil after fire* [in:] Úbeda X., Outerio L. (eds.) Abstracts of the International Meeting of Fire Effects on Soil Properties, Barcelona 31.01-3.02.2007. Universitat de Barcelona.
- Gonet S.S. 2010. *Impact of forest fire on soil organic matter properties* [in:] Sewerniak P., Gonet S.S. (eds.) Environmental results of forest fire. Polish Humic Substances Society, Wrocław: 51-81 (in Polish).
- Hille M., Ouden J. 2004. *Improved recruitment and early growth of Scots pine (Pinus sylvestris L.) seedlings after fire and soil scarification*. Eur. J. Forest Res. 123: 213-218.
- IUSS Working Group WRB (2007) World Reference Base for soil resources 2006. World Soil Resources Reports, No 103, FAO, Rome. Electronic update 2007: <http://www.fao.org/ag/agl/agll/wrb/>.
- Lewis W.M. 1974. *Effects of fire on nutrient movement in a south Carolina pine forest*. Ecology 55: 1120-1127.
- Marozas V., Racinskas J., Bartkevicius E. 2007. *Dynamics of ground vegetation after surface fires in hemiboreal Pinus sylvestris forests*. Forest Ecology and Management, 250: 47-55.
- Obmński Z. 1970. *Ecology* [in:] Białobok S. (eds.) Our forest trees. Scots pine. National Scientific Publisher, Warsaw-Poznań: 152-231.
- Pritchett W.L. 1979. *Properties and management of forest soils*. J. Wiley&Sons, New York, Chichester, Brisbane, Toronto.
- Sewerniak P. 2010. *Impact of fire on some properties of pine phytocenosis in aspect of silviculture* [in:] Sewerniak P., Gonet S.S. (eds.) Environmental results of forest fire. Polish Humic Substances Society, Wrocław: 83-107 (in Polish).
- Wójcik G., Marciniak K. 2006. *Climate* [in:] Andrzejewski L., Weckwerth P., Burak S. (eds.) Toruń and its vicinity. Nicolaus Copernicus University in Toruń Publisher, Toruń: 99-128.



Bioavailable metal micronutrient in the rhizosphere burned soils

Marcet Miramontes, P.*; González Pimentel, S.

Departamento de Biología Vegetal y Ciencia del Suelo. Área de Edafología. Escuela de Ingeniería Forestal.
Universidad de Vigo. Campus a Xunqueira s/n 36005 Pontevedra. España

*marcet@uvigo.es

Key-words: metal micronutrients, rhizosphere, pH, organic matter.

Introduction

The rhizosphere has been recognized as a distinct microenvironment in which the properties and the intensity of soil processes differ from those of bulk soil (Legrand P. et al, 2005). The specific physicochemical and biological characteristics of the rhizosphere, such as the pH, the OM content and the exudation of organic substances by roots, mycorrhizae and microorganisms, all contribute to the establishment of distinct trace metal species and metal pool covering a range of bioavailability levels (Assadian and Fenn 2001).

Most metals are essential nutrients to plant growth, thus of practical relevance to productivity of agricultural and forest ecosystems. It is well established in the literature that pH and organic matter content are two key factors influencing the concentrations of metals. Because of its generally higher acidity combined to a large organic matter content, the rhizosphere should differ in metal concentrations and speciation compared to other soil component (Marschner and Romheld, 1996). The rhizosphere is mostly presented as an environment that is impoverished in metals (Wang et al., 2002), although not all metals have the same behaviour (Youssef and Chino, 1989).

The objectives of this work were to compare the Cl_2Ca extractable metal micronutrient concentrations of the solid phase between the rhizosphere and the bulk burned soils under two different tree species.

Material and methods

Burn soil was sampling from Cuspedriños- Pontevedra (Spain), a site which was completely burned by a wildfire in August 2006. Burn soil sample was collected from the top 30 cm. under *Eucalyptus globulus* Labill. (BE) and *Pinus pinaster* Ait. (BP). At each of the sampling sites, three trees were carefully uprooted. A separation between rhizosphere and bulk materials was performed at the sampling site. The roots sampled were hand-shaken and the soil adhering to the roots was considered as rhizosphere material. The soil falling from the roots and the remainder of the soil collected were regarded as bulk soil (Rollwagen and Zasoski, 1988).

The physicochemical properties of the air-dried soils were carried out in triplicate. Soil pH (1:2,5 soil:water) was measured, TOC and TN by elemental analysis (Leco CN-2000). Extraction with Cl_2Ba , were used to determine CEC and concentrations of Ca, Na, Mg, K and Al (Hendershot and Duquette, 1986). Cation concentrations were measured with an AAS- Varian AA-1475. The NH_4^+ , NO_3^- and PO_4^{3-} were extracted using acidified calcium chloride solution (0.1 M), according to the method developed by Houba et al. (2000), and analyzing with a segmented-flow auto analyzer (Bran Luebbe-AA3). Extraction with Cl_2Ca , were used to determine Fe, Mn, Cu and Zn bioavailable in bulk and rhizosphere materials and concentrations of extractable metals were determined by

inductively coupled plasma-mass spectrometry (Perkin Elmer Optima 4300 DV). Statistical analyses were carried on the software SPSS.

Results and discussion

The bulk soils studied have proportion of sand very high (>85%), low pH, low CEC and low base saturation, typical of soils located in a high-leaching environment. The pH values of the rhizosphere soils were always lower than those of bulk soils, with a difference of one pH unit under *Pinus pinaster* (Fig. 1). The acidification is considered to be mainly induced by the response of roots to ionic charge imbalances in the soil solution. In general, metal solubility and desorption increase at lower soil pH values (Lindsay, 1979)

The proximity of roots has a direct influence on the organic matter content (Hinsinger, 1998). The levels of organic carbon, in rhizosphere soils are significantly greater than in bulk soils, higher than 20% in two rhizospheric soils (Fig. 1). Soil N content is also higher in rhizospheric soils.

Cation exchange capacity values are very low, although an increase in rhizospheric soils is observed, principally under *Pinus pinaster* Ait.(Fig. 1).

Availability of metals in the rhizosphere is influenced by its ionic species and contents, which depend on the pH and chemical compositions of root exudates (Chiu et al 2002).

For Cu, Zn and Mn bioavailable found a higher content in the rhizosphere of *Eucalyptus globulus* Labill... than in the bulk soil, suggesting the existence of a higher bioavailable metal pool close to roots and to the sites of elemental uptake by plants. For Fe content, there is no significant difference between rhizospheric and bulk soil. For Zn a Fe bioavailable found a higher content in the rhizosphere of *Pinus pinaster* Ait. (Fig. 2)

The lower pH of the rhizosphere can also increase the solubility of metals and nutrients. For example, the increased extractability of mobile Zn in the rhizosphere has been attributed to the acidification of this environment (McGrath et al 1997).

Nevertheless, higher content can be observed for Mn and Cu in *Pinus pinaster* Ait. bulk soil (Fig. 2), suggesting that elemental uptake by plants was an important factor contributing to the depletion of elements near the roots.

The concentrations of metals and nutrients in the rhizosphere depend on both soil and plant properties.

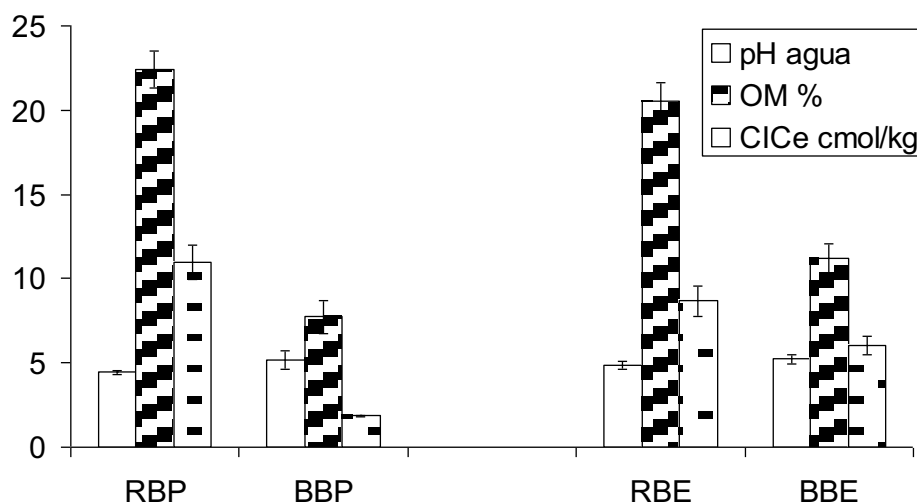


Figure 1. Chemical properties (pH, OM and CECe) of the bulk and rhizospheric soil.

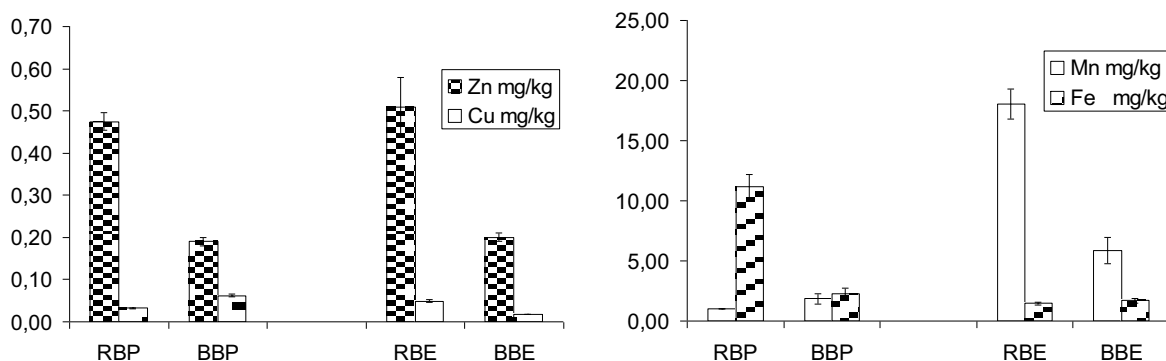


Figure 2. Concentrations of bioavailable Zn, Cu, Mn and Fe in the rhizospheric and bulk soil under *Pinus pinaster* Ait. and *Eucalyptus globulus* Labill..

Conclusions

The rhizosphere is enriched in organic carbon and has a lower pH than the bulk soil. Available Cu, Zn, Mn content increases close to roots under *Eucalyptus globulus* Labill., and Zn and Fe under *Pinus pinaster* Ait..

References

- Carter M R 1993. Soil sampling and methods of analysis. Lewis Publishers. Boca Raton, USA.
- Chiu C, Wang M K, Hwong J, King H B. 2002 Physical and chemical properties in rhizosphere and bulk soils of *Tsuga* and *Yushania* in a temperate rain forest. Commun. Soil Sci. Plant Anal. 33, 1723-1735.
- Hinsinger P. 1998 How do the plant roots acquire mineral nutrients? Chemical processes involved in the rhizosphere. Adv. Agron. 24, 225-265
- Houba, V., Temminghoff, E., Gaikhorst, G., Van Vark, W. (2000): Soil analysis procedures using 0,01M calcium chloride as extraction reagent. Soil Sci. Anal. 31(9/10), 1299-1396
- Lindsay WL 1979. Chemical equilibria in soils. Wiley, New York.
- Marschner H., Römhild V, Horst W, Martin P. 1986. Root induced changes in the rhizosphere: importance for the mineral nutrition of plants. Z. Pflanzenern Boden. 149, 441-416.
- Rollwagen B A, Zasoski R J 1988. Nitrogen source effects on rhizosphere pH and nutrients accumulation by Pacific Northwest conifers. Plant Soil 105 79-86.
- Wang Z W, Shan X Q, Zhang S Z, 2002. Comparison between fractionation and bioavailability of trace elements in rhizosphere and bulk soils. Chemosphere 46, 1163-1171.
- Youssef R, Chino M 1989. Root-induced changes in the rhizosphere of plants. II. Distribution of heavy metals across the rhizosphere in soils. Soil Sci. Plant Nutr. 35, 609-621.



Reclamation of a burned forest soil with fish manure vermicompost

Marcet Miramontes, P.*; González Pimentel, S.; Coleiro, B

Departamento de Biología Vegetal y Ciencia del Suelo. Área de Edafología. Escuela de Ingeniería Forestal.
Universidad de Vigo. Campus a Xunqueira s/n 36005 Pontevedra. España.
* marcet@uvigo.es

Key-words: fish manure vermicompost, soil restoration, organic matter.

Introduction

Fire may affect different chemical and physical properties of the soil, increasing runoff and promoting erosion processes. The loss of organic matter through fire, as well as the effect of fire on microbiota and diminution in vegetation and soil cover (Guerrero et al 2001).

The addition of organic materials with a high macro and micronutrient content and a diverse microbial population can help in the reestablishment of a burned soil characteristics, favouring plant development and reducing the time needed to reach suitable levels of soil protection.

It is well known that the fish wastes have been used as organic fertilizer and nutrients for both agricultural purposes and for rehabilitation of degraded areas (Alfaro et al 2004, Mazzarino et al 1998). Fish sludge contains macro and micro nutrients, especially high levels of nitrogen and phosphorus. Sewage sludge mixed with different organic waste materials is now usual in composting experiments (Li et al., 2001; Mupondi et al., 2006, Roca-Pérez et al 2009). Composting is a generally accepted as a beneficial method of stabilizing the organic matter contained in these wastes. The composting process kills the pathogens due to the heat generated during the thermophilic phase; the organic compositions in waste will be converted into stabilized humic substances through mineralization and humification with a significant reduction in volume. An odourless innocuous and stable organic amendment can be obtained by composting, and its use for improving soil structure and soil organic matter has been reported worldwide (Laos et al. 2002).

Compost and vermicompost made from fish manure or sludge from biofilter could provide an effective source of nutrient-rich organic matter. Instead of creating a disposal problem, composting these organic materials with a suitable carbon source creates a useful and potentially marketable product (Shelton et al 1998). Considerable information is available about composting of biosolids, animal manures, and municipal solid wastes, but it is limited in the case of highly decomposable materials such as fish wastes.

Our main objectives were to evaluate the influence of addition of a fish manure vermicompost in burned forest soils properties and the influence on the vegetation.

Methodology

Sludge sampling was carried from commercial turbot farm located in O Grove, Ria of Arousa (Insuiña S.L.), which is the oldest one that produces this specie in Galicia. It generates 150t per year and a effluent volume between 1,000 and 1,500 m³/h, of which around 60 m³/h are prefiltered (with a rotary filter <200 microns). Sampling was carried out with the sludge which was sown in the pool and others were collected from the rotary filter. Six samples of sludge were taken during 2008-2009. The samples were stored in plastic containers and refrigerated until they reached the laboratory (<4°C) Sludge was analyzed for pH, OM, macronutrients, micronutrients, heavy metals, pathogens, and



electrical conductivity. Outside composting experiments were conducted at Ponteareas (Pontevedra) during 2008-2009. The local climate is humid oceanic type, mean annual maximum temperature is 19,7°C and minimum 9,1°C, precipitation concentrated mainly in winter, with dry summers. Two different processes were employed composting and vermicomposting. The turning pile system was used for the composting process, using piles of 1m³ and were placed in an open site to facilitate turnings. Temperatures were measured twice a day, at 0.50 m depth with a compost thermometer. The plastic box systems (30L) were used for vermicomposting. The boxes were placed in an open site.

Burn soil was sampling from Cuspedriños- Pontevedra (Spain), a site which was completely burned by a wildfire in August 2006. Burn soil sample was collected from the top 30 cm. Composting requires bulking agents in order to facilitate aeration and provide carbon sources for microorganisms. Selected waste mixtures – pine sawdust + fish manure (C1, compost 1), pine sawdust + fruit waste + fish manure (C2, compost 2) were composted during four months. At the end of this process *Eisenia andrei* and *Eisenia fetida*, were added to C1 and C2 and the aerobic treated compost were vermicomposted for two month (VC1 and VC2).

Soil samples were collected under field-moist conditions, sieved to 2 mm, and thoroughly mixed with the vermicompost, which were previously ground to pass a 2-mm sieve. Vermicomposted fish manure was applied at a rate of 90 and 120 Mg.ha⁻¹. Samples of the mixtures were placed in 3kg plastic pots and incubated aerobically at 25°C, 20% soil moisture (equivalent to the water content at 0.01 MPa) for 90 days. At each sampling date (0, 15, 30, 45, 60, 90 days), three replicates of control and amended soils were randomly selected for organic matter, inorganic N and P analysis. The net N mineralized was calculated according to Sims (1990).

Soil pH and CE was measured in water extract, TOC and TN by elemental analysis (Leco CN-2000). The NH₄⁺, NO₃⁻ and PO₄⁻³ were extracted using acidified calcium chloride solution (0.1 M), according to the method developed by Houba et al. (2000), and analyzing with a segmented-flow auto analyzer (Bran Luebbe-AA3). Statistical analyses were carried on the software SPSS.

Other experiment was installed using young plant of *Eucalyptus nitens*, grown in pots (burned soil +vermiculite+ VC1; burned soil+vermiculite + VC2; burned soil + vermiculite). Biomass, water transpired by the leaves, chlorophyll, chlorophyll fluorescence, leaves number were evaluated.

The plant material was sampled from Norton tree nursery (Pontevedra), plants in early phase of growth (10-15 cm). The plants were placed in circular pots (15 x 15cm) with soil-vermiculite (1Kg:50g) substrate and 50g of vermicompost (VC1 or VC2). Twelve pots (one plant per pot) for each vermicompost (soil+ vermiculite + VC) and twelve for control (soil + vermiculite), were submitted to concrete conditions of lighting (120 photon mol/ms), temperature (20°C), humidity and aeration. The plants were previously conditioned in the laboratory (15 days). At each sampling date (15, 30, 45, 60, 74 days), biomass, water transpired by the leaves, chlorophyll, chlorophyll fluorescence, leaves number were evaluated.

Results and Conclusions

Sludge from turbot farm was analyzer for pH, OM, macronutrients, micronutrients, heavy metals, pathogens, and electrical conductivity. Results showed a very high water content in fresh fish manure (86%), an organic matter content around 33.8 %, and a neutral pH (7.5), total N content with values around 3% of which >90% was in the organic form. Heavy metal content was much lower than the upper pollutant limits set by the European

legislation. Electrical conductivity was very high (50.55 mS/cm), the salt concentration being about 3.25%. The C:N ratio was very low (6.3).

The results showed an important electrical conductivity decrease after composting and the vermicomposting process, VC1 and VC2 showed EC values about 4,5 and 5,6 mS/cm. At the end of the compost and vermicompost processes, VC1 presents a pH value slightly lower (6.62), it could be caused by nitrogen mineralization process; VC1 had the highest NO_3^- content and C/N slightly high (34,4). The virtual absence of ammonium nitrogen in the final compost is a good indicator of their maturity (Roca-Pérez et al 2009). In this study the NH_4^+ content, in the final vermicompost and compost, was around 101 and 186 mg.kg^{-1} VC1, VC2, respectively.

In the laboratory incubation assay with similar rates of vermicompost, values of N_m were $>100 \text{ mg.kg}^{-1}$ in the case of VC1 (pine sawdust + fish manure). For VC2 (pine sawdust + fruit waste + fish manure) with 120 Mg.ha^{-1} rate, the N_m values were very low ($<45 \text{ mg.kg}^{-1}$), and low ($<53 \text{ mg.kg}^{-1}$) with 90 Mg.ha^{-1} rate (Figure 1), probably this low values were due to the fruit waste is a source of C that immobilise N.

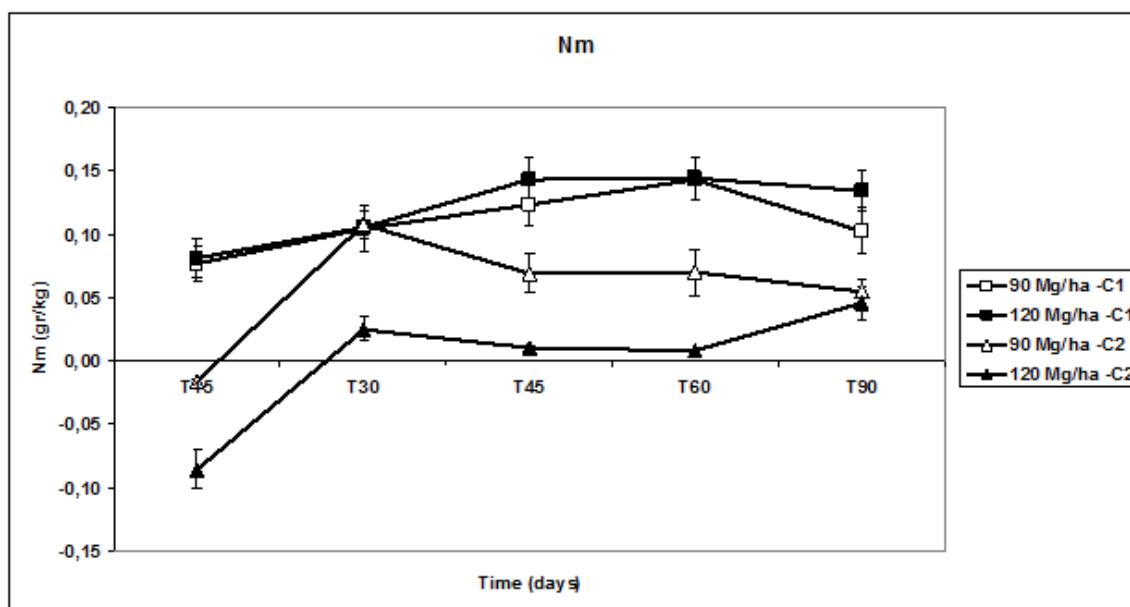


Figure1. Net mineralized N (g.kg^{-1}). (C1-vermicompost 1– pine sawdust + fish manure; C2-vermicompost 2- pine sawdust + fruit waste + fish manure).

NH_4^+ -N was the predominant form of inorganic N at the incubation start (T0). Nitrification increased gradually and at the end of the incubation (T90), NO_3^- -N represented the predominant form. Samples with 90 and 120 Mg.ha^{-1} rate of C2 vermicompost showed a slight N immobilization during the incubation period.

P added with the vermicompost was retained in the soil; the retention was high in the C1 treatment, coincided with a higher N min, probably indicating an increase in P consumption by the microorganisms.

The results obtained in the first plant sampling (to 15 days) do not present significant differences in any of the measured parameters. The data obtained in the next sampling (to 30 days) reveals significant differences in the height ($\text{CV1} > \text{CV2}$, Control), chlorophyll ($\text{CV1} > \text{CV2}$) and transpiration (control $> \text{CV1}$). Chlorophyll showed significant differences between CV2 and CV1 in the last sampling (75 days). Biomass



results were not significant with any treatment. *Eucalyptus nitens* plants did not present stress for the application of the vermicompost.

Conclusions

Fish manure vermicompost application increase the organic matter content and inorganic-N of burn soils. Rates of N mineralization depended on bulking agents. Net mineralized N was about twice as high with VC1 as with VC2 vermicompost, at similar rates of application. Bioavailable P content was higher than control in all case.

The results suggest that fish manure vermicompost have a potential use as fertilizers in soils, which could reduce the direct risks of water pollution from the fish farming industry.

The two vermicompost used did not produce any negative effect on the development *Eucalyptus nitens*. There were no significant differences between CV1 and CV2 effect on the plants.

References

- Alfaro M, Salazar F, Valdebenito A 2004. In: Hatch, D., Chadwick, D.R., Jarvis, S., Roker, A. (Edts), *Proceedings 12th Nitrogen Workshop: Controlling N flows and losses*. UK 136-137.
- Guerrero C, Gómez I, Moral R, Mataix –Solera J, Mataix-Beneyto J, Hernández T. 2001. Reclamation of burned forest soil with municipal waste compost: macronutrient dynamic and improved vegetation cover recovery. *Bioresource Technology* 76(2001) 221-227
- Houba V, Temminghoff E, Gaikhorst, G., Van Vark W 2000. Soil analysis procedures using 0,01M calcium chloride as extraction reagent. *Soil Sci. Anal.* 31(9/10): 1299-1396
- Laos F, Mazzarino M, Walter I, Roselli L, Satti P, Moyano S. 2002. Composting of fish and biosolids in northwestern Patagonia. *Bioresource Technology* 81: 179-186.
- Li G, Zhang F, Sun Y, Wong J, Fang M 2001. Chemical evaluation of sewage sludge composting as a mature indicator for composting process. *Water Air Soil Poll.* 132: 333-345.
- Mazzarino M, Laos F, Satti P, Moyano S 1998. Agronomic and environmental aspects of utilisation of organic residues in soils of the Andean-Patagonian region. *Soil Science and Plant Nutrition* 44: 105-113.
- Mupondi L, Mnkeni P, Brutsch M 2006. The effects of goat manure, sewage sludge and EM on the composting of pine bark. *Compost Sci. Utilization* 14: 201 – 210
- Roca-Pérez L, Martínez C, Marcilla P, Boluda R 2009. Composting rice straw sewage sludge and compost effects on the soil-plant system. *Chemosphere* 75: 781-787.
- Shelton E, Hinshaw J, Thompson S. 1998. An evaluation of composted fish wastes. 2nd International conference on recirculating aquaculture.
- Sims J. 1990. Nitrogen Mineralization and Elemental Availability in Soils Amended with Cocomposted Sewage Sludge. *J Environ Qual.* 1990; 19: 669-675



Applicability of the curve number to the soil hydrological response following prescribed burning in a heathland ecosystem (temperate-humid NW Spain)

Basanta, R.^{1*} and Díaz-Fierros, F.²

^{1*} UIQA. Instituto Superior de Agronomia, TULisbon, Tapada da Ajuda, 1349-017 Lisboa, Portugal.

² Departamento de Edafología e Química Agrícola. Faculdade de Farmácia. Universidade de Santiago de Compostela (A Coruña) Spain.

* rosariobasan@isa.utl.pt

Key-words: Slash-and-burn; Hillslope plots; Natural rainfall; Runoff; SCS CN method; NW Spain.

Introduction

In the context of burnt soil studies, rainfall erosivity, water repellency, and runoff response have severe implications in soil fertility. Moreover, an accurate runoff prediction is important for estimating the transfer of dissolved substances into surface water bodies (Huang *et al.*, 2006). The most used methodology for predicting direct runoff from rainfall is the curve number (CN) method developed by USDA-Soil Conservation Service (SCS, 1972) which is widely accepted in the world. It is an easy-to-use method applied extensively in hydrologic, erosion and water-quality models, as CREAMS, EPIC, SWRRB and others (Mintegui and López, 1990; Auerswald and Haider, 1996). CN values have been obtained experimentally from rainfall and runoff measurements over a wide range of geographic, soil and land management conditions. Nevertheless, data do not exist from the temperate-humid hilly ecosystems in NW Spain subjected to conventional prescribed fires. Traditional slash-and-burn management for the conversion of heathland to cropland and pasture was historically used in this area and can be considered as medium-intensive agricultural practice (Soto *et al.*, 1995). The soil response on runoff and soil erosion for this kind of prescribed fire can be increased in hill-slopes because slope is an important factor determining water movement within the landscape. Thus, the concurrence of the effects of slope and fire is a controversial issue in soil erosion studies. We processed rainfall-runoff relationship from slash-and-burn applied in this temperate-humid climate where there are scarcely studies for different soil uses and the necessary CNs had never been verified for fire management.

Objectives

The main aim of this study was to assess the applicability of the CN method for estimating direct runoff compared with field data obtained from two hillslope experimental plots subjected to slash-and-burn practice for the conversion of heathland to cropland and grassland. To verify CNs and to suggest modifications would be considered necessary.

Methodology

The soil was an Umbric Leptosol (FAO, 1988) developed over granite. Mean slope was 30% and altitude 350m. The scrubland vegetation consisted of mainly *Ulex europaeus* and Ericaceae. Surface runoff was collected in two tanks located at the down-slope end of the burned plots as well as the undisturbed plot. We encountered the common difficulty in adequately estimating the total capacity of collection system that will be required for the variety of the storms, therefore, four runoff events indeed exceeded the capacity of the

tanks and they were excluded from the estimates of runoff and from the comparison of observed values with CN-estimated values. Finally, 48 available runoff events were registered. The burning of vegetation and of the organic-matter-rich layer of the soil in piles (as part of the traditional slash-and-burn) Fig. 1, led to higher temperatures below the surface of the soil than those reached during prescribed light fires or moderate fires (Soto *et al.*, 1995). Soil use and cover were as follow:

1- First year included a fallow period following slash-and-burn practice, the rye crop sowing and the transition from fallow to rye crop. A second fallow period was present during clearance of rye crop remains, liming, mineral fertilization and seeding with a pasture mixture; 33 whole rainfall-runoff events were registered during this period.

2- Second year included the transition from fallow to developing pasture and mature pasture, 15 whole rainfall-runoff events were registered.

Rainfall was recorded by two gauges close to the plots. The remaining climatic data were obtained from an automated weather station located 6 km from the study area. Site properties, as well as the consecutive soil management and cover are showing in Table 1.

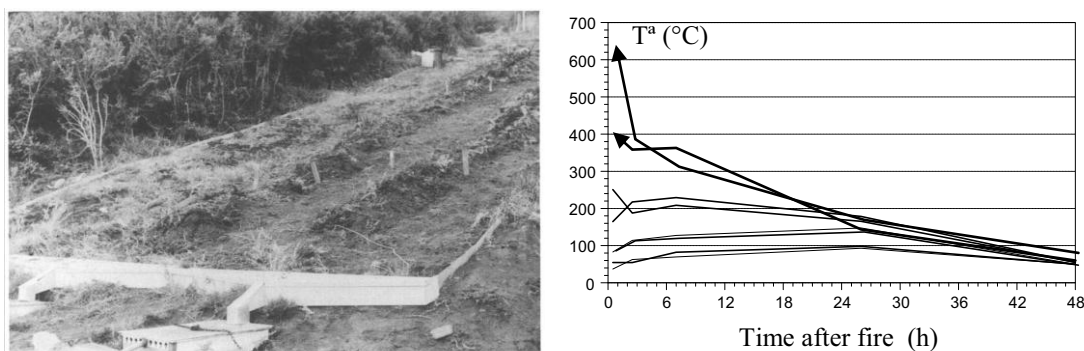


Figure 1. Burning of vegetation and the organic-matter-rich layer of the soil in piles during slash-and-burn. In the two experimental plots, temperatures were registered in the piles (with arrow), in the soil surface and both 2 and 5 cm in soil depth.

Table 1. Physicochemical characteristics of the soil at the study site. Values showing standard deviation are means of six determinations. Soil use, plant cover, rainfall and number of runoff events during the study.

Parameter	
Sand (%)	65.2 (2.05)
Silt (%)	19.5 (0.51)
Clay (%)	15.3 (0.78)
C (%)	6.74 (0.55)
Soil depth (cm)	45-65
Slope (%)	30
Height (m)	350
Plots size (m ²)	80

Soil use and plant cover	Rainfall (mm)	Runoff events
Fallow following slash-and-burn and the transition from fallow to rye crop	1551.1	27
Fallow during the clearance of rye crop remains and seeding with a pasture mixture	422.9	7
Transition from fallow to developed pasture, 20-30 % plant cover	461.8	2
Developed pasture, 50-60 % plant cover	252.6	2
Mature pasture, 60-70 % plant cover	581.6	11

CNs values were determined from land cover and management, and from the hydrologic soil group using the equation and the table from the SCS methodology (1972):

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Q = direct runoff (mm); P = rainfall (mm); S = 254 (100/CN - 1) (mm).

As runoff is affected by the soil moisture before a precipitation event, the antecedent moisture condition (AMC) was adjusted based on 5-day prior rainfall depth that depends on whether the crop is in the dormant or growing season. We used condition II (average) for AMC and P0= 0.2S. The SCS methodology permits to correct CNs values for AMC condition I (dry) or condition III (wet).

Results and conclusions

Experimental data collected in the field showed a weak correlation ($r = 0.44$; $n = 48$) with those calculated with the CN method as it can be observed in Fig. 2 (a, b) showing data estimated with CN having slight adjustment during the first year only for some observed runoff events. In general, the CN method overestimated runoff discharge. In a first approach, we are suggesting some modifications in the method related with qualitative characteristics of the climatic, hydrologic and soil conditions of the study area. As a result, we implemented an adapted table of the runoff CN for hydrologic soil-cover complexes assuming condition II and P0= 0.2S (Table 2). We recalculated estimated runoff using this modified CN method. The new correlation analysis showed good adjustment between the observed and the estimated values defined by the equation: $y = -0.129 + 0.813 x$ ($r = 0.79$; $p < 0.001$).

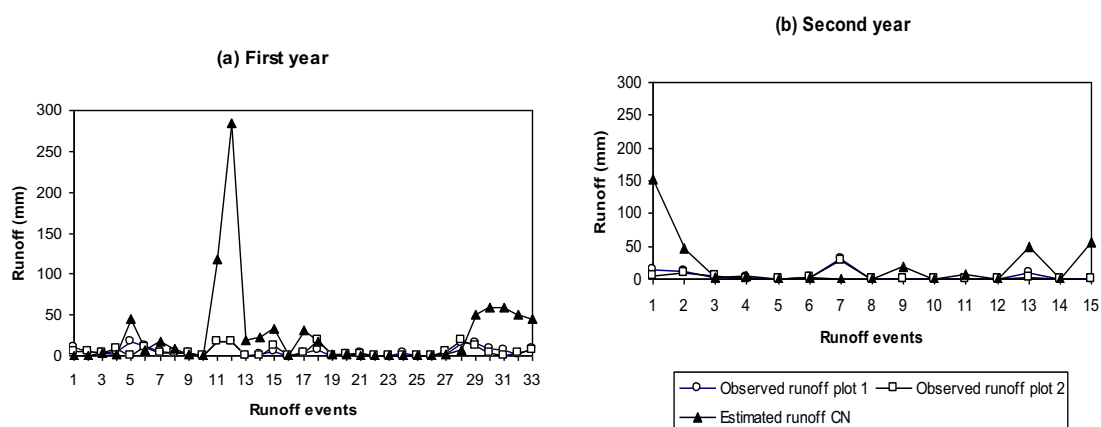


Figure 2. Estimated and observed runoff. Soil use and cover during the first year (a): fallow following slash-and-burn and the transition from fallow to rye crop (from 1 to 27 runoff event). Fallow between 28 and 33 runoff event during the clearance of rye crop remains and seeding with a pasture mixture. Second year (b): transition from fallow to developed pasture, 20-30% cover (1 and 2 runoff event); developed pasture, 50-60% cover (3 and 4 runoff event) and mature pasture, 60-70% cover (from 5 to 15 runoff event).



Table 2. Modified runoff curve number for hydrologic soil-cover complexes assuming condition II and $P_0 = 0.2S$

Soil use and cover	Method or treatment	Cover (%)	Hydrofobicity	Hydrological soil group			
				A	B	C	D
Fallow after fire management (slash-and-burn)	Straight rows	0	+++				95
			++			90	
			+	50	70		
Transition fallow-cropland	Straight rows	Initial	+++	70			
		Intermediate	++	60			
		Final	+	55			
Transition fallow-pasture		<20-20%	+	40			
		30-60%	+	35			
		>60%	+++				100
			++			95	
			+	30	55		

The adjusted method decreases CNs for hydrological soil groups with low potential runoff and increases CNs for hydrological soil groups with moderated and elevated potential runoff. Thus, CNs for the hydrological soil group A, B and C during the fallow after fire management (slash-and-burn), were adjusted from 77, 86 and 91 respectively to 50, 70 and 90. But D group with elevated hydrofobicity was larger in the adjusted CNs changing from 94 to 95. For the transition fallow to cropland was considered only the hydrological soil group A (low potential runoff) and three different cover and hydrofobicity levels. As well as, only the soil group A was considered until 60% cover in the case of transition fallow to pasture. For mature pasture (>60% cover) CNs for soils groups A (30) and B (55) were smaller than the original CNs for pasture (39 and 61 respectively). On the contrary, CNs for soil groups C and D were adjusted from 79 to 95 for C and from 89 to 100 for D.

Our adjusted method allowed us to complete the not whole runoff events to be included for future analysis in this particulate case and it is a first approach to adjust the CN method for heathland ecosystems in NW Spain in the case of 30% maximum slope, soil-vegetation combination as those scrubland developed over granite and land use as fallow, transition fallow-crop and transition fallow-pasture, all related with slash-and-burn practice for the conversion of heathland soils to cropland and pasture.

We are considering that the modified CN method appears to be most appropriate for runoff estimation in these hilly soils subjected to medium-intensive agricultural practice with fire, but it needs to be validated and improved for other vegetative covers, land uses and number of runoff events. Furthermore, due the huge significance of the erosion processes in cultivation on land with slopes above 30%, it would be appropriate to incorporate a slope factor into the CN method, as was suggested by Huang *et al.*, 2006.

References

- Auerswald, K., Haider, J. 1996. Runoff Curve Numbers for Small Grain Under German Cropping Conditions. *Journal of Environmental Management*, 47: 223–228.
- FAO, 1988. *Mapa de suelos del mundo. Revised llegend. Versión española.*
- Huang, M., Galiichand, J., Wang, Z., Goulet, M. 2006. A modification to the Soil Conservation Service curve number method for steep slopes in the Loess Plateau of China. *Hidrologycal Processes*, 20:579-589.



- Mintegui Aguirre, J. A., López Unzu, F. 1990. *La ordenación agrohidrológica en la planificación*. Servicio Central de Publicaciones del Gobierno Vasco. Madrid. 308 p.
- SCS, Soil Conservation Service, ed. (1972). *National engineering handbook, Section 4, "Hydrology"*. Washington, D.C.: SCS.
- Soto, B.; Basanta, R.; Pérez, R.; Díaz-Fierros, F. 1995. An experimental study of the influence of traditional slash-and-burn practices on soil erosion. *Catena*, 24:13-23.



Effectiveness of hydro-mulching to reduce runoff and erosion in a recently burnt and logged Maritime Pine stand in north-central Portugal

Sérgio Prats Alegre*, Maruxa Malvar Cortizo, Sílvia Regina Faria, Diana Catarina Simões Vieira, Paula Alexandra Aquino Maia, Ana Vasques, Alexandra Albuquerque, Max Xufeng Shen, Hein Vermin, Jan Jacob Keizer

Centro de Estudos do Ambiente e do Mar (CESAM), Departamento de Ambiente e Ordenamento,
Universidade de Aveiro, 3810-193 Aveiro, Portugal,

* sergio.alegre@ua.pt

Key-words: wildfire; pine; hydro-mulching; runoff; erosion.

Introduction

It is well-established that wildfires can produce marked changes in geomorphological and hydrological processes. Whilst the removal of vegetation and litter cover by burning plays an important role in these changes, mulching - the application of an artificial litter cover - is a widely accepted technique to reduce the risk of post-fire soil erosion (Bautista et al 1996, Wagenbrenner et al., 2006). Hydro-mulching - a more recent variant of mulching in which besides (in-)organic fibers also water, nutrients, green colorant and seeds are applied to the soil surface (Naveh, 1974)- is less commonly applied in recently burnt areas. This is perhaps especially due its more elevated costs but, at the same time, its effectiveness remains to be fully clarified.

In Portugal, few studies have assessed the effectiveness of mulching following wildfires (Shakesby et al., 1996) but, to the best of our knowledge, no field trial with hydro-mulching was carried out so far. This research gap was addressed by the EROSFIRE-II project, in collaboration with the company Serraic - Create And Innovate, Lda, which provided and applied the hydro-mulch, and with the support of the National Forestry Authority and the fire brigade from Arganil.

Objectives

This work aims to assess the effectiveness of the hydromulching as a technique to reduce soil erosion and runoff generation in burnt areas. Additionally, it was assessed the differences that the hydromulching will induce on the key parameters for runoff generation (soil moisture, soil water repellence) and soil erosion processes (vegetation cover and soil resistance).

Methodology

This study was carried out in the municipality of Arganil in a Maritime Pine stand on common grounds ("baldio") that burnt during August 2008 and that was logged during the winter of 2008/2009 (mainly because of the nematode plague risk). The experimental set up involved 6 bounded plots of roughly 10 m² and 8 bounded plots of 0.25-0.50 m². The former plots involved the measurements of erosion rates only, using a sediment fence-type construction at the basis of the plots. The latter plots also involved the measurement of runoff amounts, by connecting the plot outlets to tanks. In addition, an automatic and a totaliser rainfall gauge were installed close to the plots. Half of the larger and half of the smaller plots were treated with hydro-mulch on March 31 2009. To this end, the plots were divided into neighboring pairs and, for each pair, the plot to be treated

was selected randomly. Furthermore, a strip of some 50 m² was delineated and on half of it hydro-mulch was also applied. The monitoring of the field equipment was carried out till august 2010, and involved: (i) 1- to 2-weekly measurement of rainfall and runoff, and gathering of runoff samples; (ii) monthly measurement and sampling of the sediments accumulated in the 10 m² plots; (iii) monthly measurement of selected soil properties (shear stress, soil moisture and soil water repellency) in the treated and untreated parts of the above-mentioned strip. At the end of the monitoring period, a detailed vegetation description was made.

Results and conclusions

Total rainfall from 31 March 2009 to 20 May 2010 was 1327 mm. The untreated bounded plots showed an overall runoff coefficient of 47% while the treated plots produced 14%, which means a reduction of 70% (Figure 1). This is possibly linked to the effect that the green cover of organic fibers of the hydromulching will induce over the black and burned soil: surface water storage capacity was promoted by the hydromulching layer over the soil surface, soil water repellency decreased, since it was present more often in the control than in the hydro-mulched strip (38% against 20% of the observations respectively), and soil water content increased slightly on the treated area (14.7% versus 13.8% on average) during the 15 months of the experience.

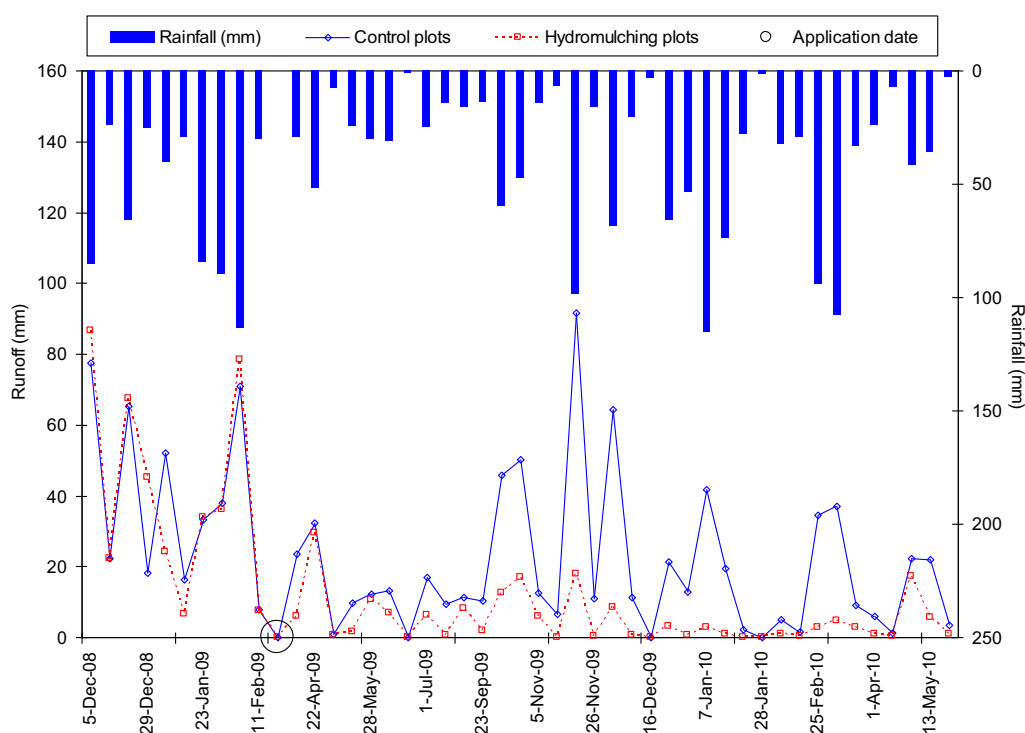


Figure 1. Runoff production and rainfall amount measured on the hydromulching and control plots at week intervals.

The overall soil erosion was 506 g m⁻² for the control plots, and 99 g m⁻² for the hydromulched plots, which means a reduction of 80% (Figure 2). This is attributed to the greater runoff and percent bare soil presented on the untreated plots, but also the soil resistance was slightly different on the hydromulch area (2,8 versus 2,5 Kg cm⁻²). Nonetheless, also at the end of the monitoring period, the vegetation cover was lower in

the control (20.8%) than hydro-mulched plots (28%), and there was still more plant individuals on the treated than on the control plots (164 indiv. m⁻² versus 65 indiv. m⁻²).

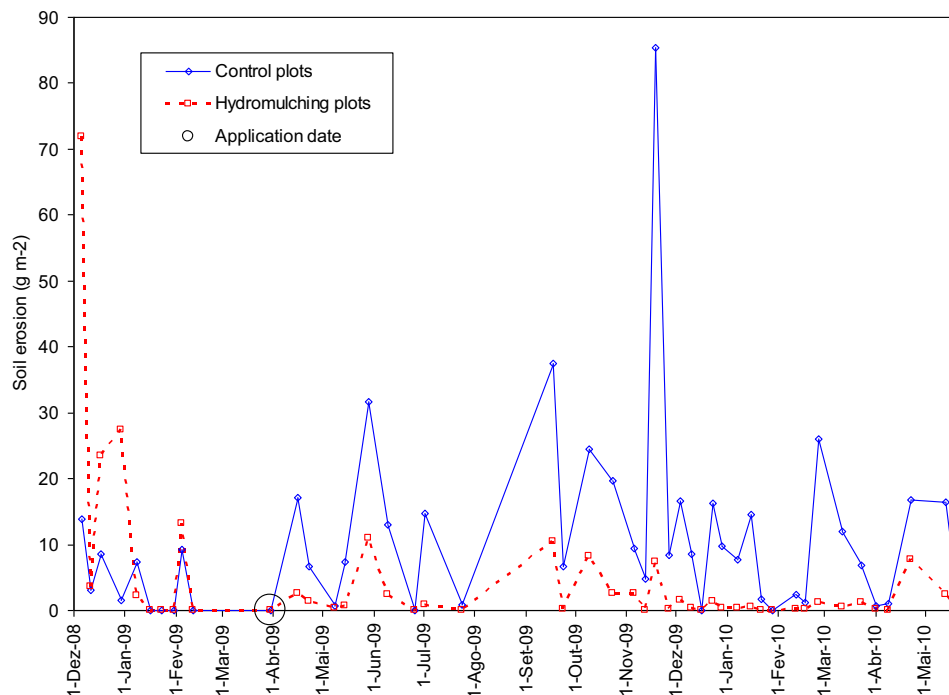


Figure 2. Soil erosion measured on the hydromulching and control plots at week intervals.

The results indicate an excellent effectiveness during the first year after the treatment with hydromulching. It was checked that mulching affects some of the most important key factors involved on the processes that generates overland flow in a recently burnt area. Soil cover, soil water repellence, soil moisture, soil resistance, vegetation species and cover were affected by the treatment in order to decrease the soil erosion.

References

- Bautista S, Bellot J, Vallejo VR. 1996. *Mulching treatment for postfire soil conservation in a semiarid ecosystem*. Arid Soil Research and Rehabilitation 10: 235–242.
- Naveh Z. 1975. *Degradation and rehabilitation of Mediterranean land-scapes: Neotechnological degradation of Mediterranean landscapes and their restoration with drought resistant plants*. Landscape Planning Volume 2, 1975, Pages 133-146.
- Shakesby R.A., Boakes J.D., Coelho C.O.A., Bento Gonçalves J.A., Walsh R.P.D. 1996. *Limiting the soil degradational impacts of wildfire in pine and eucalyptus forests in Portugal*. Applied Geography. Vol. 16. No. 4. pp. 337-355.
- Wagenbrenner JW, MacDonald LH, and Rough D. 2006. *Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range*. Hydrological Processes 20, 2989-3006.



Coal palaeofires in the western Dacic Basin (Romania): geophysical, mineralogical and geochemical signatures recovered from porcelanites and clinkers; a case history

Sorin - Corneliu Rădan^{a*} and Silviu Rădan^b

^aGeological Institute of Romania (GIR), 1 Caransebeș St., 012271 Bucharest (Romania);

^bNational Institute of Marine Geology and Geoecology (GeoEcoMar), 23-25 Dimitrie Onciul St., 024053 Bucharest (Romania)

* sc.radan@yahoo.com

Key-words: coal palaeofires, clays, porcelanites, magnetism, Romania.

Introduction

The paper presents the case history of the various signatures (*i.e.* geophysical, geological and geochemical) which were discovered in the southwestern Romania, and which provide evidence of past coal-bed fires (Rădan and Rădan, 2010a,b).

A geophysical signal sent by the products of the underground coal fires was detected for the first time in 1969, during the field works for the regional magnetic measurements carried out to draw up the ΔZ and ΔZ_a (*i.e.* geomagnetic field vertical component and its anomaly) maps of Romania (scale 1:200,000). Particularly, on the occasion of the magnetic survey performed by one of the authors, a magnetic anomaly was revealed (Roșca *et al.*, 1973) in a zone where important lignite quarries have later entered into exploitation. Moreover, the location is close to the area where the maximum thickness of the coal seam X was estimated (Țicleanu and Andreescu, 1988), *i.e.* the lignite bed proved to be mainly responsible for the “baked clays” occurrences in the western Dacic Basin. The magnetic field works were carried out more than forty years ago in a zone which was not uncovered at the time, where the porcelanites could be observed in rare outcrops only. The ΔZ_a anomaly was produced by a horizon of “baked clays”, formed as a result of the autocombustion of a coal bed. The thermo-mineralogical signatures recovered by X-ray diffractometry from the rocks affected by underground coal palaeofires show temperatures of about 1000°C having been reached within the initial clays (Roșca *et al.*, 1973).

The research gained momentum when the magnetostratigraphic studies have been initiated (in 1984) in order to correlate the coal beds in a series of lignite quarries. Their location was close to the previously mentioned zone, where the effects of the past underground coal-fires on the clays was firstly detected. In fact, in the Upper Pliocene coal deposits of the western Dacic Basin, numerous occurrences of baked and/or fused sedimentary rocks generated by natural spontaneous burning of lignite seams are present (Rădan and Rădan, 2011a). Usually, these rocks consist of hardened red clays and sands with brick-like appearance (“porcelanites”/“porcellanites”; according to the *Dictionary of geological terms*, American Geological Institute, 1976, 1984). Yet, sometimes they show a slaggy or vitreous texture with marked vesicularity and dark colour (“clinkers”).

Objectives

The “baked clays”, which actually prove the existence of the coal palaeofires at one time during the geological evolution of the lignite-clay sequences (well exposed now in the coal quarries), are able to produce significant magnetic anomalies. Apart from these geomagnetic markers, the paper is focused on the rock-magnetic, palaeomagnetic,



thermo-mineralogical and geochemical signatures recovered from porcelanites, porcelanite-like clays and clinkers, which were sampled on the occasion of carrying out field works for magnetostratigraphic studies (Rădan and Rădan, 1998).

Methodology

The approach of the paper's subject is based on field and laboratory works. Oriented samples of "original"/"fresh" clays (non-affected by heating), as well as of "baked clays" (*i.e.* porcelanites, porcelanite-like clays) were collected from the western Dacic Basin (particularly, from Lupoia and Jilt-Sud lignite quarries). In addition, partially oriented (up/down) cores of "fresh" clays and unoriented fragments of porcelanites were collected from two exploration boreholes located southward of Lupoia quarry. Rock magnetic and palaeomagnetic methods were used to detect the "signal" sent by the rocks. The intensity and the direction of the natural remanent magnetisation (NRM) were achieved. The magnetic susceptibility (MS) and its anisotropy were measured and the directions of the principal susceptibilities and several anisotropy parameters were determined. To isolate the characteristic remanent magnetisation (ChRM), the stepwise thermal demagnetisation technique was applied.

Mineralogical and geochemical analyses were used in order to clear up certain aspects regarding the transformation process of the clays into porcelanites.

Results and conclusions

The rock-magnetic signal sent by the "baked clays" is changed in comparison with the "original" ("initial"/"thermally non-affected") clays. For instance, the magnetic susceptibility increased considerably, *i.e.* one to three magnitude orders higher for porcelanites and porcelanite-like clays. At the same time, due to the high and very high temperatures (often 250°-400°C, but also 1000°C), the Curie point of the ferromagnetic (*s.l.*) minerals was exceeded, the other component of the rock-magnetic signature – the remanent magnetisation – being modified as well (Rădan and Rădan, 2011b). On cooling from above the Curie temperature, the porcelanites, newly formed at the expense of initial/original clays, acquire an important thermoremanent magnetisation (TRM). Its intensity records high and very high values, three magnitude orders higher as compared with the clays that were not affected by palaeofires, and which acquired a detrital remanent magnetisation (DRM) at the deposition time.

As regards the thermo-mineralogical signature, the heat-affected clays show modified mineral assemblages or even newly-formed minerals (*e.g.* hematite, cristobalite, tridymite, mullite, spinel, cordierite and possibly, magnetite), characteristic for high temperature conditions. These are playing the role of a geothermometer, leading to an attempt to place the clays affected by coal fires on a 6 steps temperature scale, with possible limits of 250°-1200°C.

The geochemical signature points out changes comparable to the thermal contact metamorphism. These newly-formed rocks are also known as "combustion-metamorphic rocks" or "pyrometamorphic rocks". The oxido-reducing index ($\text{Fe}_2\text{O}_3/\text{FeO}$) shows the lowest values in the coal clays, and the highest values (> 50) in porcelanites; in the latter, FeO is sometimes totally oxidized to Fe_2O_3 . Thus, regarding the chemical constituents (Table 1), the porcelanites show higher Fe_2O_3 contents as compared with the "original"/"fresh" clays, while the FeO, CO_2 , S_{tot} and H_2O^+ contents are higher in the latter.

Table 1. Chemical composition of the clays and porcelanites sampled in the Lupoia lignite quarry (western Dacic Basin, Romania).

Legend: red – higher contents; blue – lower contents.

Chemical constituents (%)														
SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	Fe ₂ O ₃ total	MnO	MgO	CaO	K ₂ O	Na ₂ O	P ₂ O ₅	CO ₂	S _{total}	H ₂ O
Clays														
39.54	0.39	11.7	0.00	0.14	4.37	0.00	1.18	0.85	1.13	0.00	0.04	0.0	0.00	3.92
68.32	1.05	26.4	8.80	7.63	10.08	0.38	4.36	11.85	2.95	2.08	0.23	9.24	0.86	22.68
Porcelanites														
45.80	0.69	17.0	6.05	0.00	6.69	0.02	1.11	1.31	0.81	0.00	0.10	0.0	0.00	0.39
62.54	0.94	28.4	10.46	0.57	10.70	0.17	2.85	6.73	2.88	0.68	0.80	3.41	0.09	13.08

The palaeogeomagnetic signature and the evolution conditions of the sedimentary basin constrain the time of the coal seam burning in the investigated area to the Middle-Upper Pleistocene. The geomagnetic palaeofield polarity recovered from porcelanites is normal and it is assigned to the Brunhes Chron (0.781 – 0.00 Ma; ATNTS-2004).

To present some geophysical and mineralogical features determined for porcelanite deposits, an example from the southern area of the Lupoia lignite quarry is given in Fig. 1.

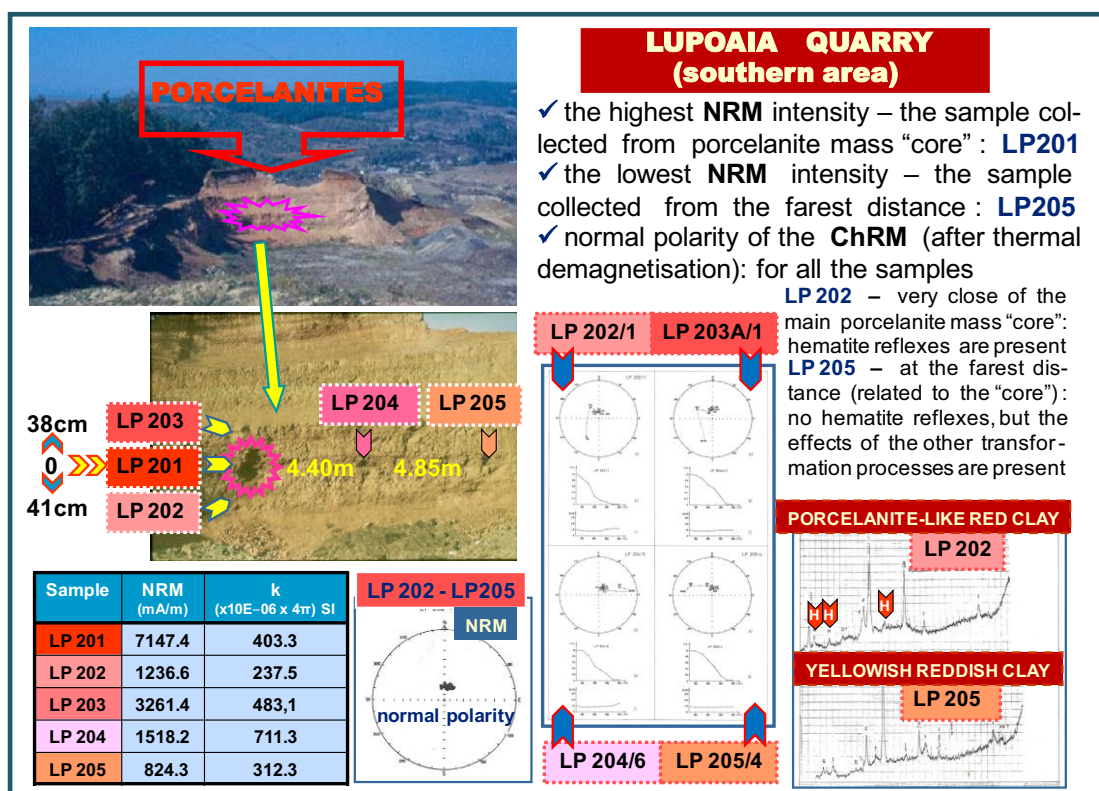


Figure 1. Model showing some rock magnetic, palaeomagnetic and mineralogical signatures recovered from porcelanites and porcelanite-like clays (Lupoia quarry, western Dacic Basin).

The paper ends with a conclusion which integrates the thermo-mineralogical, geochemical and rock-magnetic signatures recovered from both the porcelanites and the unbaked clays: there is a strong contrast of magnetic properties between the two categories of rocks, so that magnetic anomalies are easily measured with portable

magnetometers. The examples coming from the western Dacic Basin reveal amplitudes up to 1880 nT (Fig. 2).

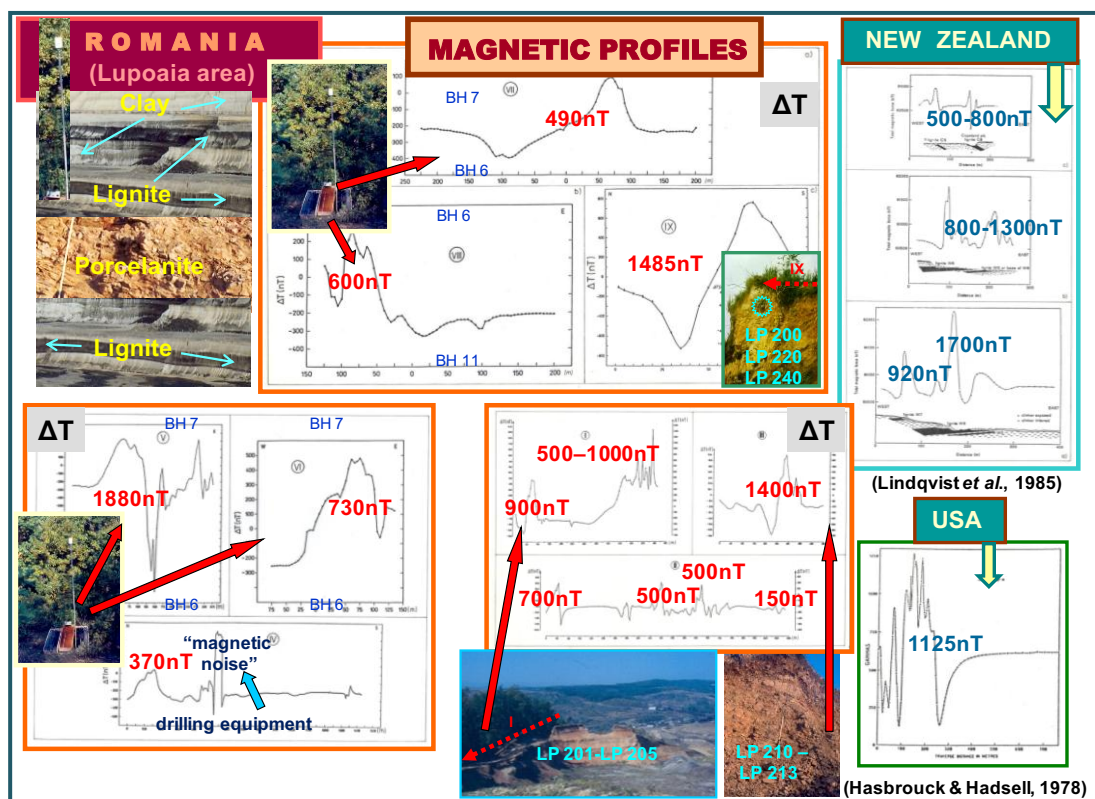


Figure 2. Magnetic profiles carried out in the Lupoaia – Motru area (western Dacic Basin, Romania), showing the anomalies caused by the porcelanites and clinkers.
Note: examples from New Zealand and USA are presented on the right side.

In addition, it is known now that some Pliocene clays, assigned to the Gilbert Chron, C2Ar Subchron (4.187 – 3.596 Ma; ATNTS-2004), according to the recovered palaeogeomagnetic signature, were burned after about 3.5 Ma by the fires that had been caused by the natural autocombustion of certain coal seams with petrographic-mineralogical availability for autoignition. These processes have taken place near surface, usually when lignite beds are to be exposed to erosion. The shallow burial position of the porcelanite horizons is confirmed by three boreholes carried out southward of Lupoaia quarry, which have shown a depth ranging between 9 – 34 m. Among the applications and implications of the study of the burnt rock deposits, the palaeoenvironmental impact and some economic consequences should be taken into consideration.

References

- Rădan, S.C., Rădan, M. 1998. *Study of the geomagnetic field structure in Tertiary in the context of magnetostratigraphic scale elaboration. I - The Pliocene*. An. Inst. Geol. al României, 70, București, 215-231.
- Rădan, S.-C., Rădan, S. 2010a. *Coal Palaeofires in the Western Dacic Basin: Geophysical, Mineralogical and Geochemical Signatures Recovered from Porcelanites and Clinkers; a Case History*. In: C. Drebenstedt, C. Fischer, U. Meyer, W. Jianjun, K. Bing (Eds.) – *Latest Developments in Coal Fire Research*,



- Bridging the Science, Economics, and Politics of a Global Disaster*, Proceedings of ICCFR2 – Second International Conference on Coal Fire Research, 19 – 21 May 2010, dbb forum Berlin, Germany TU Bergakademie Freiberg, Germany, 2010, ISBN 978-3-86012-397-3, 400-401.
- Rădan, S.C., Rădan, S. 2010b. *Coal Palaeofires in the Western Dacic Basin: Geophysical, Mineralogical and Geochemical Signatures Recovered from Porcelanites and Clinkers; a Case History*, Travaux Géophysiques, XXXIX, Abstracts of the 12th "Castle Meeting" New Trends in Geomagnetism. Palaeo, Rock and Environmental Magnetism, Castle of Nové Hradý, Czech Republic, August 29 – September 4, 2010, 66-67.
- Rădan, S.C., Rădan, S. 2011a. *Changes induced by coal paleofires in the magnetic recording medium constituted by cyclic lignite - clay sequences, as inferred from porcellanites and clinkers (Western Dacic Basin, Romania); a synopsis*. In: G. B. Stracher, A. Prakash and E. V. Sokol (Eds.). *Coal and peat fires: A global perspective*, vol. 2 – *Photographs and Multimedia Tours*, Elsevier (in press).
- Rădan, S.C., Rădan, S. 2011b. *Remagnetisation as evidence of a natural thermal event in the history of the lignite-clay sequences: magnetic signals from porcelanites (Dacian Basin, Romania)*. In: G. B. Stracher, A. Prakash and E. V. Sokol (Eds.). *Coal and peat fires: A global perspective*, vol. 2 – *Photographs and Multimedia Tours*, Elsevier (in press).
- Roșca, Vl., Rădan, S.C., Rădan, S. 1973. *Thermoremanent magnetization of some Neogene clays from NW Oltenia*. St. Cerc. Geol. Geofiz. Geogr. - Geofizică, 11, 2, București, 303-313 (in Romanian with an English abstract).
- Țicleanu, N., Andreescu, I. 1988. *Considerations on the development of Pliocene coaly complexes in the Jiu – Motru sector (Oltenia)*. D. S. Inst. Geol. Geofiz., 72-73/2 (1985-1986), București, 227-244.



Importance of dtm accuracy, precision and acquisition technique for estimating contributing areas of post-fire erosion at the slope and catchment scale

S. Cambra, L. Pereira, Jacob J. Keizer*

Centre for Environmental and Marine Studies (CESAM), Department of Environment and Planning,
University of Aveiro, 3810-193 Aveiro (Portugal).

* jjkeizer@ua.pt

Key-words: DTM; post-fire erosion.

Abstract

Wildfires are a frequent phenomenon in Portugal, affecting over 300.000 ha in dry years like 2003 and 2005. Directly and/or indirectly, wildfires can strongly enhance the hydrological response and associated sediment losses and, thereby, negatively affect land-use sustainability as well as ecosystem functioning of downstream aquatic habitats. Therefore, the EROSFIRE projects aim at developing a GIS-tool for predicting soil erosion hazard following wildfire and post-fire land management practices. Assessment and modeling of runoff and soil erosion rates critically depends on accurate estimates of the contributing areas. In the case of catchments as well as unbounded erosion plots (arguably, the only practical solution for slope-scale measurements), delineation of contributing area requires a Digital Terrain Model (DTM) with an adequate resolution and accuracy. The DTM that was available for the Colmeal study area (Goís municipality, central Portugal) was that of the 1:25.000 topographic map produced by the Military Geographic Institute. Since this study area involves a rather small experimental catchment of roughly 10 ha and relatively short study slopes of less than 100 m long, two different data acquisition techniques were used to produce high-resolution and high-accuracy DTM. One is aerial photogrammetry, whilst the other is terrestrial laser scanning. To produce a DTM by photogrammetric means, a dedicated digital aerial photography mission was carried out. The images had a pixel size of 10 cm. Manual measurements permitted to measure breaklines and were complemented by automatic measurements. In this way, a DTM in a TIN format was produced. This was further converted to grid format using the ArcGIS software system. Signalized control points allowed obtaining the DTM in the same global reference system as that employed for terrestrial laser scanning. The terrestrial laser scanning was done using a Riegl LMS Z360I, stationed in 8 points within the area to provide a complete coverage. The resulting dense cloud of points was filtered – by the company carrying out the scanning mission - to remove the non-terrain points (in particular vegetation). Several grids of different sizes were produced (0.10 x 0.10, 0.20 x 0.20, 0.50 x 0.50, 1 x 1 and 2 x 2 m²). The proposed work will compare and analyze estimates of contribution areas that were obtained with the two above-mentioned data acquisition techniques and for different spatial resolutions. This will be done for selected slope-scale sediment fences as well as for the outlet of the experimental catchment. In addition, different algorithms available in ArcGIS for TIN-to-grid conversion will be compared, since preliminary results have suggested that these procedures produce markedly different results.



Soil nutrients and organic matter stocks and their losses by runoff following wildfire in north-central Portugal

J.J. Keizer*, N.J. Abrantes, I.M.A.N. Campos, M.M.A. Cerqueira, G. Erny, V.I. Esteves, S.R. Faria, R.S.V. Ferreira, M.C Malvar, J.P. Nunes, M.I.S. Nunes, S.A. Prats, M.E.T. Varela, S. Van den Heuvel, M. Xufeng Shen

Centre for Environmental and Marine Studies (CESAM), Department of Environment and Planning,
University of Aveiro, 3810-193 Aveiro (Portugal).

* jjkeizer@ua.pt

Key-words: Wildfires, soil stocks, runoff losses, nutrients, organic matter, carbon, PAHs.

Abstract

It is well documented that wildfire - through its direct effects on vegetation cover and soil properties can lead to considerable changes in geo-morphological and hydrological processes. Studies in various parts of the world have shown strong to extreme responses in runoff generation and associated soil losses following wildfire, especially during the earlier stages of the so-called “window-of-disturbance”. Nonetheless, it has been argued that these wildfire effects are: (i) much better known at small spatial scales (especially erosion plots) than at the scale of catchments; (ii) much better studied with respect to overland flow and streamflow (and, then, especially peak discharges) than to soil erosion and, to a markedly greater extent still, organic matter and nutrient exports.

The above-mentioned research gaps certainly apply to the case of Portugal. Therefore, the FIRECNUTS project (PTDC/AGR-CFL/104559/2008) has recently started to study the losses of organic matter, carbon and nutrients (N and P especially) by runoff in a recently burnt area, also in relation to the stocks in the topsoil. Furthermore, a PhD study in collaboration with IPIMAR is giving special attention to the stocks and export of polycyclic aromatic hydrocarbons (PAHs) and selected metals.

The FIRECNUTS study area is situated in the municipality of Sever do Vouga, north-central Portugal. It was burnt by a wildfire towards the end of July 2010. Within the burnt area, five burnt hillslopes were instrumented with micro- to slope-scale runoff plots as well as slope-scale sediment fences. Four of these slopes were eucalypt plantations and one a Maritime Pine plantation. The installation of the various plots was completed before the occurrence of any significant rainfall and, since then, monitoring is being done at regular, 1-to-2 weekly intervals, depending on rainfall.

The soil stocks were sampled at all 5 burnt slopes in August 2010. At two of these slopes sampling was repeated at monthly intervals, whereas at the remaining three slopes sampling will be done at 3-monthly intervals. In addition to the burnt slopes, also two unburnt slopes just outside the burnt area are being studied. One was equipped with slope-scale runoff plots and is being soil sampled at monthly intervals, whereas the other is being soil sampled at 3-monthly intervals.

The proposed presentation will give an overview of the ongoing work at the FIRECNUTS study area in Sever do Vouga.



POST-FIRE NUTRIENT LOSSES BY RUNOFF FROM PLOT SCALE IN NORTH-CENTRAL PORTUGAL

R.S.V. Ferreira*, M.M.A. Cerqueira, J.J. Keizer

Centre for Environmental and Marine Studies (CESAM), Department of Environment and Planning,
University of Aveiro, 3810-193 Aveiro (Portugal).

* raquelferreira@ua.pt

Key-words: Wildfires, runoff, nutrient losses, nitrogen, phosphorus.

Abstract

Post-fire erosion is a major concern following forest fires. The consumption of vegetation and litter cover together with the commonly-observed enhancement of water-repellent soil conditions can lead to a marked increase in runoff generation and associated soil losses. Also the risk of enhanced nutrient losses following wildfire is generally recognized but this has received considerably less research attention than post-fire runoff generation and sediment losses. The FIRECNUTS project (PTDC/AGR-CFL/104559/2008) addresses this knowledge gap by investigating the losses of nitrate, total nitrogen, orthophosphate and total phosphorus by runoff from micro-plot to catchment-scale. The proposed presentation, however, will focus on the smallest spatial scale.

The study area of the FIRECNUTS project is located near to the village of Ermida, in the municipality of Sever do Vouga, north-central Portugal. It was burnt by a wildfire towards the end of July 2010. Within the burnt area, five burnt hillslopes were each instrumented with three or four bounded micro-plots (0.28 m²), four unbounded slope-scale plots (0.50 m wide) and one unbounded slope-scale sediment fences (2-3 m wide). Four of these slopes were eucalypt plantations and one a Maritime Pine plantation, which by and large reflects the frequency of occurrence of these two land covers in the burnt area. In addition, various automatic and totalizer raingauges were installed in the area. The instrumentation was completed before the occurrence of any significant rainfall and, since then, monitoring is being done at regular, 1-to-2 weekly intervals, depending on rainfall.

The runoff samples are collected in 0.5 L polyethylene containers pre rinsed with hydrochloric acid (pH < 2.0), distilled and deionised water. After collection, all samples are stored in thermal boxes and transported to the laboratory. Aliquots of these samples are immediately filtered through a 0.45 µm pore size Milipore® HA membrane filter for the analysis of nitrate and orthophosphate. For the analysis of total nitrogen and total phosphorus, aliquots are collected without any filtration step. These four parameters are determined using a FOSS-Tecator FIAstar 5000. Electrical conductivity and pH are measured in the lab using a pre-calibrated portable meter HI 991300 (HANNA® Instruments). Finally, total suspended solids are quantified gravimetrically after filtration of an adequate volume through a glass fibre filter and following drying to a constant weight at 105 °C.

The presentation will concern the runoff generation and associated nutrient transport during the first five to six months after the wildfire.



AUTHOR INDEX.....





AUTHOR INDEX

Alba Lombao	136, 165, 168
Alexandra Pinheiro	132, 192, 263
Américo Castro	181
Ana Barreiro	123, 136
Ana Cristina Meira	68, 165, 168
Ana Vasques	241, 263
Andrea Pérez-Bejarano	171
Ángela Martín	123, 136, 165, 168
Ann Youberg	60, 90, 128, 140
Anne-Karine Boulet	132, 192
Annelies Voogt	110
António Bento Gonçalves	175, 181, 186, 198
António Ferreira	69, 94, 132, 160, 192
António Parra	228
António Vieira	175, 181, 186, 198
Artemi Cerdà	80, 208, 242
Aušra Treigienė	197
A. Couto-Vázquez	136
Beatriz Coleiro	254
Brian Irvine	69
Brian Lamb	64
Bruno Mary	153
Bryant Rob	59
Carla Martins	186
Carla Sofia Santos Ferreira	69, 160
Carles M. Rubio	115
Cathelijne Stoof	94, 160
Celeste Coelho	39, 69, 119, 132, 192
Célia Bento	160
César Guerrero	171
Chris Chafer	104
Christian Valentin	153
Cornelia Rumpel	153, 237
Cristina Fernandez	123
Cristina Ribeiro	119
Cyriel Adnès	195
C. Alvarez	203
C. Anquetil	237
C. Martí	203
C. Nocentini	153
Dan Malkinson	110
Daniel George Neary	60, 90, 128, 140
Danny Leska	110
David António Ramírez	228
Deborah A. Martin	33, 50, 242
Deborah P. Dick	45



Dennis Fox	195
Diana Catarina Vieira	196, 263
Domingos Silva	175
Domingos Viegas	241
D. Badia	203
Elena Benito Rueda	229, 230
Eli Argaman	110
Elisabete Figueiredo	119
Emiella Yusiharni	44, 49
Enrique Jiménez	123
Ernestas Kutorga	197
Felícia Fonseca	144
Felipe Macías Vázquez	75
Flora Ferreira Leite	175, 181, 186, 198
Francesc Ferrer	115
Francisco Díaz-Fierros	136, 214, 258
Francisco Javier González Vila	213, 218
Francisco Javier León Miranda	80, 203, 208
Francisco Matus	153
Francisco Moreira	38
Frédéric Darboux	195
Gary Sheridan	59
Gema Bárcenas	171
Giovanni Mastrolonardo	43, 153
Grażina Adamonytė	43
G. Certini	197
G. Erny	272
Heike Knicker	45, 213, 218, 237
Hein Vermin	263
Isabel Fernandes	241
I. Campos	272
Jan Jacob Keizer	196, 218, 229, 240, 241, 263, 271, 272, 273
Jean Morschel	195
Jessica Tamara Heath	104
João Pedro Nunes	196, 240, 272
Jonas Kasparavičius	197
Joost Iwema	94
Jorge Mataix-Beneyto	171
Jorge Mataix-Solera	80, 171, 208, 242
José António Carreira	228
José António González Pérez	218
José António Vega	32, 123
José Aranha	231
José Javier Cancelo González	214
José Manuel Moreno	228
Jose Maria de la Rosa	218
Jose Martín Soriano-Disla	171
José Salgado	181
José Martins	175



Joseph W. Wagenbrenner	156
Juli Pausas	241
Jurga Motiejūnaitė	197
J. A. Soares	69, 132
J. P. Meixedo	68
Karen A. Koestner	60, 90, 128, 140
Kwonchai Chinwong	55, 224
Kobsak Wanthongchai	55, 224
Lea Wittenberg	99, 110
Luciano Lourenço	181
Luis Clemente Salas	213
Luís Mendes	181, 186
Luís Outeiro	115
Luís da Vinha	198
L. Iglesias	136
L. Pereira	271
Maite Echeverria	203, 208
Manuel Bao Iglesias	75
María Ermitas Rial Rivas	214
Maria Eufemia Varela Teijeiro	218, 229, 230, 272
Maria Fátima Araújo	218
María Rodríguez-Alleres	229, 230
Maria Rosario Basanta	258
Maria Rosario Costa	231
María Teresa Fonturbel	123
María Teresa García Ares	75
Marie A. Alexis	237
Markus Egli	43
Maruxa Malvar Cortizo	196, 263, 272
Mathew Germino	64
Max X. Shen	263, 272
Merche B. Bodí	80, 208
Micaela Leite	144
Michael Plotze	43
Mike D. Carroll	90
Mike Kirkby	69
Montserrat Diaz-Raviña	123, 136, 165, 168
M. A. Carreiras	69
M Belén Hinojosa	228
M. Cerqueira	272, 273
M. J. Gómez	136
M. Nunes	272
Naama Tessler	99
Natalie Wagenbrenner	64
Noam Greenbaum	99
N.J. Abrantes	272
Paula Maia	241, 263
Paulo Mateus	27
Paulo Pereira	50, 242



Patrick Lane	59
Peter E. Koestner	60, 90, 140
Peter R. Robichaud	64, 156
Phanpong Kongdetadisak	55, 224
Piotr Sewerniak	247
Pura Marcet	251, 254
P. Ibarra	203
Reda Iršénaitė	197
Ricardo S.D. Dalmolin	45
Richard Shakesby	59, 69, 160
Robert Gilkes	44, 49
Roberto García-Ruiz	228
Rolf Krebs	43
Rory Walsh	160
Ruedi Seiler	43
Rutger Willem Vervoort	94
R. Pardo Lorenzo	75
R. Ferreira	272, 273
Saleta Gonzalez	251, 254
Sandra Valente	119
Saskia Keesstra	110
Scott W. Woods	85
Serafin J. González-Prieto	123
Sérgio Prats Alegre	132, 192, 263, 272
Sigitas Juzėnas	197
Silvia Regina Faria	218, 263, 272
Silviu Radan	148, 266
Singkhorn Rugsamanee	55, 224
Slawomir S. GONET	247
Smith G. Hugh	59
Sorin - Corneliu Radan	148, 266
Stefan Helmut Doerr	59, 80
Svetlana Markovskaja	197
S. Cambra	271
S. Van den Heuvel	272
Tanya Esteves	69
Tarsy Carballas	123, 136
Teresa Carvalho	119, 132, 192
Thomas Bishop	104
Tina Bell	59
Tomás de Figueiredo	144
Vera Soares	175
Victoria Arcenegui	171
Victoria N. Balfour	80, 85
Voradet Tarusadamrongdet	55, 224
V. Esteves	272
William Blake	59
Xavier Úbeda	50, 115, 242
Yessica Rivas	153

Organizing Institutions:



Universidade do Minho

Núcleo de Investigação em
Geografia e Planeamento



Centro de Estudos de Geografia
e Ordenamento do Território



Funded by FCT-MCTES