



International Meeting of  
Fire Effects on Soil Properties  
3rd Edition

15-19 March 2011  
University of Minho - Guimarães, Portugal

## FIRE EFFECTS ON SOIL PROPERTIES

Proceedings of the 3rd International Meeting  
of Fire Effects on Soil Properties

António Bento Gonçalves, António Vieira (Eds.)

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Universidade do Minho



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## PREFACE

The first edition of the International Meeting of Fire Effects on Soil Properties was held in Barcelona, Spain, in February 2007 by the Grup de Recerca Ambiental Mediterrània (GRAM) and the second in Marmaris, Turkey, in February 2009 by the research group on fire ecology (Hacettepe University).

This third edition will take place in Minho University (scheduled for March 15-19, 2011 in the city of *Guimarães*), is organized by the *Núcleo Investigação em Geografia e Planeamento da Universidade do Minho (NIGP)*, with the collaboration of the *Centro de Estudos de Geografia e Ordenamento do Território (CEGOT)*, brings together more than 80 researchers from countries like Australia, United States, Brazil, Israel, Thailand, Czech Republic, Poland, the Netherlands, France, Greece, Italy, Romania, Spain, United Kingdom, Germany and Portugal, who bring the experience of decades of scientific and technical work in areas affected by forest fires.

The main subjects of the meeting will be as followed:

- Fire effects on hydrology and soil physical properties;
- Fire effects on organic matter content and soil chemical properties;
- Methodologies to study fire effects on soil;
- Fire intensity, fire recurrence and fire severity measurements;
- Soil erosion and management strategy for recovery after forest fires.

The International Meeting, five days of duration, will consist in 5 Key Lectures given by senior scientific and managers from the United States, Spain and Portugal, 31 oral communications, 33 poster communications and a Tribute to Maria Sala (Departament de Geografia Física i AGR, Universitat de Barcelona, Spain).

Three oral communication sessions will be presented on the first day, with discussions after each session and three key lectures will be given (Paulo Mateus - Prescribed Fire - the spark that led to a new paradigm in Portugal; José Antonio Vega – Criteria to develop protocols for post-wildfire soil rehabilitation: current experience en Galicia (NW Spain); Deborah Martin – Research on ash from prescribed and wildland fires since the 1950's: past approaches and future directions).

The second day will have, in the afternoon, three oral communication sessions with discussions after each session and one key lecture (Francisco Moreira - The contribution of the PHOENIX project centre to post-fire research in Europe). In the morning we will have a workshop of the Thematic Network FUEGORED “Effects of Forest Fires on Soils”.

The third day will be a field day devoted to visit burnt areas and discuss about forest fire effects on soil properties in mountainous areas in the northwest of Portugal.

The fourth day will have, in the morning, one oral communication session, one poster session with discussions after each session and one key lecture (Celeste Coelho - Forest fires as



drivers of land degradation in Portugal). In the afternoon, after announcing the winner of the poster award, FESP 2011 will pay a well-deserved Tribute to Maria Sala. The day will end with the main conclusions of the Meeting and with the presentation and vote for the host and the date of the next FESP.

The fifth day will be devoted to a Post-meeting tour: “Alto Douro Wine Region” - UNESCO World Heritage.

One social event is planned: the closing dinner of the FESP 2011 to be held on Friday 18 March. The same day is organized a cultural visit to Guimarães (World Heritage).

Finally, we want to express here our gratitude to all who will join us from 15 to 19 March, to all who have helped in organizing the conference and all institutions that, in one form or another, have helped us. Without participants and without the cooperation and assistance of the persons and institutions mentioned, this International Meeting would not be possible.

Guimarães 02 March 2011

The editors,

António Bento Gonçalves, António Vieira

## TRIBUTE TO MARIA SALA



Maria Sala has worked in the effects of fires on soil erosion since the 80's. There were different sites: Prades Mountains, Collserola Massif, Les Gavarres and Cadiretes Massifs. Prades was an experimental plot where Maria's team studied the effects on soil and runoff and erosion increase after a prescribed experimental fire. Collserola (1993), Gavarres and Cadiretes (1994) were forest fires where the interesting thing was to study the role of the fire intensity in the effects and runoff and erosion generation.

Maria Sala at the beginning of the 90's also worked in the Arbúcies basin, monitoring the water quality and sediment transport, in 1994, a fire in part of the Arbúcies basin, was an opportunity to compare the results of the effect that that fire had in the quantity of sediment and even in changes in the discharge. The most used methodology to study the runoff and erosion generation was the installation of Gerlachs traps in the areas affected by fires and also in the control plot in order to do comparisons. Several projects, European and Spanish projects, were important in order to do all this research in the different sites. And different thesis of the Maria's students was elaborated in these sites. Some of the conclusions of these researches point that the slope and the fire intensity was a key factor to understand the runoff and erosion generation after fires (prescribed and wildfires) and how the first months and the rainfall after the fire determine the quantity of the material eroded.

It is also very important to study the vegetation recovery after forest fires because in the Mediterranean the fast regrowth of vegetation is essential to understand the erosion processes.

Xavier Úbeda ([xubeda@gmail.com](mailto:xubeda@gmail.com))

- Soler, M. & Sala, M. (1992): Effects of Fire and of Clearing in a Mediterranean *Quercus ilex* Woodland: An Experimental Approach. *Catena*, 19, 321-332.
- Sala, M. & Rubio, J. L. (EDS.) (1994): Soil Erosion and Degradation as a consequence of Forest Fires. *Geoforma*, Logroño, 275 pp.
- Sala, M., Soler, M. & Pradas, M. (1994): Temporal and spatial variations in runoff and erosion in burnt soils. *Proc. 2nd Int. Conf. on Forest Fire Research*, Coimbra, 21-24 November 1994. Vol. II, D.34, 1123-1134.
- Ubeda Cartaña, X. & Sala Sanjaume, M. (1994): Erosion as a consequence of rains immediately following a forest fire. *Proc. 2nd Int. Conf. on Forest Fire Research.*, Coimbra, 21-24 November, 1994, Vol. II, D.37, 1139-1148.
- Soler, M. & Sala, M. (1995): Variabilidad longitudinal de la escorrentía y la erosión en una ladera quemada. *Pirineos*, 145-146, 81-89
- Batalla, R. & Sala, M. (1995): Fire impact on river load in a catchment: preliminary results. *Proc. IGU Study Group on Mediterranean Erosion and Desertification in Regions of Mediterranean Climate*, Aveiro, 14-18 June,
- Ubeda, X & Sala, M. (1996): Impact of forest fires on slope hydrology: four case studies. *Fire Ecology and the European Biota: Research Carried out under the Auspices of the European Commission*, Toledo
- Ubeda, X. & Sala, M. (2001): Chemical concentrations in overland flow from different forested areas in a Mediterranean environment: burned forest at different fire intensity and unpaved road. *Zeitschrift für Geomorphologie*, 45, 2, 225-238.



## PROGRAMME

### Tuesday, 15 March 2011

Morning: 9.00 – Registration

9.30 - Opening Ceremony

10.30 - Key Lecture 1 - Paulo Mateus

11.20 - Coffee break

11.35 - Key Lecture 2 - José Antonio Vega

12.25 – Lunch

Afternoon: 14.00 - OC 1- Moderator: Paulo Pereira

1 - Giovanni Mastrolonardo, Ruedi Seiler, Giacomo Certini, rolf krebs, Michael Plotze, Markus Egli - FIRE-INDUCED CHANGES IN SOIL ORGANIC MATTER STABILITY ALONG A CATENA ON MT. ETNA, SICILY

2 - Robert Gilkes, Emielda Yusiharni - THE EFFECTS OF HEATING A LATERITIC PODZOLIC SOIL ON SOIL PHOSPHATE AVAILABILITY, A GLASSHOUSE STUDY

3 - Heike Knicker, Deborah P. Dick, Ricardo S.D. Dalmolin - HOW DOES BIENNIAL BURNING ALTER THE QUALITY AND QUANTITY OF ORGANIC MATTER IN SOILS?- AN EXAMPLE FROM THE CAMPO IN THE HIGHLAND OF SOUTHERN BRAZIL

4 - Emielda Yusiharni, Robert Gilkes - MINERALOGICAL AND CHEMICAL CHANGES IN A LATERITIC SOIL DUE TO A BUSHFIRE IN THE DARLING RANGE, WESTERN AUSTRALIA

15.30 - Key Lecture 3 - Deborah A. Martin

16.20 - Coffee break

16.30 - OC 2 - Moderator: Jorge Mataix-Solera

1 - Paulo Pereira, Xavier Úbeda, Deborah Martin - FIRE SEVERITY EFFECTS ON ASH CHEMICAL COMPOSITIONS AND EXTRACTABLE ELEMENTS



- 2 - Kobsak Wanthongchai, Singkhorn Rugsamane, Phanpong Kongdetadisak, Voradet Tarusadamrongdet, Khwanchai Chinnawong - QUANTIFYING THE INTENSITY OF PRESCRIBED FIRE IN DEGRADED PINE FOREST AND PINE-OAK FOREST, NAM NAO NATIONAL PARK, THAILAND
- 3 - Stefan Doerr, Richard A Shakesby, Bryant Rob, Smith G Hugh, Gary J Sheridan, Patrick NJ Lane, Tina Bell, William H Blake - IMPACT OF UNPRECEDENTED FIRE INTENSITY ON SOIL PHYSICAL AND CHEMICAL PROPERTIES: THE CASE OF THE CATASTROPHIC VICTORIA FIRES OF 2009
- 4 - Daniel George Neary, Karen A. Koestner, Ann Youberg, Peter E. Koestner - POST-FIRE RILL AND GULLY FORMATION, SCHULTZ FIRE 2010, ARIZONA, US

18.00 - OC 3 - Moderator: Dennis Fox

- 1 - Natalie Wagenbrenner - DEVELOPMENT OF A PM10 EMISSIONS MODEL FOR POST-FIRE ENVIRONMENTS
- 2 - Ana Cristina Meira, J Gois, J P Meixedo - SOME REFLECTIONS ON ACQUISITION, PROCESSING AND ANALYSIS OF STATISTICAL DATA IN FOREST SOILS
- 3 - Tanya Esteves, Antonio Ferreira, J A Soares, Mike Kirkby, Rick Shakesby, Brian Irvine, C S Ferreira, Celeste Coelho, M A Carreiras - USING PESERA TO MANAGE DESERTIFICATION PROCESSES FOLLOWING WILDFIRES IN GÓIS AND MAÇÃO, PORTUGAL
- 4 - María Teresa García Ares, Manuel Bao Iglesias, Felipe Macías Vázquez - CHEMICAL CHARACTERIZATION OF TERRA PRETA DO ÍNDIO SOILS AND CHARCOAL SAMPLES IN PREHOLOCENIC SEDIMENTS FROM THE NORTH OF GALICIA

### Wednesday, 16 March 2011

Afternoon: 14.00 - OC 4 - Moderator: Montserrat Diaz-Raviña

- 1 - Merche B Bodí, Francisco Javier León Miranda, Artemi Cerdà, Stefan Helmut Doerr, Jorge Mataix-Solera - RUNOFF RATES, WATER EROSION AND WATER QUALITY ON A SOIL COVERED WITH ASH
- 2 - Scott W. Woods, Victoria N Balfour - CHARACTERIZING THE HYDROLOGICAL PROPERTIES OF WILDFIRE ASH
- 3 - Karen Ann Koestner, Daniel G. Neary, Mike Carroll, Peter E. Koestner, Ann Youberg - DEPOSITIONAL CHARACTERISTICS OF POST-FIRE FLOODING FOLLOWING THE SCHULTZ FIRE, SAN FRANCISCO PEAKS, ARIZONA



- 4 - Cathelijne R Stoof, Joost Iwema, Antonio Dinis Ferreira, Rutger Willem Vervoort - HYDROLOGICAL RESPONSE OF A SMALL CATCHMENT BURNED BY EXPERIMENTAL FIRE

15.30 - Key Lecture 4 - Francisco Moreira

16.20 - Coffee break

16.30 - OC 5 - Moderator: Cathelijne Stoof

- 1 - Naama Tessler, Lea Wittenberg, Noam Greenbaum - UNDERSTANDING SOIL WATER REPELLENCY PERSISTENCE AFTER RECURRENT FOREST FIRE
- 2 - Jessica Tamara Heath, Chris Chafer, Thomas Bishop - IMPACTS OF WILDFIRE ON SOIL REPELLENCY WITHIN OBLIGATE RESPROUTER COMMUNITIES NEAR SYDNEY, AUSTRALIA
- 3 - Lea Wittenberg, Dan Malkinson, Annelies Voogt, Danny Leska, Eli Argaman, Saskia Keestra - THE RELATIVE IMPORTANCE OF SOIL WATER REPELLENCY IN DETERMINING RUNOFF-INFILTRATION PROCESSES IN BURNED MEDITERRANEAN FOREST SOILS
- 4 - Carles M Rubio, Luís Outeiro, Francesc Ferrer, Xavier Úbeda - VARIABILITY OF THE SOIL THERMAL PROPERTIES AFTER PRESCRIBED FIRE
- 5 - Cristina Ribeiro, Celeste Coelho, Sandra Valente, Teresa Carvalho, Elisabete Figueiredo - DO STAKEHOLDERS KNOW WHAT HAPPENS TO SOIL AFTER FOREST FIRES? A CASE STUDY IN CENTRAL PORTUGAL

18.00 - OC 6 - Moderator: Ana Cristina Meira

- 1 - María Teresa Fonturbel, Montserrat Diaz-Raviña, José Antonio Vega, Serafín J. González-Prieto, Cristina Fernandez, Ángela Martín, Enrique Jiménez, Ana Barreiro, Tarsy Carballas - COMPARISON OF THE EFFECTS OF POST-FIRE SOIL STABILIZATION TREATMENTS ON SOIL EROSION CONTROL AND IN SELECTED SOIL PROPERTIES IN GALICIA (NW SPAIN)
- 2 - Daniel George Neary, Karen A. Koestner - ROCK GABION, RIP-RAP, AND CULVERT TREATMENTS CONTRIBUTING TO AND REDUCING EROSION DURING POST-FIRE FLOODING - SCHULTZ FIRE 2010
- 3 - Celeste Alves Coelho, Sérgio Prats, Alexandra Pinheiro, Teresa Carvalho, Anne-Karine Boulet, António Ferreira, João Soares - EFFECTIVENESS OF TWO MULCH TREATMENTS CONTROLLING SOIL EROSION AND WATER CONSERVATION



- 4 - Montserrat Díaz Raviña, A Martín, A Barreiro, A Lombao, M J Gómez, A Couto-Vázquez, L Iglesias, F Díaz-Fierros, T Carballas - PRELIMINARY DATA OF SOIL PROPERTIES AND SOIL EROSION FOLLOWING A WILDFIRE AND DIFFERENT POST-FIRE SOIL STABILIZATION TREATMENTS IN LAZA (NW SPAIN)
- 5 - Ann Youberg, Karen Ann Koestner, Daniel G. Neary, Peter E. Koestner - GEOMORPHIC ASPECTS OF POST-FIRE SOIL EROSION – SCHULTZ FIRE 2010

### **Thursday, 17 March 2011**

Mid-conference field trip - Moderators: Antonio Bento, Antonio Vieira, Luciano Lourenço, Hermínio Botelho, Xavier Úbeda, Artemi Cerdà, Flora Leite

Serra da Cabreira

Visiting burnt areas and discussion about forest fire effects on soil properties in mountainous areas.

### **Friday, 18 March 2011**

Morning: 9.30 - OC 7 - Moderator: Robert Gilkes

- 1 - Felícia Fonseca, Micaela Leite, Tomás de Figueiredo - SOIL PROPERTIES IN BURNT AND UNBURNT SHRUBLANDS IN MONTESINHO NATURAL PARK, NORTHEAST PORTUGAL
- 2 - Sorin - Corneliu Radan, Silviu Radan - HOW COAL FIRES AFFECT THE CLAYS: AN INTERDISCIPLINARY APPROACH
- 3 - Cornelia Rumpel, Bruno Mary, Yessica Rivas, Christian Valentin, Francisco Matus - CONTRASTING EFFECTS OF FIRE ON FOREST AND AGRICULTURAL SOILS
- 4 - Joseph W Wagenbrenner, Peter R Robichaud - RILL EROSION IN BURNED FORESTS
- 5 - Richard A Shakesby, Carla Sofia Santos Ferreira, Rory PD Walsh, Célia Bento, António JD Ferreira, Chatelijne R Stoof - FIRE IMPACT ON SOIL AND NUTRIENT LOSSES IN SCHIST MOUNTAIN AREAS: CENTRAL PORTUGAL STUDY

11.00 - Key Lecture 5 - Celeste Coelho

11.50 - Poster Session

12.30 – Lunch



- Afternoon:
- 14.15 - Poster award
  - 14.30 - Tribute to Maria Sala
  - 14.30 - Tribute: Xavier Úbeda
  - 14.45 - Key Lecture - Maria Sala
  - 15.30 - Coffee break
  - 15.45 – Conclusions
  - 16.10 - Presentation and voting for the host and the date of the next FESP
  - 16.30 - Closing session
  - 17.30 - Guimarães (World Heritage) tour
  - 21.00 - Farewell dinner

### **Saturday, 19 March 2011**

- Post-meeting tour
  - Douro Vinhateiro (world heritage) – mini cruise





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



Universidade do Minho

**KEY LECTURES.....**





## Prescribed Fire - the spark that led to a new paradigm in Portugal

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**Key-words:** prescribed fire in Portugal.

### Abstract

This document is not intended to constitute itself as a course on Prescribed Fire, but is a reflection on the role that Prescribed Fire plays as a "starter" solution to the problem of wild fires. A solution born from inside of the problem.

The aim is to integrate theory and practical application, presenting a holistic and also reductionistic point of view. It is not intended to give any answers, but to confront the scientific community with a new kind of paradigmatic thinking and take her to wonder whether, somehow, fit in it.

### Before

It is known that fire is part of the forest ecosystems in Portugal and has been used by man since time immemorial. Currently it is used by rural communities based on traditional know-how.

In terms of forestry, the first documentary reference in Portugal's use of fire with silvicultural purposes was in 1836, on the Manual Practice of Friderico Varnhagen. We can also remark, in this context, the notes and comments on the use of "current fire" by Tude de Sousa, in 1926, at "Mata do Gerês".

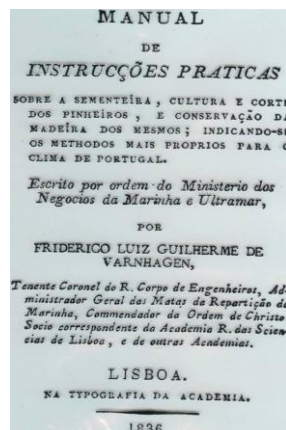


Figure 1

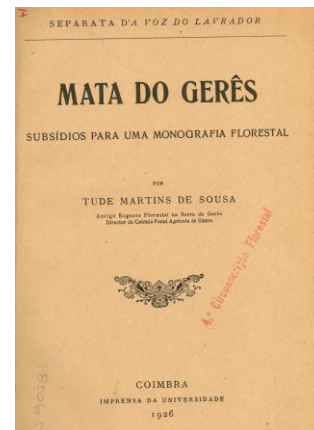


Figure 2

In the 40 years following fire was seen as something that should, definitely, be put out of forest landscape.

It was with the visit of American technicians to Portugal in 1976, Dr. Edwin Komarec and his wife Betty, of Tall Timbers Research Station, Florida, that was considered the possibility of reintroduction fire in forest ecosystems advocating health benefits and especially the reduction of forest fuel loads that lead to the reducing the fire risk. The visit of Komarec was a milestone, according to Moreira da Silva. So, were re-initiated the first experiments with Prescribed Fire as a forestry technique. These early experiences



were developed in Vila Real, Coimbra, Marinha Grande, Tapada Nacional de Mafra and Peneda Gerês National Park.

In 1982, extensive burning was made with the implementation of the Prescribed Fire Emergency Plan (Moreira da Silva) by the Forest Service in the north of Portugal, involving researchers at the University of Trás-os-Montes e Alto Douro (UTAD) and the Institute of Agronomy (Instituto Superior de Agronomia - ISA). Thousands of hectares have been burned with the use of the technique of Prescribed Fire.

Then, was followed a 15 years gap in use of Prescribed Fire. During this period, also on the land managed by the Forest Service, were being made ad hoc Prescribed Fire actions which kept the flame alive until the beginning of the XXI century.

In the last quarter of the XX Century Prescribed Fire was the starting point for a change of how foresters face forest. This new perspective was very upset by the foresters of the time. Moreira da Silva said - "there was much resistance from my colleagues. They had difficulty accepting fire inside the forest."

The idea of excluding fire from forest, and fire seen as a forest enemy in the mind of foresters since the 30s of last century, has been questioned. The old paradigm "Fire is an Enemy" began to fall because it did not respond to the increasing problems of wild fires so highly destructive.

But it was only after the terrible fire campaign of 2003 and 2005, highly destructive, with tens of deaths, 765.000 hectares burned, that emerge new ideas related to knowledge of fire behavior and began to take shape a new system. This new system took in account a comprehensive thought, broad spectrum, trying to identify the individual parts that build the new paradigm.

### **The spark**

The new concept of fire is revealed in the Finnish proverb that says "fire is a bad boss but a good servant". It is assumed, increasingly, as an essential tool for restoring forest ecosystems in our country.

Prescribed Fire introduced topics such as "fire ecology", "landscape ecology" in the structure of thought of the new Foresters. Prescribed Fire combines theory and practical application and triggers a new paradigm in Portugal. It was assumed as anchor idea of the new paradigm that still takes the first steps in Portugal.

Known as "the application of a fire under specified environmental conditions, which allow the fire to be confined to a predetermined area and to attain planned resource management objectives", Prescribed fire is the basis of a whole new design paradigm.

At this level a mention the project "Fire Paradox" need to be done, for his role in motivating a revolution that contributed to the establishment of the new paradigm, and also as a builder of after paradigmatic science, with many products and tools developed by the project, directly related to new paradigm "integrated fire management".

### **New paradigm**

The new paradigm "of the integrated fire management" includes the use of different strategies and techniques of fire, including prescribed fire, the traditional use of fire and the use of fire suppression. This new paradigm that emerges, in Portugal, through the technique of Prescribed Fire, links the concepts of "fire management", "ecology" and "culture of fire", and emphasizes the importance of landscape heterogeneity on the development of resistance to disturbances, the recovery of disorders and the promotion of overall system stability, giving substance to the theory of landscape ecology.



As a result of this new paradigm, there are new answers to the questions:

How to do forests?

How to organize the landscape? - Mosaics, as stated Moreira da Silva?

What models can be taken to ensure a fire resistant landscape?

What forest species to choose? - Specialize in the area?

What protection measures should be followed to avoid the large and destructive wild fires?

Which systems must be built to answer the questions above?

### **New solutions**

Trying to conceive and apply this transformative strategies based on this new paradigm, with the synthesis of whole process thinking, were developed in Portugal two crucial Systems.

The **first system** to be built based on the new paradigm was the “National Forests Strategy, 2006” which fits a context of forest changing and emerge of new risks. The “National Forests Strategy” emphasizes this reality, and highlights the need to reduce the risks associated with forest.

This document distinguishes the real risks, like climate change and the possible change of dominant species or the areas of distribution of various forest types. The lack of forest management which stems directly from the abandonment of farming activities, desertification of rural areas and the changes that occurred in the Portuguese society in the second half of the twentieth century. The phenomenon of internationalization, also a real risk, with the evolution of international trade rules - the certification requirements is one example. And finally, another real risk is the recent appreciation of environmental services and the need to adapt to this reality, which highlights efforts to mitigate emissions of greenhouse gases, in particular following the commitment made in the Kyoto Protocol.

Moreover the “National Strategy for Forests” also highlights how necessary is the reduction of perceived risks, which are the visible consequences of the real risks - the phenomenon of forest fires essentially, but also the increasing sensitivity of forest to the attack of biotic (pests and diseases) and even the possibility of spread of invasive species into new areas.

The actions in each of these areas (mitigation of real risks or mitigation of perceived risks) are different but interdependent. A necessary change that will lead to forest rebalancing is needed. A change in the perspective of how the population, forest owners and technicians, face “Forest” is needed.

New thinking, new ideas, new paradigms and new solutions are needed to cope with this changing forestry world. The specialization of the territory in order to improve the landscape increased resistance to disturbance (eg wild fire) advocated in the National Forests Strategy reveals how the new paradigm “of the integrated fire management” influences this document.

Alongside the work to minimize the real risks, there is work that acts directly on the visible consequences of the problem, which are the perceived risks that have been outlined earlier. This work allows us to accelerate the process of change, with the aim of restoring confidence to the forest sector so that there are better conditions to attract investment into forest.

In this context, also influenced by the new paradigm was built a **second system**, the “National System of Forest Fire Defense” (SNDFCI) and the related “Forest Defense

Against Fire National Plan” (PNDFCI), that adds in a holistic system, the structural prevention, surveillance and law enforcement and fire fighting.

This system, although still very much conditioned by the previous paradigm that relies mainly on the need for “fire fighting” should, year after year, and taking advantage of the increasing knowledge of fire and its behavior, contribute to balance forest areas, and as a result will spend less energy in fight wild fires. This is however a slow process.

In Portugal, Prescribed Fire, as technical, economic and efficient process of reducing fuel load in forest areas, has already led to numerous success cases in fighting large fires, as shown below.

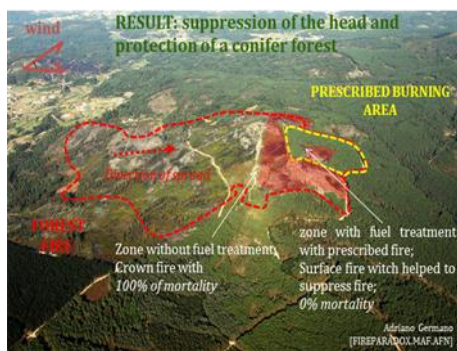


Figure 3

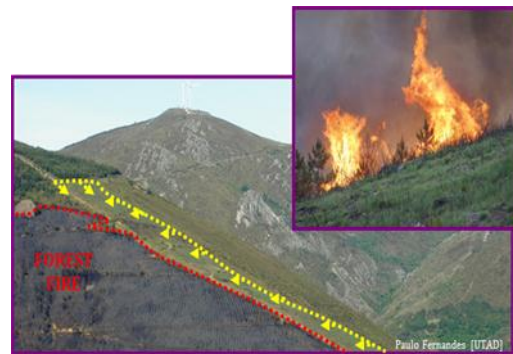


Figure 4

Prescribed Fire can provide the foundation of knowledge for a better and more effective combat as well as being the basis of practical use of fire suppression (the application of the fire to Accelerate or strengthen the suppression of wildfires).

The continued work of experts in the use of fire is essential for that the processes and systems described above do not end. Under the Law that regulate Use of Fire, already published, which clarifies the rules for using this tools in order to increase their effectiveness and efficiency, safeguarding the protection of persons, goods and forest assets, and with the advent of a National Fire Use Plan, Portugal can maintain the line that will consolidate the new paradigm that will allow to rebalance the forest and thereby increase its intrinsic wealth.

### After

Although the technique of Prescribed Fire has been used several times throughout history, as we have already shown above, now retrieves the appropriate *modus faciendi* concerns our time, with methods adapted.

The current process of recovery the Prescribed Fire technique has parallels with the processes of recovery of ancestral knowledge of the other activities of modern society in the fields of medicine, health and welfare, for example. It is the recovery of ancient knowledge with new clothing, to solve problems that are not new, but are contemporary. Issues that emerge from time to time!

Forest ecosystems alternate from less equilibrium to new equilibrium state, according to the Laws of Thermodynamics. And fire, as destructive element but also as renewal, has a fundamental role in this process of recover the lost balance. Thus, fire must be consider as a kind of homeopathic element, which can be prescribed in appropriate doses for the restoration of forest, *lato sensu*.



The future? Knowledge and Time. The nature is itself economic, invariably choosing the simplest path. Fire is an easy way. “Everything should be made as simple as possible but no simpler than that” (Einstein).

### References

- DGRF, 2006. Estratégia Nacional para as Florestas. Lisboa. Direcção Geral dos Recursos Florestais.
- Loureiro C., Fernandes P., Botelho H., Mateus P., 2006. A simulation-based test of a landscape fuel management project in the Marão range fo northern Portugal. *Forest Ecology and Management* 234S (2006) S245.
- Moreira da Silva J., 1981. O fogo na floresta: inimigo ou aliado do silvicultor? II encontro dos técnicos agrários de Galiza, Trás-os-Montes e Entre Douro e Minho. Braga
- Moreira da Silva J., 1983. Utilização de fogos controlados como factor de prevenção dos incêndios florestais. I Simpósio sobre ensino do meio natural, Santiago de Compostela, Espanha.
- Rego F., Rigolot E., Fernandes P., Montiel C., Sande Silva J., 2010. Towards Integrated Fire Management. EFI Policy Brief 4. European Forest Institute
- Project “Fire Paradox”, 2010. Towards Integrated Fire Management. Outcomes of the European Project “Fire Paradox”. Freiburg, Germany. GFMC, EFICIENT, EFI
- Tude de Sousa, 1926. Mata do Gerês. Imprensa da Universidade. Coimbra
- Varnhagen F., 1836. Manual de instruções práticas. Lisboa





## **Criteria to develop protocols for post-wildfire soil rehabilitation: current experience in galicia (nw spain)**

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**Key-words:** post-wildfire soil rehabilitation, Galicia.

### **Abstract**

Once wildfire is suppressed, forest managers have to face fire impact evaluation on affected ecosystems and decide post-fire activities. From this moment, these activities are conditioned by the ecosystem characteristics (soils, vegetation, topography and watersheds hydrology), climate, fire severity and socioeconomic and technical factors.

In some cases, soil rehabilitation treatments are advisable and, then, the availability of clear criteria to decide when and where and which of these treatments need to be applied is necessary. A protocol setting up the main steps to be followed in the decision-making process can be useful. As an example of application, the protocol developed after summer forest fires in Galicia in 2010 is discussed. Basically, the main stages of this protocol are: 1) gathering of documentation (wildfire and site characteristics, fire recurrence and land use), 2) fire severity field evaluation, 3) runoff, flooding and erosion risk assessment and values at risk-vulnerability evaluation 4) prioritize areas to be treated, 5) selection and conduction of rehabilitation treatments and 6) monitoring treatments effectiveness.

The connection between research and management becomes crucial for the success of the protocol. Researchers can provide with a good knowledge of the state of the art and tools to evaluate fire severity, erosion and floods risk and to help to select the most appropriated rehabilitation techniques for a specific affected area. On their turn, managers need to filter this information to adequate it to the technical and socioeconomic conditions. A lot of questions are still unsolved, a deeper knowledge on hydrological processes involved, a better definition of fire severity, a higher availability of operational tools to evaluate it at landscape scale, as well as, an improvement of the linkage between fire severity indexes and changes in soil properties. From the management point of view, economic, logistical and safety issues need to be also improved.



## Research on ash from prescribed and wildland fires since the 1950's: past approaches and future directions

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**Key-words:** wildland fire, prescribed fire, ash, review.

### Introduction

What is ash? Currently, it is well accepted that the residue from the combustion of organic material during prescribed and wildland fire is a complex mixture of partially burned organic matter, products within the black carbon continuum including charcoal and char (Hammes et al., 2007; Kuo et al., 2008), soil particles, phytoliths (Wattez and Courty, 1987; Morris et al., 2010) and the oxalates, carbonates, and silicates of elements whose volatilization temperatures are below the maximum temperatures reached during the fire (Canti 2003). This latter portion is termed mineral ash and is the fraction measured by standard techniques such as American Society for Testing and Materials (ASTM) D1102-84(2007) (ASTM, 2007a) and E1755-01(2007) (ASTM, 2007b). This review focuses on research concerned with the complex mixture of products formed during the combustion of organic matter or the mineral fraction created under standard conditions and explicitly excludes research where the charcoal fraction has been isolated for study (e.g. DeLuca et al., 2006) and studies on volcanic ash.

### Previous work

Ancient texts have described the use of wood ash as a soil fertilizer (Virgil, 29 B.C.), insect repellent (Gowariker et al., 2009), and ingredient in the manufacture of soap (al-Hassan et al., 2002). During the early twentieth century research on ash first appears in the scientific literature. Before 1950 some notable research was conducted on the influence of ash on soil fertility (Alway and Rost, 1928; Sampson, 1944; Young and Golledge, 1948) and the effect of temperature on the retention of elements during heat treatments (St. John, 1941). Since the 1950's, the pace of research on ash and its effect on soil properties has accelerated and studies are being conducted worldwide, often as international collaborations (e. g. Cerdá and Doerr, 2008; Pereira et al., 2011). The acceleration in ash research is demonstrated by the number of articles published in each decade: 1950's 6; 1960's 12; 1970's 26; 1980's 47; 1990's 78; 2000's 140; 2010 to early 2011 11. These numbers do not include most of the research on wood ash targeted for land disposal (reviewed by Augusto et al., 2008).

The research on the ash from both prescribed and wildland fire can be broadly grouped into eight major, interrelated categories: 1. the chemical and physical properties of ash (e.g. Etiegni and Campbell, 1991; Hageman et al., 2008a,b; Úbeda et al., 2009), 2. effects of ash on infiltration and surface erosion, including debris flows (e.g. Burgy and Scott, 1952; Gabet and Sternberg, 2008; Stoof et al., 2010; Woods and Balfour, 2008, 2010), 3. effects of ash on soil properties and soil chemistry (e.g. Allen et al., 1969; Christensen and Muller, 1975), 4. effects of ash on plant germination and plant cover (e. g. Reyes and Casal, 2004; Izhaki et al., 2000), 5. effects of ash on the soil microbiota (e.g. Bauhus et al., 1993; Badía and Martí, 2003), 6. influence of ash on the chemistry of surface water runoff and aquatic ecosystems (e.g. Gerla and Galloway, 1998; Barber et al., 2003; Earl



and Blinn, 2003), 7. use of the spectral signature of ash as an indicator of burn intensity or fire severity (e. g. Roy and Landmann, 2005; Robichaud et al., 2007), and 8. potential effects of ash on the health of humans and aquatic organisms (e. g. Kelly et al., 2006; Plumlee, 2009).

### Future work

Despite the extensive research on ash since the 1950's, gaps still exist in our knowledge about the chemical and physical characteristics of ash, its use as a predictor of post-fire biological and hydrological response, and its potential effects on downstream water quality. We lack comprehensive information about the extent to which the chemistry of ash is a function of the type of plant material, the underlying geology, and the legacy of atmospheric deposition of chemicals such as mercury (Biswas et al., 2008), lead (Rothwell et al., 2007), and PAH's (García-Falcon et al., 2006). Only limited research exists on the water holding capacity of ash (Woods and Balfour, 2008, 2010; Stoof et al., 2010) and its water repellency (Bodí et al., 2011) and hence its effect on runoff generation. We don't have a good understanding of the genesis of "fly ash" and its movement during fire (Smith and Bowes, 1974; Raison et al., 1985), when and how ash is moved from burned landscapes by wind (Whicker et al., 2006; Wagenbrenner et al., 2010) and runoff (Ferreira et al., 2005; Howell, 2006; Liu and Hu, 2007) and we have little knowledge of the fate and persistence of the material once it is transported elsewhere (Blake et al., 2006). Furthermore, we lack standardized techniques to compare ash across different ecosystems. We should adopt existing methods to allow this comparison; for example, 1. use a standard gray scale such as that described by Roy et al. (2010) to report the color of ash; 2. measure and report the pH of the ash slurry according to a standard protocol, e.g. Henig-Sever et al. (2001), or Goforth et al. (2005); and 3. routinely combust ash samples according to the methods summarized by Dimitrakopoulos and Panov (2001) (650°C for 1 hour) or Smith et al. (2005) (500°C for 18 hours) to measure the completeness of combustion for comparison among different fires and ecosystems. Finally, we should continue to hold international meetings to promote collaboration, communication, and progress on research related to fire, an issue of global importance.

### References

- Al-Hassan, A.Y., Ahmad, M., Iskander, A.Z., 2002. Science and Technology in Islam in The Different Aspects of Islamic Culture. UNESCO. Available online at: [http://www.unesco.org/culture/aic/html\\_eng/volume4.htm](http://www.unesco.org/culture/aic/html_eng/volume4.htm), accessed Feb. 10, 2011.
- Allen, S.E., Evans, C.C., Grimshaw, H.M., 1969. The distribution of mineral nutrients in soil after heather burning. *Oikos* 20, 16-25.
- Alway, F.J., Rost, C.O., 1928. Effect of Forest Fires on the Composition and Productivity of the Soil. *Proceedings and Papers of the First International Congress of Soil Science*. The American Organizing Committee of the First International Congress of Soil Science, Washington, D. C., pp. 546-576.
- ASTM, 2007a. ASTM D1102-84(2007) Standard Test Method for Ash in Wood. American Society for Testing and Materials, West Conshohocken, Pennsylvania.
- ASTM, 2007b. ASTM E1755-01(2007) Standard Test Method for Ash in Biomass. American Society for Testing and Materials, West Conshohocken, Pennsylvania.
- Augusto, L.L., Bakker, M.R., Meredieu, C.C., 2008. Wood ash applications to temperate forest ecosystems—potential benefits and drawbacks. *Plant and Soil* 306, 181-198.



- Badía, D., Martí, C., 2003. Effect of simulated fire on organic matter and selected microbiological properties of two contrasting soils. *Arid Land Research and Management* 17, 55-69.
- Barber, T.R., Lutes, C.C., Doorn, M.R. J., Fuchsman, P.C., Timmenga, H.J., Crouch, R.L., 2003. Aquatic ecological risks due to cyanide release from biomass burning. *Chemosphere* 50, 343-348.
- Bauhus, J., Khanna, P.K., Raison, R.J., 1993. The effect of fire on carbon and nitrogen mineralization and nitrification in an Australian forest soil. *Australian Journal of Soil Research* 31, 621-639
- Biswas, A., Blum, J.D., Keeler, G.J., 2008. Mercury storage in surface soils in a central Washington forest and estimated release during the 2001 Rex Creek Fire. *Science of the Total Environment* 404, 129-138.
- Blake, W.H., Wallbrink, P.J., Doerr, S.H., Shakesby, R.A., Humphreys, G.S., English, P., Wilkinson, S., 2006. Using geochemical stratigraphy to indicate post-fire sediment and nutrient fluxes into a water supply reservoir, Sydney, Australia. *Sediment Dynamics and the Hydromorphology of Fluvial Systems (Dundee, UK, July 2006)*. IAHS Publ. 306, pp.. 363-370.
- Bodí, M.B., Mataix-Solera, J., Doerr, S.H., Cerdá, A., 2011. The wettability of ash from burned vegetation and its relationship to Mediterranean plant species type, burn severity and total organic carbon content. *Geoderma* 160, 599-607.
- Burgy, R.H., Scott, V.H., 1952. Some effects of fire and ash on the infiltration capacity of soils. *Transactions, American Geophysical Union*. 33, 405-416.
- Canti, M.G., 2003. Aspects of the chemical and microscopic characteristics of plant ashes found in archaeological soils. *Catena* 54, 339-361.
- 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.
- Christensen, N.L., Muller, C.H., 1975. Effects of fire on factors controlling plant growth in *Adenostoma chaparral*. *Ecological Monographs* 45, 29-55.
- DeLuca, T.H., MacKenzie, M.D., Gundale, M.J., Holben, W.E., 2006. Wildfire-produced charcoal directly influences nitrogen cycling in ponderosa pine forests. *Soil Science Society of America Journal* 70, 448-453.
- Dimitrakopoulos, A.P., Panov, P.I., 2001. Pyric properties of some dominant Mediterranean vegetation species. *International Journal of Wildland Fire* 10, 23-27.
- Earl, S.R., Blinn, D.W., 2003. Effects of wildfire ash on water chemistry and biota in South-Western U.S.A. streams. *Freshwater Biology* 48, 1015-1030.
- Etiegni, L., Campbell, A.G., 1991. Physical and chemical characteristics of wood ash. *Bioresource Technology* 37, 173-178.
- Ferreira, A.J.D., Coelho, C.O.A., Boulet, A.K., Lopes, F.P., 2005. Temporal patterns of solute loss following wildfires in Central Portugal. *International Journal of Wildland Fire* 14, 401-412.
- Gabet, E.J., Sternberg, P., 2008. The effects of vegetative ash on infiltration capacity, sediment transport, and the generation of progressively bulked debris flows. *Geomorphology* 101, 666-673.
- García-Falcon, M.S., Soto-González, B., Simal-Gándara, J., 2006. Evolution of the concentrations of Polycyclic Aromatic Hydrocarbons in burnt woodland soils. *Environmental Science and Technology* 40, 759-763.
- Gerla, P.J., Galloway, J.M., 1998. Water quality of two streams near Yellowstone Park, Wyoming, following the 1988 Clover-Mist wildfire. *Environmental Geology* 36, 127-136.



- Goforth, B.R., Graham, R.C., Hubbert, K.R., Zanner, C.W., Minnich, R.A., 2005. Spatial distribution and properties of ash and thermally altered soils after high-severity forest fire southern California. *International Journal of Wildland Fire* 14, 343-354.
- Gowariker, V., Krishnamurthy, V. N., Gowariker, S., Dhanorkar, M., 2009. *The Fertilizer Encyclopedia*. John Wiley & Sons, Hoboken, New Jersey.
- Hageman, P.L., Plumlee, G.S., Martin, D.A., Hoefen, T.M., Adams, M., Lamothe, P.J., Todorov, T., Anthony, M.W., 2008a. Leachate Geochemical Results for Ash Samples from the June 2007 Angora Wildfire near Lake Tahoe in Northern California, 2008: U.S. Geological Survey Open-File Report 2008-1170. 14 p. Available at: <http://pubs.usgs.gov/of/2008/1170/>, accessed Feb. 10, 2011.
- Hageman, P.L., Plumlee, G.S., Martin, D.A., Hoefen, T.M., Meeker, G.P., Adams, M., Lamothe, P.J., Anthony, M.W., 2008b. Leachate Geochemical Results for Ash and Burned Soil Samples from the October 2007 Southern California Wildfires: U.S. Geological Survey Open-File Report 2008-1139, 14 p. Available at: <http://pubs.usgs.gov/of/2008/1139/>, accessed Feb. 10, 2011.
- Hammes, K. and others, 2007. Comparison of quantification methods to measure fire-derived (black/elemental) carbon in soils and sediments using reference materials from soil, water, sediment and the atmosphere. *Global Biogeochemical Cycles* 21, GB3016/1-GB3016/18.
- Henig-Sever, N., Podiakov, D., Broza, M., 2001. A novel method of estimation of wild fire intensity based on ash pH and soil microarthropod community. *Pedobiologia*, 45, 98-106.
- Howell, P.J., 2006. Effects of wildfire and subsequent hydrologic events on fish distribution and abundance in tributaries of North Fork John Day River. *North American Journal of Fisheries Management* 26, 983-994.
- Izhaki, I., Henig-Sever, N., Ne'eman, G., 2000. Soil seed banks in Mediterranean Aleppo pine forests: The effect of heat, cover and ash on seedling emergence. *Journal of Ecology* 88, 667-675.
- Kelly, E.N., Schindler, D. W., St. Louis, V.L., Donald, D.B., Vladicka, K.E., 2006. Forest fire increases mercury accumulation by fishes via food web restructuring and increased mercury inputs. *Proceedings of the National Academy of Sciences* 103, 19380-19385.
- Kuo, L.-J., Herbert, B.E., Louchouart, P., 2008. Can levoglucosan be used to characterize and quantify char/charcoal black carbon in environmental media? *Organic Geochemistry* 39, 1466-1478.
- Liu, Y., Hu, H., 2007. Concentration variations of several ions in stream after a wildfire. *Journal of Forestry Research* 18, 319-321.
- Morris, L.R., Ryel, R.J., West, N.E., 2010. Can soil phytolith analysis and charcoal be used as indicators of historic fire in the pinyon-juniper and sagebrush steppe ecosystem types of the Great Basin Desert, USA? *Holocene* 20, 105-114.
- Pereira, P., Úbeda, X., Martin, D., Mataix-Solera, J., César Guerrero, C., 2011. Effects of a low severity prescribed fire on water-soluble elements in ash from a cork oak (*Quercus suber*) forest located in the northeast of the Iberian Peninsula. *Environmental Research* 111, 237-247.
- Plumlee, G., 2009, Report from Ground Zero: How geoscientists aid in the aftermath of environmental disasters. *Earth* 54, 38-47.
- Raison, R.J., Khanna, P.K., Woods, P.V., 1985. Mechanisms of element transfer to the atmosphere during vegetation fires. *Canadian Journal of Forest Research* 15:132-140.



- Reyes, O., Casal, M., 2004. Effects of forest fire ash on germination and early growth of four *Pinus* species. *Plant Ecology* 175, 81-89.
- Robichaud, P.R., Lewis, S.A., Laes, D.Y.M., Hudak, A.T., Kokaly, R.F., Zamudio, J.A., 2007. Postfire soil burn severity mapping with hyperspectral image unmixing. *Remote Sensing of Environment* 108, 467-480.
- Rothwell, J.J., Evans, M.G., Liddaman, L.C., Allott, T.H.E., 2007. The role of wildfire and gully erosion in particulate Pb export from contaminated peatland catchments in the southern Pennines, UK. *Geomorphology* 88, 276–284.
- Roy, D.P., Landmann, T., 2005. Characterizing the surface heterogeneity of fire effects using multi-temporal reflective wavelength data. *International Journal of Remote Sensing* 26, 4197-4218.
- Roy, D.P., Boschetti, L., Maier, S.W., Smith, A.M.S., 2010. Field estimation of ash and char colour-lightness using a standard grey scale. *International Journal of Wildland Fire* 19, 698–704.
- St. John, J.L., 1941. Report on ash: effect of ashing temperatures on percentage of mineral elements retained. *Journal of the Association of Official Agricultural Chemists* 24, 848-854.
- Sampson, A.W., 1944. Plant succession on burned chaparral lands in northern California. *Bulletin of the California Agricultural Experiment Station* 685, 144 pages.
- Smith, A.M.S., Wooster, M.J., Drake, N.A., Dipotso, F.M., Perry, G.L.W., 2005. Fire in African savanna: testing the impact of incomplete combustion on pyrogenic emissions estimates. *Ecological Applications* 15, 1074-1082.
- Smith, D.W., Bowes, G.C., 1974. Loss of some elements in fly ash during old-fields burns in southern Ontario. *Canadian Journal of Soil Science* 54, 215-224.
- Stoof, C.R., Wesseling, J.G., Ritsema, C.J., 2010. Effects of fire and ash on soil water retention. *Geoderma* 159, 276-285.
- Úbeda, X., Pereira, P., Outeiro, L., Martin, D.A., 2009. Effects of fire temperature on the physical and chemical characteristics of the ash from two plots of cork oak (*Quercus suber*). *Land Degradation & Development* 20, 589-608.
- Virgil, 29 B.C. *Georgics Book I*, translated by A.S. Kline, 2002. Available at: <http://www.poetryintranslation.com/PITBR/Latin/VirgilGeorgicsI.htm>, accessed Feb. 10, 2011.
- Wagenbrenner, N.S., Lamb, B.K., Foltz, R.B., Robichaud, P.R., 2010. Modeling post-fire ash and dust emissions in complex terrain, Abstract, American Society of Agricultural and Biological Engineers, June 20-23, 2010, Pittsburgh, Pennsylvania.
- Wattez, J., Courty, M.A., 1987. Morphology of ash of some plant materials, in Fedoroff, N., Bresson, L.M., and Courty, M.A., editors, *Soil Micromorphology*, Proceedings of the VIIIth International Working Meeting on Soil Micromorphology, Paris, France, p. 677-683.
- Whicker, J.J., Pinder, J.E. III, Breshears, D.D., 2006. Increased wind erosion from forest wildfire: Implications for contaminant-related risks. *Journal of Environmental Quality* 35, 468-478.
- 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, 535–548.
- 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* 393, 274-286.
- Young, R.S., Golledge, A., 1948. Composition of woodland soils and wood ash in northern Rhodesia. *Empire Journal of Experimental Agriculture* 16:76-78.



## The contribution of the PHOENIX project centre to post-fire research in Europe

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**Key-words:** PHOENIX project centre; post-fire research; Europe.

### Abstract

Every year, around 45,000 wildfires occur in Europe, burning an area of 500,000 hectares. Between 1995 and 2004, more than 4 million hectares were burned in the Mediterranean Region alone, corresponding to an area larger than the Netherlands.

The post-fire management of burned areas has been given much lesser attention than fire suppression and prevention in Europe. However, important questions raise the public concern and require scientifically-based knowledge: how to accurately evaluate fire damages in economical terms? What are the most suitable short-term intervention techniques to minimise soil erosion and runoff? What to do with burned trees? How to manage burned forests? How to approach the long-term planning for the rehabilitation of burned areas? How to manage fire-prone forests and landscapes to reduce potential fire hazard? On the other hand, wildfires can also be regarded as an opportunity to plan and establish less flammable and more resilient forests and landscapes in the recently burned areas. What information is available on these topics and how should administrations and stakeholders react after large fires? These questions are relevant not only in a southern European perspective, where wildfires are more frequent, but all over Europe. In fact, climate change and land-use trends are expected to increase fire frequency in Central and Northern Europe, and new geographical areas (and forest ecosystems) where wildfires were infrequent are becoming more fire-prone. Thus, further knowledge is needed on how to manage the millions of hectares burned in Europe, including the planning of post-fire management, the short-term intervention techniques to minimise soil erosion and runoff, and the longer-term ecosystem recovery and restoration.

Phoenix is a Project Centre of the European Forest Institute (EFI). It consists of a group of 25 institutions from Portugal, Spain, France, Italy, Greece, Morocco, Tunisia, Turkey and Lithuania, carrying out specific research on fire ecology and, in particular, post-fire management. I will present Phoenix rationale and activities.



## Forest fires as drivers of land degradation in Portugal

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### Abstract

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.

Several research projects have been carried out at CESAM/UA to better understand how forest fires contribute to land degradation and to assess the impact of post-fire techniques on soil degradation mitigation. Another important issue is public involvement in the definition and implementation of sustainable forestry practices.

The main aim of this communication is to present some of the work performed in Portugal, not only the relation between fires and soil erosion, but particularly the potential of some mitigation and prevention approaches and technologies to mitigate soil and water erosion. The activities and results of stakeholders' involvement and the social perception on land degradation after fire will also be discussed.





3<sup>rd</sup> International Meeting of Fire Effects on Soil Properties  
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**COMMUNICATIONS.....**







## Fire-induced changes in soil organic matter stability along a catena on mt. Etna, Sicily

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**Key-words:** forest fires, soil organic matter, charcoal, Mt. Etna, soil catena.

### Abstract

Forest fires are a not negligible factor of pedogenesis in the Mediterranean areas, where they occur frequently. Soil organic matter (SOM) is particularly prone to change due to forest fire, both in terms of quantity and quality. We investigated a soil catena on Mount Etna, north-eastern side of Sicily, Italy, comprising six soils having different types of climate, from subtropical (500 m asl) to subalpine (1800 m asl). Along this altitudinal and climatic gradient there are two main vegetation systems: maquis at the lower sites and coniferous forest at the upper sites. A previous study in the same area revealed an increasing aromaticity of soil organic matter with decreasing altitude, which is probably correlated to more frequent fires at the low elevations, where climate regime is warmer and drier. We hypothesised that fire frequency is increasing with decreasing altitude and that this substantially affects organic matter characteristics and abundance. We consequently focused our work on the fractionation of soil organic matter from different depth into a labile and a stable fraction, carried out by using an H<sub>2</sub>O<sub>2</sub> oxidation treatment. The bulk SOM and the stable fraction of SOM were quantified and characterised by diffuse reflectance Fourier transform infrared (DRIFT). The stable SOM fraction was also radiocarbon dated, so providing indications about its turnover time. Additionally, charcoal in the soil was collected, quantified, the plant species identified using a stereomicroscope and C-14 dated. We found a clear correlation between the aromatic content in the soil and the decreasing altitude confirming the initial hypothesis. The C and N concentration in the bulk soil increased with decreasing altitude, as well as the C stored in charcoal in the topsoil. The relative content of stable SOM is similar in the various soils of the catena, although it slightly decreases with altitude. The mean age of the stable organic fraction varies much in the different soils. In general, an age of a few hundred years is found at low altitudes, whereas at higher altitudes ages up to 8000 years could be measured. Overall, these findings suggest that the high fire frequency at low altitudes is a powerful rejuvenating factor for soil organic matter, removing part of the SOM and promoting plant recolonization.



## The effects of heating a lateritic podzolic soil on soil phosphate availability, a glasshouse study

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**Key-words:** soil heating, soil mineralogy, P availability, dehydroxylation, rehydroxylation.

### Abstract

Soil heating during a bushfire may have significant impacts on soil mineralogical and chemical properties. The availability to plants of native and added P may be substantially affected. The effects of fire on soil characteristics will vary with the duration and intensity of fire, fuel and soil type and these topics deserve further investigation. The lateritic podzolic soil used in this research has a fine fraction dominated by three readily dehydroxylated minerals (kaolinite, gibbsite and goethite) and consequently is particularly sensitive to heating at temperatures that commonly occur in soils heated by bushfires. A glasshouse study was done on the impact on phosphate (P) availability of heating soil minerals in a lateritic podzolic soil. Soil from a forest site was heated at 250, 350 and 500°C which are temperatures that may be experienced by topsoil during bushfires. P-response of annual ryegrass (*Lolium rigidum* Gaud) to the application of several levels of P as monocalcium phosphate (MCP) was also determined. Soil heating caused kaolinite, gibbsite and goethite to dehydroxylate and to partly alter into metakaolinite, amorphous alumina and hematite respectively. Heating increased soil pH and EC due to combustion of soil organic matter, although EC then decreased for 350°C and 500°C heating as soluble salts reacted with soil constituents. Yield of ryegrass decreased with increasing temperature of heating for unfertilized soil and for heated soils supplied with P fertilizer. P concentration in ryegrass for each of three harvests ranged from 0.03% to 0.3% and decreased in the same sequence as for yield (i.e unheated soil > 250°C > 350°C > 500°C heated soil). Heating the soil increased Bic-P and had little effect on the retention of added P as indicated by bicarbonate extraction. However prior heating of soil decreased the agronomic effectiveness of applied P with smaller reductions occurring for lower heating temperatures. Heating at 500°C greatly increased amounts of reactive Si and Al in the soil due to the formation of metakaolinite and amorphous alumina which are highly reactive compounds and are presumably responsible for the reduced effectiveness of the added P fertilizers. Clearly heating of soil by bushfires can reduce the availability to plants of native and added phosphate and forest managers should be aware of this process.



## How does biannual burning alter organic matter in soils of the highland of Southern Brazil?

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**Key-words:** C-sequestration; prescribed fire; Pyrogenic organic C; Soil organic matter quality.

### Introduction

Since the first arrival of European settlers in Brazil, in the highlands of Southern Brazil, burning of grassland after the winter season has been a common agricultural practice to control pests, to remove old grass biomass, to fertilize the soil with nutrient-rich ash and to increase the pH (liming effect) and the concentration of inorganic ions. This fertilizing effect is supported by biological and non-biological processes after and during low intensity burning that transform organic N forms into more available ammonium and nitrate N and increase the amount of dissolved organic matter (Prieto-Fernández et al., 2004). Thus, burning grassland soils often results in earlier grass growth at the beginning of the growing season and greater annual dry matter production (Ojima et al., 1994).

With respect to the size of the SOM pool contradicting effects of fire are reported. For sites in sub-tropical savannah of Zimbabwe (Bird et al., 2000), it was observed that 50 years of fire exclusion increased the soil organic carbon content by 40 to 50%, whereas in tropical savannahs of Northern Australia, exclusion of fire for 15 years or more significantly reduced soil organic carbon (Chen et al., 2005).

Abandoning fire results in a relatively fast change of the SOM nature (Golchin et al., 1997), possibly because of fast invasion of the grassland by forest and due to the lack of new pyrogenic organic matter (PyOM) input. The latter is expected to be a major source of the slow-cycling carbon pool in soils. However, there are indications that PyOM can be degraded at the decadal to centennial time-scale (Bird et al., 1999). Model studies revealed relatively short mean residence times of 14 to 19 years for charred grass residues and up to 56 years for pine wood char (Hilscher et al., 2009). Others showed that charred plant materials are metabolized at a much greater rate in the presence of an easily available C source (glucose) (Hamer et al., 2004). Thus, PyOM may not be as inert as commonly assumed, which leaves some uncertainties regarding its role in the global carbon cycle.

### Objectives

In order to obtain some further insights on the impact of frequent burning on SOM properties, its stocks and its stability, a chronosequence of soils under frequently burnt grassland with increasing time after the last fire was selected from the Campo area of the Planalto in Southern Brazil. In order to identify possible translocation of PyOM within the soil column, the soils were sampled as a function of depths down to 40 cm and analyzed by means of elemental analysis and solid-state <sup>13</sup>C and <sup>15</sup>N NMR spectroscopy. Their PyOM contributions and stocks were quantified from the aromatic-C contents



remaining in the residue after chemical oxidation of the soils with acid dichromate (Knicker et al., 2007).

### Material and methods

The sampled soils are located in the Planalto region, Rio Grande do Sul, Southern Brazil and developed on Basalt. According to the World Reference Base, they are assigned to Leptosols and Umbrisol (IUSS Working Group WRB and World Soil Resources Reports 103, 2006). The samples were taken from the A horizon in depth intervals from 0 to 5 cm, 5 to 10 cm, 10 to 15 cm, 15 to 30 and if possible from the AC and C horizon between 30 to 45 cm. In the Planalto region, biannual burning is practiced before the next growing season (here in August/September). The sampling took place in May 2006, approximately 0.75, 1.75, 4.75 and 21.75 years after the last burning. Correspondingly, the sites are termed C1 (0.75 years), C2 (1.75 years), C5 (4.75 years) and C22 (21.75 years). All soils were classified as clay loam and were under pasture (*Campo*), although some *Araucaria angustifolia* trees had already invaded into the field without burning for 22 years. After air-drying and manual removal of root and plant material, the samples were passed through a 2 mm sieve and the fine earth was dried for further analysis.

Total C, total N and total S were measured in duplicates by dry combustion (975°C) using an Elementar Vario EL microanalyzer and an Elementar VarioMAX macroanalyzer. As all samples were free of carbonate, the measured C concentrations represent the soil organic carbon ( $C_{tot}$ ) concentration.  $C_{tot}$ ,  $N_{tot}$  and S stocks in the different depths regions were calculated for one square meter.

After demineralization with 10% HF-solution (Gonçalves et al., 2003) all soil samples were analyzed by solid-state  $^{13}C$  cross polarization magic angle spinning (CPMAS) NMR spectroscopy with a Bruker DSX 200 NMR spectrometer operating at a resonance frequency of 50.32 MHz (Lehrstuhl für Bodenkunde, TU-München, Germany) applying the parameter set-up described by (Knicker et al., 2005).

To determine the content of PyOM, the HF-treated samples were oxidized with 40 ml of 0.1 M  $K_2Cr_2O_7$ / 2 M  $H_2SO_4$  solution at 60°C in an ultrasonic bath for 6 hours (Knicker et al., 2007). For quantification of the pyrogenic organic C (PyOC), the aromatic C content of the chemical oxidation resistant elemental C ( $COREC_{arom}$ ) was determined by solid-state  $^{13}C$  NMR spectroscopy and multiplied with a correction factor  $f$  to account for PyOC losses induced by the chemical oxidation (Knicker et al., 2008). This correction factor was yielded by calculating the contribution of  $COREC_{arom}$  to the total C of charcoal produced from native vegetation at the study site.

### Results and Conclusions

Exclusion of fire resulted in a considerable decrease of the organic C-stocks, whereas N and S stocks were only slightly affected. This leads to a decline of the C/N ratios (w/w) at all soil depth with increasing time after the last fire. However, with depth the C/N ratios (w/w) increased slightly for all soils.

All spectra of the top 5 cm are dominated by signals in the region of O-alkyl C deriving mostly from carbohydrates. Whereas within the first 5 years after ceasing burning no major alterations of the SOM composition are apparent, 22 years recovery time were sufficient to increase the alkyl C contribution at the expense of O-alkyl C. Because a vegetation change was not evident, this is best explained with declining input of fresh plant litter.

Calculating the aromatic C stocks in this soil region, an increase from 0.66 kg m<sup>-2</sup> in C22 to 0.96 kg m<sup>-2</sup> in C2 and 0.8 kg m<sup>-2</sup> in C1 was yielded. The aromatic C stocks, however,



can only account for less than half of the increase of the C-stocks in the top 5 cm due to fire application. Correspondingly, additional C-sources must have contributed to the observed C-accumulation. According to the NMR data these are O-alkyl C structures. From those observations, it can be concluded that the fire management affected the more stable C pool by the production of charred residues but at the same time enlarged the more labile SOM pool by enhancing the input of fresh and unburned litter.

With increasing soil depths the O-alkyl C contents decrease concomitantly with a slight increase of the carboxyl-C concentration, which evidences progressive degradation of SOM. At all sites, the aromatic-C stocks are slightly declining with soil depths. In the region between 10 and 30 cm, we found no indications for major fire-induced changes of the amounts of aromatic C.

Oxidation with acid dichromate of the top layer soils revealed unexpected low PyOC contributions of less than 9% of  $C_{tot}$ . A comparable observation was made for the layers down to 15 cm. With increasing time periods since the last fire, the contribution of PyOC to  $C_{tot}$  clearly decreased for the top 5 cm. In the deeper soil regions PyOC contributions increased from 8 to 19% of  $C_{tot}$ . Because it is unlikely that in the studied subsoil regions the temperature was high enough for char production, this is a clear indication that char residues were transported through the soil profile.

Calculating the decrease of PyOC stocks as a function of time since the last fire, it was revealed that comparable to fire-unaffected SOM, PyOM is composed of fractions with different stability against microbial degradation. Whereas the labile PyOM fraction showed C-losses similar to that of O-alkyl C, the more stable PyOM fraction was selectively preserved together with an alkyl fraction.

In summary, our study demonstrated that frequent burning of grassland can indeed lead to an increase of the C-sequestration potential of a soil. However, since most of the additional material derives from fresh plant litter, this additional SOM belongs to the labile C-pool with short turn-over times. In addition, our study confirmed that PyOM can contain fractions with turnover rates comparable to fire-unaffected SOM. Thus, charcoal input or prescribed burning of grasslands can increase the C stocks but does not necessarily enlarge the stable SOM fraction to a higher extent. This certainly has some important implication for C-cycling models.

The fact that charcoal can be attacked and oxidized by microorganisms can also explain the observation that PyOM can be translocated by the soil solution and accumulates in subsoils. In our soils this was indicated by an increase in the aromaticity with soil depth. Such increase has been observed in other Brazilian soils, too (Dick et al., 2005; Dieckow et al., 2005). Considering the frequent occurrence of fires in some regions and the fact that prescribed burning has always been a common land management practice, those aromatic structures may be relicts of former fires that leached into and accumulated in the subsoil.

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## References

- Bird, M.I., Veenendaal, E.M., Moyo, C., Llyod, J. and Frost, P., 2000. Effect of fire and soil texture on soil carbon in a sub-humid savanna (Matopos Zimbabwe). *Geoderma*, 94: 71-90.
- Bird, M.I., Veenendaal, E.M., Moyo, C., Lloyd, J. and Frost, P., 1999. Stability of elemental carbon in a savanna soil. *Global Biogeochemical Cycles*, 13: 923-932.
- Chen, X., Hutley, L.B. and Eamus, D., 2005. Soil organic carbon content at a range of north Australian tropical savannas with contrasting site histories. *Plant and Soil*, 268: 161-171.
- Dick, D.P. et al., 2005. Characteristics of soil organic matter in top- and subsoils of different Brazilian Ferralsols under native vegetation. *Geoderma*, 124: 319-333.
- Dieckow, J. et al., 2005. Composition of organic matter in a subtropical Acrisol as influenced by land use cropping and N fertilization, assessed by CPMAS <sup>13</sup>C NMR spectroscopy. *European Journal of Soil Science*, 56: 705-715.
- Golchin, A. et al., 1997. The effects of vegetation and burning on the chemical composition of soil organic matter in a volcanic ash soil shown by <sup>13</sup>C NMR spectroscopy. I. Whole soil and humic acid fraction. *Geoderma*, 76: 155-174.
- Gonçalves, C.N. et al., 2003. The effect of 10% HF treatment on the resolution of CPMAS <sup>13</sup>C NMR spectra and the quality of organic matter in ferralsols. *Geoderma*, 116: 373-392.
- Hamer, U., Marschner, B., Brodowski, S. and Amelung, W., 2004. Interactive priming of black carbon and glucose mineralisation. *Organic Geochemistry*, 35: 823-830.
- Hilscher, A., Heister, K., Siewert, C. and Knicker, H., 2009. Mineralisation and structural changes during the initial phase of microbial degradation of pyrogenic plant residues in soil. *Organic Geochemistry*, in press.
- IUSS Working Group WRB, W.r.b.f.s.r. and World Soil Resources Reports 103, F., Rome., 2006. World Reference Base for Soil Resources. World Soil Resources Reports 103. FAO, Rome.
- Knicker, H., Müller, P. and Hilscher, A., 2007. How useful is chemical oxidation with dichromate for the determination of "Black Carbon" in fire-affected soils? *Geoderma*, 142(1-2): 178-196.
- Knicker, H., Totsche, K.-U., Almendros, G. and González-Vila, F.J., 2005. Condensation degree of burnt peat and plant residues and the reliability of solid-state VACP MAS <sup>13</sup>C NMR spectra obtained from pyrogenic humic material. *Organic Geochemistry*, 36: 1359-1377.
- Knicker, H., Wiesmeier, M. and Dick, D.P., 2008. A simplified method for the quantification of pyrogenic organic matter in grassland soils via chemical oxidation. *Geoderma*, 147: 69-74.
- Ojima, D., Schimel, D.S., Parton, W.J. and Owensby, C.E., 1994. Long and short-term effects of fire on nitrogen cycling in tallgrass prairie. *Biogeochemistry*, 24: 67-84.
- Prieto-Fernández, A., Carballas, M. and Carballas, T., 2004. Inorganic and organic N pools in soils burned or heated: immediate alteration and evolution after forest wildfires. *Geoderma*, 121: 291-306.



## Mineralogical and chemical changes in a lateritic soil due to a bushfire in the darling range, Western Australia

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**Key-words:** Synchrotron XRD, soil mineralogy, extractable, dehydroxylation.

### Abstract

Heating of soil during a fire which burns litter and fallen timber can raise surface soil temperature to 500°C or more and may significantly impact on soil properties. Many soil minerals are affected by heating in natural and managed fires. The effects of soil heating on the mineralogy of soil have not been extensively studied although quite modest (250°C) temperatures affect minerals. Laboratory studies have shown that kaolinite decomposes at temperatures between 450°C and 700°C losing lattice water and formed metakaolinite. Gibbsite alters to an amorphous phase and boehmite on heating at ≈200°C, and goethite is transformed to a disordered mineral known as hydro-hematite at ≈300°C. The possibility that these dehydroxylated compounds persist in soils heated in bush fires is unresearched and is the subject of this investigation. Samples were collected shortly after a bushfire at Wundowie in the Darling Range, Western Australia in early March 2009. Samples were removed as a 1cm thick soil layer from under burnt Eucalyptus and grass tree (*Xanthorrhoea pressii*) logs from up-slope and down slope sites in a lateritic colluvium catena. The soils are very gravelly and were sieved to obtain the <2mm fraction for analysis. Conventional and synchrotron XRD patterns of heated and unheated soil from the Wundowie bushfire site show the effect of fire on soil minerals. The main crystalline compounds of unheated soil are quartz, kaolinite, gibbsite and goethite. The XRD patterns of heated soil show that kaolinite dehydroxylated into metakaolinite, gibbsite altered into an amorphous phase, while goethite transformed into hematite (hydrohematite). Quartz was unaltered. The bushfire was added calcite in plant ash to the soil. The addition of ash during the fire has considerably increased the pH of all soil samples relative to the original. Soil EC values also increased substantially after the bushfire with values for the heated soil being considerably higher than for unburnt soil. The increases in EC simply reflect the addition to the soil of soluble salts in plant ash. Heating had increased amounts of extractable Al, Fe and Si due to crystalline minerals becoming amorphous. Clearly dehydroxylated minerals and possibly their rehydroxylated forms must be present in naturally heated soils and may exert significant effects on the chemical behaviour of the soil. This topic deserves further investigation as amorphous compounds are chemically reactive and may affect soil fertility.



## Fire severity effects on ash chemical composition and extractable elements

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**Key-words:** Ash colour; fire severity; chemical properties; Landscape recuperation after the fire.

### Introduction

Fire severity was a term born from the necessity of describes the effects of fires, especially wildland fires in the landscape, where the information about fire intensity is not available (Keeley, 2009). Several methods have been developed to measure fire severity on the ecosystems as the diameter of the twigs and branches (Moreno and Oechel, 1989), loss of litter mass (Úbeda et al., 2009), crown consumption (Vega et al., 2008), plant mortality (Larson and Franklin, 2005), fine fuel consumption (Matt Davies et al., 2010), aerial fotos (Brais et al., 2000) and satellite images (Miller et al., 2009) and related with changes in soil properties (Keeley, 2009). Ash colour is a very useful and non expensive methodology to estimate fire severity as observed elsewhere (Pereira et al., 2010). Ash colour gives an indirect estimation of the degree of fire organic matter consumption. Is widely known that black ash is an evidence of a low fire severity and grey/white ash of high fire severity, and are indirect estimators of low and/or high temperature. However, ash colour variation according with the temperature is more complex as observed by Úbeda et al. (2009).

The effects of fire in ash properties (e.g colour) determine the amount and availability of nutrients content and leachable. However little is known about the effects of fire severity on ash chemical composition and soluble elements. This is of major importance because after the fire it is important to know the amount of nutrients available for ecosystem recuperation, especially in wildfires where, normally, fire severity is higher. The aim of this work is study the effects of fire severity on ash chemical composition and extractable elements.

### Methodology

Ash was collected in three wildfires occurred in Lisbon region in forests dominated by *Pinus pinaster* and *Quercus suber*. Wildfires occurred in the end of July 2008 and total of 102 samples were collected between 2 and 5 days after the wildfire placed in plastic bags and taken to laboratory. Subsequently, samples were pulverized with Frich Pulverizate 23 for about 2 min in order to homogenize the sample to analyse the ash colour. To classify ash colour we used the Munsell color chart (Úbeda *et al.*, 2009). Ash colour was classified according the criteria: very dark brown ash was considered when 10 YR 2/2, black when 10 YR 2.1, very dark grey when 10 YR 3/1, dark grey when 10 YR 4/1 and light grey when 10 YR 6/1 and 10 YR 7/2. The fire severity follows the increasing order, very dark brown ash, black ash, very dark grey, dark grey and light grey. The



methodologies of laboratory work used in the analysis of Calcium carbonate ( $\text{CaCO}_3$ ), pH, TN%, TC% and extractable elements Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Total Phosphorous (TP), Total Sulphur (TS) and Silica (Si) are described in Pereira et al. (2010).

Previous to data comparison we tested normality with the Kolomogorov-Smirnov test and homogeneity of the variances with the Brown-Forsythe Test. Data normality and homogeneity were considered at a  $p > 0.05$ . The majority of the data did not respect the criteria of normality and homogeneity, and only after a box-cox transformation were achieved. After this step we applied the parametric ONE-WAY ANOVA test, considering ash colour as predictor and the remains as dependent variables. If significant differences were founded at a  $p < 0.05$  we applied the post-hoc Fisher LSD test to identify significant differences between ash colour in each element in study. Also, differences were considered significant at a  $p < 0.05$ . Statistical analyses were carried out with Statistica 7.0 (Statsoft.).

### Results and conclusions

The majority of the ash colour identified was dark grey (32.35%), followed by very dark grey (26.47%), black (22.55), light grey (13.73%) and very dark brown (4.90%) which means that were mainly produced at mean-high severity (Pereira et al., 2010). The results of the ash chemical composition and extractable elements are shown in the table 1. We identified in all cases significant differences among elements concentration and leached between ash colours. Ash  $\text{CaCO}_3\%$  was higher light grey ash (32.47) and lower in very dark brown (1.54). The opposite dynamic was identified in ash TN% were the higher % was identified in very dark brown (1.67) and the lower in light grey ash (0.87). The same behaviour was identified TC% and C/N, where the major values were identified in the ash produced at lower temperatures, 46.04 for TC% and 32.64 for C/N and lower in the ash produced at higher temperatures, 17.82% for TC% and 19.47% for C/N. pH values are higher in light grey ash (8.18) and lower in very dark brown ash (7.34).

In relation to extractable elements, we did not observe a linear decrease or increase with fire severity (Table 1). It was extracted higher quantities of Ca from black ash (5553.32 mg/l) and lesser from dark grey ash (4014.85 mg/l). The same dynamic was observed in Mg, however the amount extracted was much less than the in the case of Ca. On average, black ash released in solution 1417.61 mg/l and dark grey 1075.39 mg/l. The monovalent cations showed a different behaviour. Na concentration was higher in the extracts from very dark grey ash (1920.62 mg/l) and lower in very dark brown ash (1226.76 mg/l) and K presented higher quantities on the solutions produces with black ash (3609.42 mg/l) and lower in the solutions from light grey and very dark brown ash, 2524.65 mg/l and 2521.45 respectively. Extractable TP was in higher concentrations in very dark brown ash (506.76 mg/l) and lower in light gray ash (86.24 mg/l). Extractable TP showed an opposite dynamic. The major concentrations of this element on solution were founded in light grey ash (1958.78 mg/l) and lower in very dark brown ash (979 mg/l). Si showed higher concentrations in the extracts from very dark grey ash (1375.96 mg/l) and lower in light grey ash (910.76 mg/l).

The findings in this study showed that there is a clear increase in the content of ash  $\text{CaCO}_3\%$ , pH and extractable TS with the fire severity and a decrease in TC%, TN%, C/N, TP. In the remaining elements, we observed a major concentration of Ca, Mg and Na in the extracts of black ash and K and Si in the solutions produced from very dark grey ash. The results obtained in this work shown that the amount of elements in ash depends on the fire severity. The difference of nutrients release on soil surface by each

ash type will have heterogeneous impacts on soil properties. In addition the amount and type of nutrients available for landscape recuperation depend strongly of fire severity. From our results, the increasing fire severity had important implications on the amount of Carbon and Nitrogen budgets however increase organic matter mineralization which induces a major availability of the nutrients to be leached. This is one of the causes of the increase of the solubility of some nutrients in black and very dark grey ash (e.g Ca, Mg, K and Si). The reduction of TP in solution with the temperature is very likely because this element precipitate easily at high pH levels and bind in CaCO<sub>3</sub> surfaces. The reductions of the bivalent and monovalent cations are also triggered by the presence of CaCO<sub>3</sub> surfaces and pH that induce a complex dynamic in the amount and type of elements in solution (Pereira, 2010).

**Table 1.** Concentration of CaCO<sub>3</sub>%, TN%, C/N ratio, pH and extractable Ca, Mg, Na, K, TP, TS and Si according ash colour Extractable elements in mg/l. p, significance level of the ANOVA one way test.

Differences significant at a  $p < 0.05^*$ ,  $< 0.01^{**}$  and  $< 0.001^*$ . Different letters represent significant differences at a  $p > 0.05$  (a= higher mean, b=lower mean) identified with the Fisher LSD test.  $N=102$ . n.d (not determined).

Element	P	Colour	Mean	Minimum	Maximum	S.D	CV%
CaCO <sub>3</sub> %	***	Very dark brown	1.54e	n.d	3.05	1.68	109.09
		Black	5.58d	1.27	10.99	2.65	47.49
		Very dark grey	11.08c	4.31	17.40	3.70	85.84
		Dark grey	19.29b	15.40	24.87	2.83	18.37
		Light grey	32.47a	26.67	10.99	6.03	22.60
TN%	***	Very dark brown	1.67a	0.87	2.43	0.75	44.91
		Black	1.54a	0.68	2.64	0.62	40.25
		Very dark grey	1.30ab	0.30	2.37	0.51	39.23
		Dark grey	1.16b	0.46	2.12	0.40	34.48
		Light grey	0.87c	0.44	1.31	0.30	34.48
TC%	***	Very dark brown	46.04a	37.16	53.43	6.31	13.70
		Black	39.57a	17.77	57.52	13.56	34.26
		Very dark grey	29.38b	9.92	64.87	12.81	43.60
		Dark grey	25.02b	7.27	46.53	10.24	40.92
		Light grey	17.82c	5.07	46.15	10.76	60.31
C/N	***	Very dark brown	32.64a	18.91	54.43	15.25	46.72
		Black	27.19a	18.22	58.46	8.73	32.11
		Very dark grey	23.46b	11.04	35.40	6.29	28.81
		Dark grey	21.36bc	13.74	31.32	4.85	22.71
		Light grey	19.47c	11.39	42.15	7.69	39.49
pH	***	Very dark brown	7.34d	6.93	7.61	0.26	3.54
		Black	7.44d	6.53	8.20	0.44	5.91
		Very dark grey	7.79c	7.04	8.30	0.31	3.97
		Dark grey	7.96b	7.52	8.28	0.19	2.38
		Light grey	8.18a	7.82	8.64	0.21	2.56
Ca	**	Very dark brown	5063.54ab	2577.90	7308.19	1757.60	34.71
		Black	5553.32a	1295.81	12695.04	2931.95	52.79
		Very dark grey	4760.31b	1969.23	11566.26	2177.51	45.75
		Dark grey	4014.85c	1813.05	7191.78	1355.55	33.76
		Light grey	4883.51b	25267.67	10270.21	2196.19	44.97



**Table 1.** (Continuation)

Element	p	Colour	Mean	Minimum	Maximum	S.D	CV%
Mg	**	Very dark brown	1088.39b	517.96	1789.57	470.78	43.25
		Black	1418.61a	347.60	4036.32	745.78	52.57
		Very dark grey	1165.54b	396.54	1978.68	443.94	38.08
		Dark grey	1075.39b	495.91	1811.38	396.99	36.91
		Light grey	1151.63b	605.75	1771.70	387.89	33.68
Na	**	Very dark brown	1226.76c	612.94	1995.47	501.43	40.87
		Black	1909.98a	572.32	3181.11	712.73	37.33
		Very dark grey	1920.62a	442.36	3985.95	786.42	40.94
		Dark grey	1747.07ab	426.99	3109.91	718.21	41.11
		Light grey	1714.98b	289.72	2815.30	730.77	42.61
K	*	Very dark brown	2521.45b	768.48	4324.89	1406.93	55.80
		Black	3609.42a	639.04	10773.18	2180.84	60.42
		Very dark grey	2655.42b	311.39	4965.42	1001.25	37.71
		Dark grey	3266.89a	397.93	13355.00	2715.01	83.10
		Light grey	2524.65b	575.98	7697.92	1876.99	74.34
TP	***	Very dark brown	506.76a	5.89	936.26	341.08	67.30
		Black	407.87a	6.19	850.42	281.54	69.03
		Very dark grey	239.99b	9.47	1073.55	270.51	112.71
		Dark grey	163.54b	5.57	958.22	215.67	131.87
		Light grey	86.24c	4.68	245.60	69.42	80.49
TS	**	Very dark brown	979.13d	744.32	1719.19	420.63	42.95
		Black	1370.37c	638.00	4430.08	733.02	53.49
		Very dark grey	1741.08b	728.65	6426.79	1311.84	75.34
		Dark grey	1666.71b	728.65	2573.78	545.65	32.73
		Light grey	1958.78a	1134.66	5832.47	1150.14	58.71
Si	*	Very dark brown	929.71bc	598.09	1491.13	345.35	37.14
		Black	1351.36a	473.02	5388.87	948.63	70.19
		Very dark grey	1375.96a	232.24	3460.39	881.32	64.05
		Dark grey	1165.40b	224.76	2305.09	469.50	40.28
		Light grey	910.76c	349.32	1412.76	273.72	30.05

## References

- Keeley, J.E. (2009) Fire intensity, fire severity and burn severity: a brief review and suggested usage, *International Journal of Wildland Fire*, 18, 116–126.
- Larson A.J., Franklin, J.F. (2005) Patterns of conifer tree regeneration following an autumn wildfire event in the western Oregon Cascade Range, USA, *Forest Ecology and Management*, 218, 25–36.
- Matt Davies, G., Smith, A.A., MacDonald, A.J., Bakker, J.D., Legg, C.J. (2010) Fire intensity, Fire severity and ecosystem response in heathlands: factors affecting the regeneration of *Calluna vulgaris*, *Journal of Applied Ecology*, 47, 356–365.
- Miller, J.D., Safford, H.D., Crimmins, M., Thode, A.E. (2009) Quantitative evidence for increasing forest fire severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA, *Ecosystems*, 12, 16–32.



- Moreno, J.M., Oechel, W.C. (1989) A simple method for estimating fire intensity after a burn in California chaparral, *Acta Oecologica*, 10, 57–68.
- Pereira, P. (2010) Effects of fire intensity in ash chemical and physical characteristics of Mediterranean species and their impact in water quality, Phd thesis.
- Pereira, P., Bodi, M., Úbeda, X., Cerdà, A., Mataix-Solera, J., Balfour, V., Woods, S. (2010) 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.
- 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.
- Vega, J.A., Fernández, C., Pérez-Gorostiaga, P., Fonturbel, T. (2008) The influence of fire severity, serotiny, and post-fire management on *Pinus pinaster* Ait. Recruitment in three burnt areas in Galicia (NW Spain), *Forest Ecology and Management*, 256, 1596–1603.



## Quantifying the intensity of prescribed fire in degraded pine forest and pine-oak forest, Nam Nao national park, Thailand

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**Key-words:** Fire behavior, Degraded pine forest, Pine-oak forest, Fuel loads.

### Introduction

Fires have long been, and continue to be, the significant shaping force in many forest ecosystems of the world (Pyne, 1995). The fire-related changes associated with different frequencies and severities of burning produce diverse responses in the soil, water, flora and faunal components of ecosystems. Anthropogenic burning has become a common phenomenon throughout Thailand's forest including pine-related forest ecosystem (Akaakara, 2000). This ecosystem is usually found on poor, well-drained soils in the North and North-east of the country. Pine usually grows either in pure stand, so called "pine forest community", or grows together with xerophytic deciduous broadleaves tree species, so called "pine-dipterocarp forest community" and "pine-oak forest community". Although pine forest is fire-dependent ecosystem, the resistant ability depends largely on burning severity, burning intensity and burning frequency (Goldammer and Penafiel, 1990). An inappropriate burning regime, especially too much fires in this forest ecosystem, therefore, have long been affected plant species composition and nutrient dynamics, thereby resulting in ecosystem degradation. Therefore, numbers of degraded pine forests have observed, especially at Phu Kum Khao, Nam Nao national park. Efforts for forest fire prevention and control in this degraded forest have been launched by means of budget and equipments. Unfortunately, the fundamental knowledge necessity for forest fire management policy for this area, i.e. fuel dynamics, fire intensity and severity, have not been well investigated.

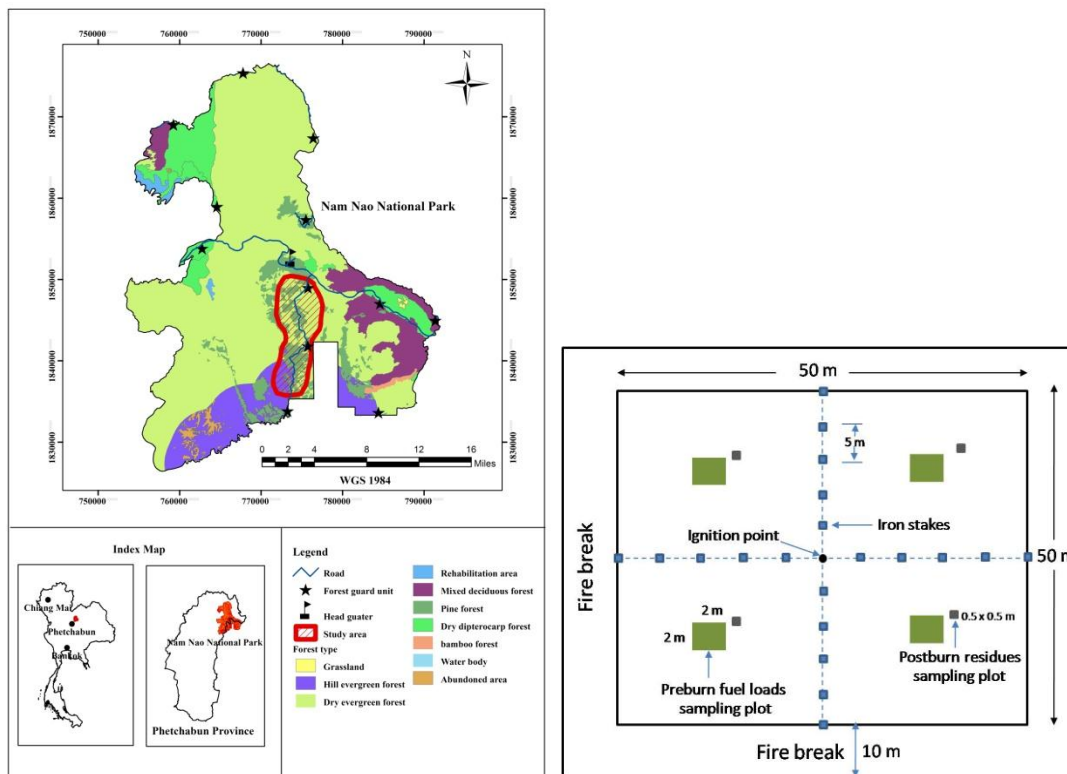
### Objectives

This study aimed to investigate fuel properties, fire behavior characteristics as well as soil temperatures during prescribed fire in degraded pine forest (PF), and pine-oak forest (O-PF) at Phu Kum Khao, Nam Nao national park, Thailand.

### Methodology

Three 50×50 m plots were set up for each sub-community. Prior to burning, fuel properties including fuel type, fuel loads, fuel arrangement and coverage were estimated from four 2×2 m subplots located systematically within the plot. Fire was ignited at the center of the plot to allow free burning. Fire behavior descriptors, i.e. fire intensity was calculated using Byram's (1959) formula. Fire and soil temperature were also recorded throughout the plot. Immediately after the fire, four 50×50 cm subplots were set up to determine the residues left after burning, including ash, charcoal and unburned material.





**Figure 1.** Location of Nam Nao National Park and plot layout for fuel and residue determination and burning pattern.

## Results and conclusions

The study revealed that the main fuel proportion in PF stand was grass (45%) and litter (44%), whereas leaf litter was the most importance source of fuel in O-PF stand (55%), followed by twig (17%) and grass (16%), respectively. Frequent fire, as occur in PF site, favour the grasses, which are well adapted to the regular occurrence of fire. This study was consistent with the study of Wanthongchai (2008), who reported an increases of grass in the forest where annual fire occurs. Obviously, the aboveground fuel loads in PF (12.9 ton/ha) is higher than that of the O-PF (8.7 ton/ha). The relative fuel consumption from burning in the PF stand was significantly high (72%), compared to only 29% of pre-burn fuel load consumed by fire on the O-PF stand (**Table 1**). Fine fuel such as grass and litter ignite readily, and the abundance and homogeneity of the grass fuels allowed for more complete burned.

All fire descriptors, including the rate of spread, flame height, fire intensity, and fire and soil temperature were influenced by fuel loads, types and fuel arrangement, as reflected by fuel consumption. Obviously, fire behavior characteristics in the PF were significantly greater than that of the O-PF (**Table 2**). According to fire intensity classification by Cheney (1994) burning was classified as a low-intensity fire for the O-PF ( $47.9 \text{ kW}\cdot\text{m}^{-1}$ ), while burning in PF was classified as medium-intensity fire ( $626.7 \text{ kW}\cdot\text{m}^{-1}$ ). However, Sutthichart (1996) reported that fire intensity for prescribed burning at pine forest, Phu Kradaung national park was  $3940 \text{ kW}\cdot\text{m}^{-1}$ , and flame length was 2.42 m. This contrasting result has demonstrated the influence of different fire environments, i.e. fuel, weather and topography on fire behavior (Chandler *et al.*, 1983). Fire behavior in this study, however, exhibited great spatial and temporal variation either within or between plots, depends on the burning spread direction and fuel properties. During burning experiment, the surface soil temperatures at all sites were higher than  $100 \text{ }^\circ\text{C}$ . However, fire did not cause in

temperature changes at deeper soil layers, especially at 5 and 10 cm depths (**Figure 2**). Based on this study, fire intensity may be too low to create surface soil temperatures of sufficient duration to heat the lower soil layers. In addition, it could recommend that fire management tools and strategies should be well-prepared to cope with wildfire in degraded pine forest.

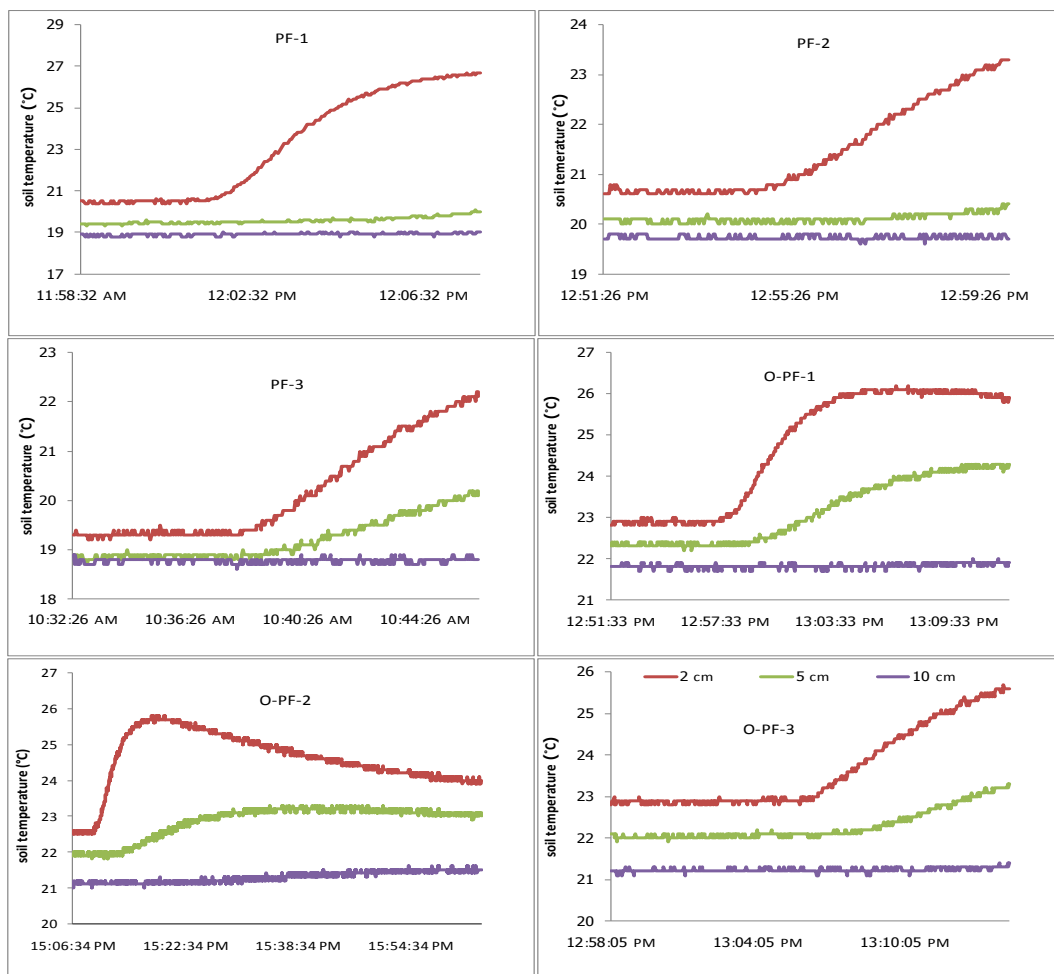
**Table 1.** Pre-burn fuel loads, post-burn residues and fuel consumption.

Site	Preburn fuel loading (t/ha)	Postburn residues			Fuel consumed (t/ha)	% Fuel consumed
		Ash	Charcoal	Unburned material		
PF	12.92	1.67	0.99	1.01	9.25	71.54
O-PF	8.72	1.16	1.57	3.23	2.75	28.53

**Table 2.** Quantitative fire behavior characteristics recorded for experimental fires.

Fire characteristics	Sub-community <sup>1</sup>	
	PF	O-PF
Rate of spread (m.min <sup>-1</sup> )	2.19 <sup>a</sup>	0.54 <sup>b</sup>
Flame height (m)	1.34 <sup>a</sup>	0.39 <sup>b</sup>
Flame length (m)	1.42 <sup>a</sup>	0.44 <sup>b</sup>
Fireline intensity (kW.m <sup>-1</sup> )	626.64 <sup>a</sup>	47.87 <sup>b</sup>
Heat release per unit area (kJ.m <sup>-2</sup> )	288.61 <sup>a</sup>	85.80 <sup>b</sup>

**Remark:** <sup>1</sup> different letters (a, b) indicate significant differences (*t*-test) at the 95% confidence interval.



**Figure 2.** Soil temperatures recorded by thermocouple data loggers for each burning plot.



## References

- Akaakara, S., 2000. Forest fire control in Thailand. Royal Forest Department, Bangkok.
- Byram, G.M., 1959. Combustion of forest fuels. In: Davis, K.P. (Ed.), Forest fire; control and use. McGraw-Hill, New York, pp. 61-89.
- Chandler, C., Cheney, P., Thomas, P., Trabaud, L., Williams, D., 1983. Fire in forestry, volume I. Forest fire behavior and effects. John Willey & Sons, Inc., New York.
- Cheney, P., 1994. The effectiveness of fuel reduction burning for fire management. In, Proceedings of fire and biodiversity: The effects and effectiveness of fire management. Dept. of the Environment, Sport and Territories, Canberra, Footscray, Melbourne, pp. 9-16.
- Goldammer, J.G., Penafiel, R.S., 1990. Fire in the pine-grassland biomes of tropical and subtropical Asia. In: Goldammer, J.G. (Ed.), Fire in the tropical biota : ecosystem processes and global challenges. Ecological Studies no. 84. Springer-Verlag, Berlin, pp. 45-62.
- Pyne, S.J., 1995. World fire : the culture of fire on earth. Holt, New York.
- Sutthichart, K., 1996. Impact of Fire on Soil and Plant at Phu Kradung National Park. In, Silviculture. Kasetsart University, Bangkok, p. 88.
- Wanthongchai, K., 2008. Effects of different burning frequencies on fire behaviour, nutrient dynamics, soil properties, and vegetation structure and composition in dry dipterocarp forest, Huay Kha Khaeng wildlife Sanctuary, Thailand. In, Ph.D. diss. Institute of Silviculture. The University of Freiburg, Freiburg, p. 190.



## Impact of unprecedented fire intensity on soil physical and chemical properties: the case of the catastrophic Victoria fires of 2009

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**Key-words:** soil heating, soil water repellency, fire intensity, burn severity, fire behaviour.

### Abstract

The catastrophic wildfires near Melbourne in 2009 occurred during unprecedented extreme fire weather when dry northerly winds gusting up to 100 km/h coincided with the highest temperatures ever recorded in this region. These conditions, combined with the high fuel loads of mostly long-unburnt eucalypt forests, very low fuel moisture content and steep topography, led to unprecedented fire intensity. Here we report outcomes of a rapid response project, launched to determine the effects of this extreme event on selected physical and chemical properties. Three replicate sites each were sampled for extremely high burn severity and high burn severity (as determined by vegetation destruction), and four sites to represent long unburnt control terrain, within mature mixed-species eucalypt forests in April 2009 near Marysville, ~80 km NE of Melbourne. Additional exploratory sampling was carried out in 'rainforest'. Ash (where present) and surface soil (0-2.5 cm and 2.5-5 cm) were collected at 20 sample grid points at each replicate site. Long-unburnt sites were sampled for fuel load and control soil. Sample analysis included organic carbon and metal content, particle size, aggregate stability, water repellency and seed bank survival. Despite the apparent extreme intensity and severity of the fire, its impact on physical and chemical properties of the soils sampled was very limited. Field and laboratory data suggest that heat input to the soil was less than might be supposed given the extreme fireline intensity of >70,000 kW/m reported for this event. Our data indicate that soil temperatures at the surface and in the top 0-2.5 cm did not exceed ~200°C. The comparatively limited heating of the soil stands in stark contrast to the extreme fire intensity and degree of vegetation destruction. Whilst this fire event has been extreme in many respects, the heat input into the ground, and the associated impacts, appear to have been limited. We speculate that this is a result of an unusually fast-moving fire front associated with the extreme wind speeds, causing a particularly short fire-residence time. Here we (i) present some of the data collected, (ii) discuss the factors that may have contributed to the limited heat penetration into the ground, and (iii) briefly explore the implications of the findings for future fire events that are anticipated under future climatic and land management conditions. The samples collected in this project are available to the scientific community for further investigation.

## Post-fire rill and gully formation, Schultz Fire 2010, Arizona, USA

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**Key-words:** Wildfire; soil erosion; rills; gullies; Schultz Fire.

### Introduction

The Schultz Fire burned 6,100 ha on the eastern slopes of the San Francisco Peaks, a dormant Middle Pliocene to Holocene aged stratovolcano in northern Arizona (Figure 1). The fire burned in the Coconino National Forest between June 20<sup>th</sup> and 30<sup>th</sup>, 2010, across moderate to very steep ponderosa pine and mixed conifer watersheds. About 40% of the fire area was classified as high-severity, mostly on mountain slopes greater than 30% and in places exceeding 100%. The upper slopes rise to over 3,300 m and are the source for high energy water, coarse sediments, and woody material. A steep gradient of nearly 1,000 m exists from the upper slopes to the base of the lower fans. Summer thunderstorms tend to develop over the mountain due to orographic lifting. Over the course of an active 2010 Monsoon, ranking the fourth highest in rainfall on record, the burned area received numerous precipitation events. The largest event occurred on July 20<sup>th</sup> and was characterized by a peak rainfall of 25 mm in fifteen minutes, resulting in numerous debris flows, historic floods and substantial hillslope erosion. Flood flows were one to two orders of magnitude larger than those produced by similar pre-fire rainfall events.



**Figure 1.** Schultz Fire burned area on the east flank of the San Francisco Peaks, July 2010.

## Objectives

The upper slopes of the San Francisco Peak have gradients range from 60 to >100%. These areas developed unprecedented erosion after the intense July 20<sup>th</sup> storm. The objective of this study was to evaluate the extent and degree of new rill and gully formation, reactivation of old gullies, and how this network contributes to the substantially altered hydrologic response of the upper mountain slopes.

## Methodology

New rill and gully formation were assessed along the Waterline Road using visual and photographic surveys. Long-term measurements are being done by on-the-ground measurements, terrestrial LIDAR, and repeat aerial photography. The first set of photos was taken on October, 27, 2010, at a scale of 1:12,000 by Kenney Aerial Mapping, Phoenix, Arizona. Repeat photography will be done in late September of each year to follow.

## Results and Conclusions

Substantial amounts of soil were eroded out of a newly developed rill and gully system, removing the A horizon and much of the B horizon. Prior to the fire there was a minimal presence of rills or gullies as the soil was protected by a thick O horizon. This protective organic layer burned off during the fire leaving the soil exposed to raindrop impact and erosion. There was widespread occurrence of high severity fire, with some watersheds classified as 70% high severity wildfire. This left most of the soils with moderate to severe water repellency, so surface runoff was extensive. Peakflows from the July 20<sup>th</sup> storm contained high concentrations of ash and topsoil material. Mineral soil loss is estimated to be >10 cm on 2,000 ha of the upper watersheds.

The development of an extensive rill and gully network fundamentally changed the hydrologic response of the upper portions of every catchment (Figure 2). Rills are self-organizing erosion systems characterized by numerous and randomly occurring small channels of only several centimetres in depth and centimetres to tens of metres long.



**Figure 2.** Large rill systems developing on a steep slope (right) and small gully development beginning (left). Schultz Fire, 2010, above the Waterline Road, Coconino National Forest, USA.

Sediment yields increase with increasing slope, rill spacing decreases as slope angle increases, rill patterns show an increased elongation and parallelism on steeper slopes, and hillslope rills tend to be evenly spaced on bare, straight slopes (Favis-Mortlock et al. 2000). Rills on the upper slopes of the San Francisco Peaks within the Schultz Fire perimeter are now 10-20 cm deep into the B and C horizons running the entire length of

slopes. Parallel rills in the right photo of Figure 2 demonstrate the transition from sheet erosion to rill erosion. The rills are 30 to 40 cm apart crossing entire slopes. They are up to 5 cm deep and beginning to coalesce. The rills shown on the left are transitioning to small gullies 20 to 30 cm deep. They are cutting below the ponderosa pine surface root systems and into fragmented and weathered C horizon andesite and dacite. Small lateral gullies that are 50–100 cm deep (Figure 3) merge into now deeply incised main drainage gullies (3–5 m deep) that occupy previous swales in the upper mountain slopes (Figure 4). Despite the elevation and precipitation regime there are no perennial stream channels.



**Figure 3.** Rapidly deepening gullies on the upper mountain slopes of the San Francisco Peaks within the high-severity portion of the Schultz Fire of 2010.

Flood flows in July and August of 2010 incised deeply into the slopes consisting of volcanic colluvial material and ash and tephra deposits. In many places the gullies have cut down to bedrock, thus allowing subsequent flood flows to scour out fresh, unweathered material. The pre-fire slope surface was about 1 m above the individual on the left in Figure 4. The deep incisions of these main drainage gullies has lowered the base level of the smaller lateral gullies, leading to additional headward cutting of the gully system.



**Figure 4.** Deeply incised (3 m) main drainage gully within the Schultz Fire along the Waterline Road, Coconino National Forest, Arizona.

Wildfires often produce severe watershed impacts, especially in steep terrain (DeBano et al. 1998, Neary et al. 2008). Interruption of watershed processes results in significantly increased runoff (Ice et al. 2004). The intense, short duration rainfall of the 2010 Monsoon in northern Arizona interacted with slope, water repellency and extensive areas of bare soil to produce flood flows orders of magnitude in excess of flows produced by similar pre-fire rainfall events. These events eroded significant amounts of soil and led to the development of large rill and gully networks. The networks now cover much of the upper mountain. Sediment delivery to the channels is likely to taper off after 3 -5 years, but could increase due and future slope failures.

Crown-replacing wildfires like the Schultz Fire of 2010 have major impacts on the forest ecosystem and hydrology of the Mogollon Rim and the people that inhabit the region. Research will continue on the Schultz Fire for many years to document changes in the landscape and post-fire ecosystem recovery.

## References

- DeBano, L.F.; Neary, D.G.; Ffolliott, P.F. 1998. *Fire's effects on ecosystems*. John Wiley & Sons, New York. 333 p.
- Favis-Mortlock, D.T.; Boardman, J.; Parsons, A.J.; Lascelles, B. 2000. *Emergence and erosion: a model for rill initiation and development*. *Hydrological Processes* **14**: 2173–2205.
- Ice, G.G.; Neary, D.G.; Adams, P.W. 2004. *Effects of wildfire on soils and watershed processes*. *Journal of Forestry* 102:16-20.
- 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.





## Measurement of PM<sub>10</sub> emissions in a post-wildfire environment

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**Key-words:** PM10; ash; dust; post-fire; aeolian transport.

### Introduction

Wind erosion and aeolian transport processes in post-wildfire environments have been less studied than rainfall-induced soil erosion and fluvial transport; however, recent investigations suggest that aeolian processes following a fire can also produce significant negative environmental effects. Burned soils are more susceptible to particle entrainment via wind because fire consumes protective ground cover, destroys naturally occurring soil crusts (Ford and Johnson 2006), induces soil water repellency (Ravi et al. 2006), and decreases aggregate stability (Varela et al. 2010), all of which increase wind erodibility. Blowing dust and ash from burned areas can impact visibility, air quality, soil productivity and nutrient transport. Deposition of wind-blown dust and ash can have implications for water quality and snowmelt processes. Few studies are available which investigate aeolian processes in burned environments; however the research that has been done, suggests that wind erosion can play a major role in burned landscapes. For example, Whicker et al. (2006) measured more than an order of magnitude increase in dust emissions after a high-severity wildfire in northern New Mexico, USA and elevated dust emissions two and three years following the fire due to continuing drought conditions. Blowing dust and ash from the 2007 Milford Flat Fire Complex in Utah, USA caused poor visibility on roadways and resulted in periodic closures of Interstate Highway 15, the major north-south transportation corridor in the state, for months following the fire. This area is still a source of emissions. Dust events in 2008 and 2009 were detectable in satellite imagery and associated with US Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS) exceedances in a populated area over 100 km downwind (Miller et al. 2010).

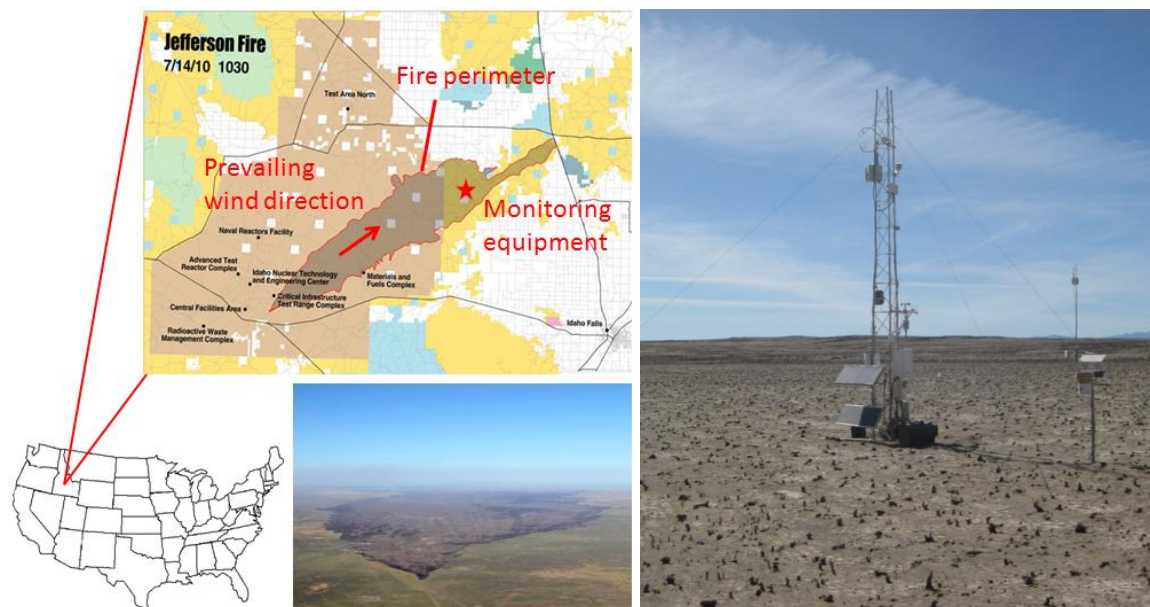
Current wind erosion models are not capable of predicting dust emissions in these burned areas because: 1) little is known about the erosion mechanisms that govern emissions from burned soil and ash; and 2) wind models have not been adapted to predict local terrain effects on winds in the mountainous regions where wildfires often occur. This paper describes initial field results related to a major post-fire dust event that occurred after a wildfire in southeastern Idaho, USA.

### Objectives

The objectives of this research are: 1) to quantify the role of wind erosion and dust emissions in post-fire environments as well as the associated potential impacts on air quality; 2) facilitate a better understanding of the mechanics governing post-fire wind erosion and dust emissions; and 3) create a modeling framework capable of forecasting future post-fire wind events. The specific goal of this paper is to address the first objective by presenting some initial findings regarding dust emissions following a wildfire in southeastern Idaho, USA.

## Methodology

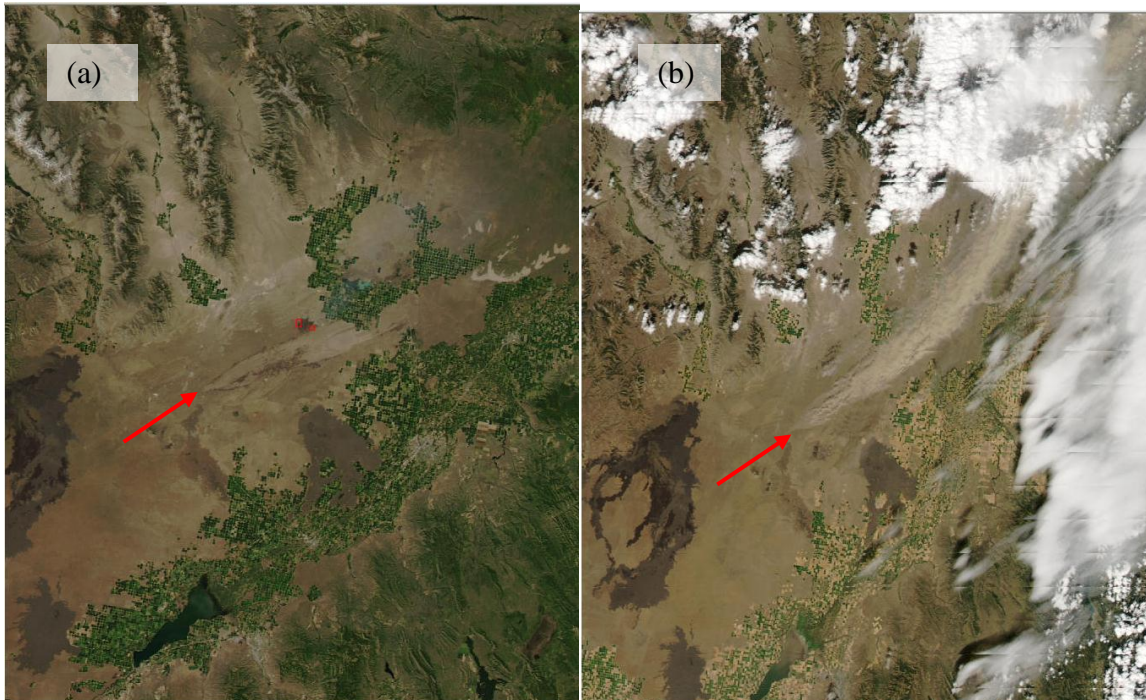
The Jefferson Wildfire burned over 44,000 ha of sagebrush steppe in southeastern Idaho, USA in July 2010. We installed two air quality instrumentation towers in the downwind portion of the burned area in August 2010 (Fig. 1) and monitored the site for three months. Real-time concentrations of particulate matter with a diameter of less than or equal to 10  $\mu\text{m}$  ( $\text{PM}_{10}$ ) were monitored at 2 and 5-m heights at each tower location. Wind statistics were monitored with a sonic anemometer (CSAT3; operated at 10 Hz) at a height of 5 m. Air temperature, relative humidity, solar radiation, precipitation, and soil moisture were also monitored throughout the study period. We limit our discussion in this paper to one specific  $\text{PM}_{10}$  event that occurred during 4-5 September 2010.



**Figure 1.** Left: the location and extent of the Jefferson Fire burned area; the star indicates the location of the site. Right: air quality instrumentation tower installed at the site.

## Results

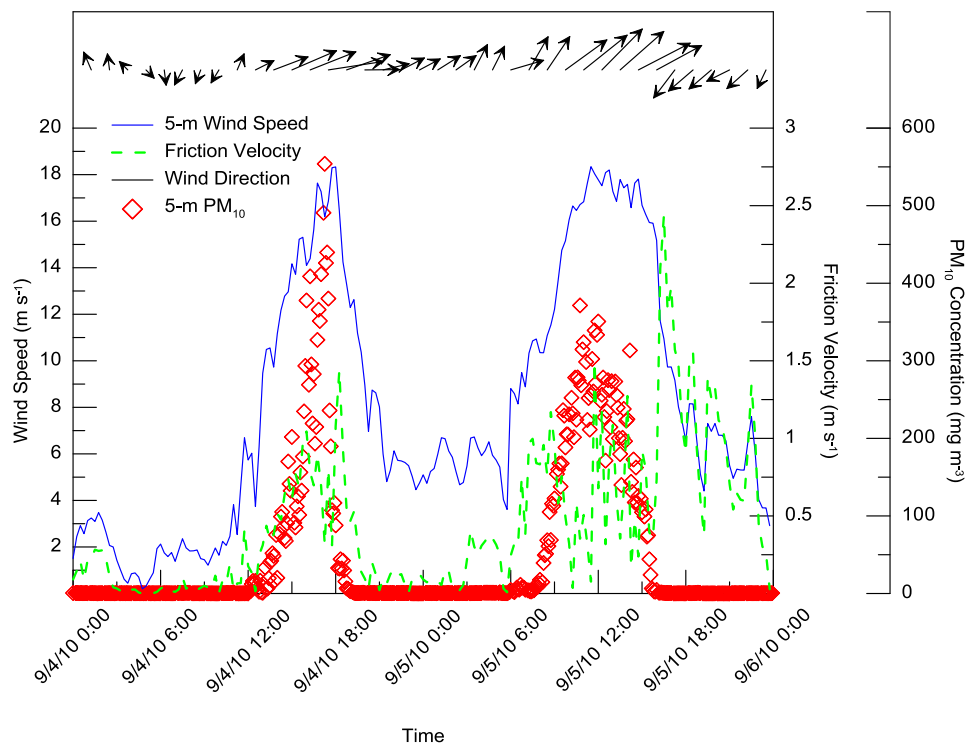
We measured elevated  $\text{PM}_{10}$  concentrations since the fire was contained, but the largest dust event to-date occurred over 4-5 September 2010 during the passage of a frontal system. A dust plume originating from the burned area on 4 September is visible in MODIS imagery and clearly extends 50 to 100 km downwind of the source (Fig. 2).



**Figure 2.** MODIS satellite imagery showing a) the Jefferson Fire burn scar on 19 July 2010 and b) a large dust plume originating from the burned area and extending downwind on 5 September 2010. The arrows indicate the ignition point of the wildfire.

The frontal system had sustained winds of  $18 \text{ m s}^{-1}$  during mid-day and nighttime winds around  $6 \text{ m s}^{-1}$  (Fig. 3). Early morning winds were from the northeast, with the stronger mid-day winds from the southwest. The dust plume visible in the MODIS imagery clearly followed the mid-day wind trajectory. The real-time  $\text{PM}_{10}$  concentration tracked well with the observed wind speed and friction velocity data (Fig. 2).  $\text{PM}_{10}$  concentrations were slightly higher on 4 September than on 5 September, although observed wind speed was not notably different between the two days. One potential difference was the slight shift in wind direction between days; winds were slightly more from the west on 4 September. The change in wind direction could explain some of the difference in  $\text{PM}_{10}$  concentrations at the sampling towers if the area to the west was more erodible than the area to the southwest or if the microtopography was a significant factor.

To our knowledge, this is the first study to report  $\text{PM}_{10}$  concentrations in a post-fire environment. The observed two-day dust event demonstrates that particulate emissions from burned areas can be large and potentially result in both local and downwind impacts. Satellite images depict the areal extent of the dust plume and ground-based  $\text{PM}_{10}$  measurements provide a quantitative account of the dust event on-site. Based on these initial findings, additional research is warranted to better characterize and understand post-fire wind events including particulate emissions and transport and dispersion of post-fire ash and dust. Understanding these processes is crucial for development of a  $\text{PM}_{10}$  model suitable for making predictions of post-fire dust impacts on air quality, nutrient transport, and deposition processes such as effects on snowmelt and chemistry.



**Figure 3.** Observed wind speed, wind direction, friction velocity, and PM<sub>10</sub> concentration for the 4-5 September 2010 event.

## References

- Ford, P.L. and G.V. Johnson. 2006. Effects of dormant- vs. growing-season fire in shortgrass steppe: Biological soil crust and perennial grass responses. *J. Arid Environ.* 67: 1–14.
- Miller, M.E., R.L. Reynolds, H. Goldstein, M.C. Reheis, and J.C. Yount. 2010. Wildfire, land management, and Aeolian processes in dryland ecosystems—Lessons from the Milford Flat Fire. American Geophysical Union Fall Meeting Abstracts, Dec. 2010. No. B33B-0410.
- Ravi, S., P. D’Odorico, T.M. Zobeck, T.M. Over, and S.L. Collins. 2007. Feedbacks between fires and wind erosion in heterogeneous arid lands. *J. Geophys. Res.* 112.
- Varela, M.E., E. Benito, and J.J. Keizer. 2010. Effects of wildfire and laboratory heating on soil aggregate stability of pine forests in Galicia: The role of lithology, soil organic matter content and water repellency. *Catena.* 83: 127–134.
- Whicker, J.J., J.E. Pinder, and D.D. Breshears. 2006. Increased wind erosion from forest wildfire: Implications for contaminant-related risks. *J. Environ. Qual.* 35(2): 468–478.



## Some reflections on acquisition, processing and analysis of statistical data in forest soils

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**Key-words:** data acquisition; statistical data analysis; multivariate statistics; forest soils.

### Abstract

Beyond the classical statistical approaches (determination of basic statistics, regression analysis, ANOVA, etc.) a new set of applications of different statistical techniques has increasingly gained relevance in the analysis, processing and interpretation of data concerning the characteristics of forest soils. This is possible to be seen in some of the recent publications in the context of Multivariate Statistics. These new methods require additional care that is not always included or referred in some approaches. In the particular case of geostatistical data applications it is necessary, besides to geo-reference all the data acquisition, to collect the samples in regular grids and in sufficient quantity so that the variograms can reflect the spatial distribution of soil properties in a representative manner. In the case of the great majority of Multivariate Statistics techniques (Principal Component Analysis, Correspondence Analysis, Cluster Analysis, etc.) despite the fact they do not require in most cases the assumption of normal distribution, they however need a proper and rigorous strategy for its utilization. In this work, some reflections about these methodologies and, in particular, about the main constraints that often occur during the information collecting process and about the various linking possibilities of these different techniques will be presented. At the end, illustrations of some particular cases of the applications of these statistical methods will also be presented.



## Using PESERA to manage desertification processes following wildfires in Góis and Mação, Portugal

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**Key-words:** Modelling, Geographical Information System, PESERA, Land Use, Erosion, Forest fires

### Introduction

Annually, around 50 000 wildfires ravage forests of the Mediterranean countries, affecting an average burnt area of 600 000 ha [1]. These sub-humid regions are particularly susceptible to the occurrence of wildfires, due to high vegetative growth during the wet season and the long, hot and dry summer periods, and are characterized by having ecosystems with a dense vegetative cover that allows for rapid fire propagation. Although fire is a natural agent and essential for the management of the dynamics of the vegetation and their fire-prone ecosystems, wildfires are also considered to be one of the main agents of soil erosion and degradation [2, 3].

The significant increase in the number of wildfires in the last decades [4] has turned this natural element into a problem of catastrophic proportions, due to changes in land use level and the practices associated with it which, in large degree, reflect socio-economic and demographic changes and consequent land use transformations. These changes have resulted in weaker control and greater accumulation of biomass, allowing changes in ecological natural processes, associated with a substantial increase in wildfire risk [5]. Wildfires have a very high environmental impacts, and contribute strongly to degradation and desertification over large areas in the country [5], altering soil hydrological response, reducing resistance to erosion and increasing overland flow production, during subsequent rainstorms [1].

### Soil erosion

Soil erosion is a natural process of global importance, occurring over geological time, but its rate can be significantly increased by human activities, especially clearing of forests for cultivation; urbanization and infrastructural development; over-grazing; wildfires or controlled burning; and inappropriate land management, for example cultivation of steep slopes or collapse of terrace structures through poor maintenance [6,7]. Increased erosion leads to removal of the most fertile topsoil and organic matter, with a progressive and ultimately irreversible loss in soil productivity.

In southern Europe, climate change is expected to increase both soil erosion and wildfire risk, impacting ecosystems through a series of physical, chemical, mineralogical and biological changes [9]. The complex wildfire effects depend on: 1) Fire characteristics, 2) type of fuel, and its humidity, 3) nature of the terrain and 4) soil characteristics [3, 10]. This diversity makes it difficult to generalise, but wildfires are thought to significantly reduce the rates of interception, transpiration and infiltration, increasing storm runoff and damaging ecosystem sustainability. In burned forest environments, the runoff generation

may also be increased by development and/or reinforcement of the hydrophobic layer [10], which prevents wetting of aggregates and so severely reduces infiltration capacity. After a wildfire, subsequent rain events may promote severe erosion [3, 13]. Initially, erosion rates are boosted due to the destruction of the vegetation layer and associated changes in soil physical and hydrological properties, leading to an increase in both runoff and shear stress at the soil surface, increasing the detachment and transportation of sediment [3]. Studies reveal that exposure to fire also reduces the structural stability of the soil aggregates, making it more erodible [10]. Fire also creates a weak surface layer of ash and disaggregated mineral particles; may burn some roots, further contributing to loss of soil cohesion and leads to loss of nutrients by volatilization and dissolution in overland flow in post-fire storms [9]. Increases in degradation generally persist for at least one year, depending on the weather, the severity of the fire and the post-fire ecosystem condition [10]. Much of the soil and runoff removed during a major storm accumulates below the eroded areas, with potentially damaging off-site effects. All these processes generate strong positive feedbacks between erosion and fires, and argue for control of damaging fires as one important protection of ecosystem services.

### The Portuguese study areas: Mação and Góis

The DESIRE EU-funded project is designed to recommend alternative strategies for the use and protection of arid and semi-arid areas that are at risk of desertification. Within DESIRE, the Portuguese study sites have been chosen to investigate how sustainable land management strategies can best be applied within a fire prone environment. The DESIRE project, after promoting a meeting of local and external stakeholders in each study area, established two main conservation measures to be applied in the Portuguese study areas, namely preventive forestry and prescribed fire.

Mação and Góis are two municipalities located in Central Portugal, where forest fire risk is at its highest. The Mação study area in the lower Tagus river basin lies in a transition zone between the Atlantic and the Mediterranean climate types and is composed of forest, consisting dominantly of *Pinus pinaster*, with some *Eucalyptus globulus*. The soils are typically very shallow and stony Humic Cambisols on steep slopes (>20°), overlying metamorphic bedrocks. Mação annual rainfall grades from 1000 mm in the North to less than 700 mm in the south, with wet winters and dry summers. It was burned for the first time in 1998 and then in the catastrophic 2003 fires. After the first fire, the burned forest area only partially regenerated. After further fires in 2005, more than 70% of the Mação municipality had been burned. Natural degradation and regeneration, together with mitigation techniques are being assessed at this location (Fig. 1).

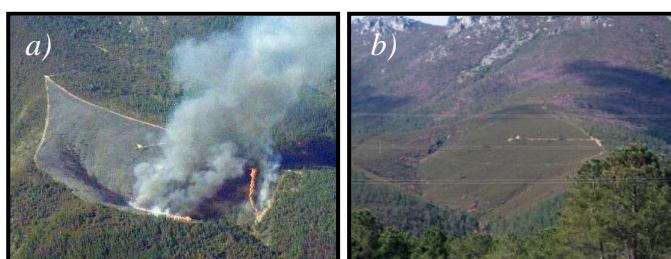


Figure 1. Land degradation in the Caratão catchment.

Soils in the Vale Torto catchment of Góis municipality are shallow lithosols on steep slopes (>20°) below a quartzite ridge crest, which is the NE part of Lousã Mountain (“Penedos de Góis”). Góis has an annual rainfall of about 1200 mm, mostly during the

winter. After several fires in the 1970s and early 1980s, prescribed fires were introduced for common land in the early 1990s to improve local grazing areas. The area was burned again by prescribed fire in February 2009.

The Vale Torto study area is more focused on the use of prescribed fire as a wildfire prevention tool, since it is a shrubland area. A prescribed fire was carried out on February 20<sup>th</sup> 2009 (Fig. 2) as an experimental fire (broadly equivalent to a prescribed fire near the catchment boundaries but hotter towards the main drainage line), and the impacts will be assessed for at least 2 years after the fire. An unburnt catchment of similar size is being monitored for discharge and bedload sediment trapped behind the gauging station v-notch weir. Land use here consists of pasture and dense shrubland, subject to prescribed fire from time to time. Land abandonment and neglect are the main problems encountered in this area, although the area is also used for extensive grazing.



**Figure 2.** Vale Torto a) Prescribed fire and b) 4 months later.

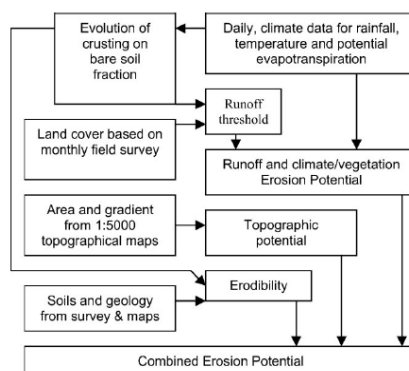
The technology to be implemented by the Mação Municipality is Preventive Forestry. The monitoring sites and procedures to be adopted to assess the impacts of this management are not yet finally formulated. Preventive forestry covers a wide range of technologies, including terracing, the use of fire resistant species, understorey management, tree-to-tree distance, Primary Strip Network Systems for Fuel Management, and Prescribed Fire. These technologies are currently being developed by the Municipality.

For the Vale Torto catchment, prescribed fire was the selected conservation measure in the DESIRE project. The catchment was subject to prescribed fire on February 20<sup>th</sup> 2009. Continuous monitoring of hydrological processes was carried out before and after the fire. Repeated rainfall simulations were carried out, with regular measurements of infiltration capacity, water repellency and soil moisture.

### **The PESERA Model**

The Pan European Erosion Risk Assessment (PESERA) was used to provide an objective coarse-scale assessment of erosion risk at a given location, taking account of both wildfires and prescribed burns. PESERA is a physically based, spatially distributed, with frequency distribution and continuous prediction model [8,14]. This model makes use of progress in process understanding, whilst retaining a simple structure with relatively modest data requirements. It simulates the interactions between land-use types, soil and topographic characteristics, estimating monthly water storage, erosion rate, vegetation and humus biomass, rainfall interception by plants and overland flow. It also calculates average soil erosion rates and the contribution of individual storms, bringing together the effects of topography, climate, soil and land-use into a single integrated forecast of runoff and soil erosion (Fig. 4) [14].





**Figure 3.** PESERA model elements

Using the PESERA modelling framework has several advantages, namely a description of the basic characteristics of the processes involved (runoff and sediment transport), allowing for a more realistic incorporation of effects of global change (land use and climate) and may be easier integrated in more general modelling frameworks. The model can be used to predict runoff and erosion with reasonable accuracy based on limited input data. However, proper calibration is a prerequisite when the model is run for different spatial resolutions: this is an inherent characteristic of spatially distributed models. The model results have been validated at catchment level and compared with results of other erosion risk assessment methods across Europe at country and pan-European scales.

Any process model, and particularly a coarse-scale model such as PESERA, has a number of inherent disadvantages compared with simpler models, including: **1** The need for input data, which may not be freely or readily available. **2** The need to rely on spatial soil data that were collected nationally, using criteria that differ from country to country, combined into soil types that are not completely uniform, and only partially harmonized. **3** A concentration on the relevant dominant processes that are more widespread, in this case Hortonian overland flow, so that erosion by saturation overland flow, for example, is poorly estimated. Nevertheless, there are a series of advantages for the use of these types of models, namely: **1** It applies the same objective criteria to all areas, and can be applied throughout a region, subject to the availability of suitable generic data. **2** It provides a quantitative estimation of erosion rate, which can be compared with long-term erosion rates averages. **3** The methodology can be re-applied with equal consistency as available data sources are improved, and for past and present scenarios of changed climate and land use. Overall, the PESERA model has a secure theoretical base, although the accuracy of forecasts is limited by the restriction, based on data quality and availability, to daily rainfall data, and to a greatly simplified analysis of topography. Within these constraints, the model responds both rationally and in accordance with established principles to variations in climate, land use and topography.

Initial application of the PESERA model shows its potential and some limitations. Modelling is able to simulate at least some of the major interactions between fire and erosion, but some important effects are not yet incorporated in to the model, in particular the effect of soil stripping with the potential irreversible soil loss, and the increases in Hydrophobicity immediately after major fires. One of the main effects that the model is able to emulate is the high sensitivity of the erosion response to the magnitude of events immediately after each fire, and before recovery of the vegetation. For the climatic and soil conditions of the study areas, the model suggests that the practice of prescribed burns reduces the total erosion and the number of major fires, but not necessarily the number of



small wildfires that occur. The application of PESERA modelling to wildfire management is still far from complete, requiring further model site-targeted model development and a fuller incorporation of existing field data into the model framework.

### Conclusions

Wildfires are a menace to ecosystems sustainability, namely to the forest ones, not just because they eliminate the forest production, but also because they promote a continued and accelerated degradation of the forest soils. This way, and taking into consideration the risk of the increase of wildfires as a result of climate change, it is extremely important to understand the degradation processes at various scales. The degradation of the physical and chemical properties of the soil may limit the recovery capacity of the ecosystems, diminishing the options of management and sustainability of important areas of the territory. Tools such as PESERA are essential to optimise land use management and recovery.

The use of functional tools such as the PESERA modelling framework is of extreme importance, once it will allow to recognize areas in need of urgent intervention in what respects to soil conservation, as well as for the simulation of future scenarios, as to prevent said degradation.

### Acknowledgment

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### References

- [1] M.C. Rulli, S. Bozzi, M. Spada, D. Bocchiola and R. Rosso, “Rainfall simulations on a fire disturbed Mediterranean area”, *Journal of Hydrology*, Vol. 327, pp. 323-338, 2006.
- [2] L. Trabaud, “Post-fire vegetation recovery and dynamics in the Mediterranean area”, in *Fire, landscape and biodiversity: an appraisal of the effects and effectiveness*, G. Pardini, and J. Pinto, Girona: Diversitas. UdG, 2002, pp. 39-55.
- [3] A.J.D. Ferreira, C.O.A. Coelho, C.J. Ritsema, A.K. Boulet and J.J. Keizer, “Soil and water degradation processes in burned areas: lessons learned from a nested approach”, *Catena*, Vol. 74, pp. 273-285, 2008.
- [4] A.J.D. Ferreira, S.A. Prats, C.S.S. Ferreira, M.C. Malvar, C.O.A. Coelho, M. Carreiras and T. Esteves, “Los incendios florestales como gestores de los procesos hidrológicos y erosivos. Dos ejemplos clave en el avance científico”, in *Efectos de los incendios florestales sobre los suelos en España – El estado de la cuestión visto por los científicos españoles*, A. Cerdá and J. Mataix-Solera, Valencia: Cátedra Divulgación de La Ciencia. Universitat de València, 2009, pp. 79-103.
- [5] J.M. Moreno, A. Vázquez and R. Vélez, “Recent history of forest fires in Spain”, in *Large forest fires*, J.M. Moreno, Leiden: Backhuys Publishers, 1998, 159-185.
- [6] C.O.A. Coelho, A.J.D. Ferreira, A.K. Boulet and J.J. Keizer, “Overland flow generation processes, erosion yields and solute loss following different intensity fires”, *Quarterly Journal of Engineering Geology & Hydrogeology*, Vol. 37, pp. 233-240, 2004.
- [7] A.J.D. Ferreira, C.O.A. Coelho, A.K. Boulet, G. Leighton-Boyce, J.J. Keizer and C.J. Ritsema, “Influence of burning intensity on water repellence and hydrological processes at forest sites in Portugal”, *Australian Journal of Soil Research*, Vol. 43 (3), pp. 327-336, 2005.



- [8] M.J. Kirkby, B.J. Irvine, R.J.A. Jones, G. Govers, M. Boer, O. Cerdan, J. Daroussin, A. Gobin, M. Grimm, Y. Le Bissonnais, C. Kosmas, S. Mantel, J. Puigdefabregas and G. van Lynden, “The PESERA coarse scale erosion model for Europe. I. – Model rationale and implementation”, *European Journal of Soil Science*, Vol. 59, pp. 1293–1306, 2008.
- [9] D.G. Neary, C.C. Klopatek, L.F. DeBano and P.F. Ffolliott, “Fire effects on belowground sustainability: a review and synthesis”, *Forest Ecology and Management*, Vol. 122, pp. 51-71, 1999.
- [10] A.C. Imeson, J.M. Verstraten, E.J. van Mulligen and J. Sevink, “The effects of fire and water repellency on infiltration and runoff under Mediterranean type forest”, *Catena*, Vol.19, pp. 345-361, 1992.
- [11] S. Doerr, R.A. Shakesby and R.P.D. Walsh, “Soil hydrophobicity variations with depth and particle size fraction in burned and unburned *Eucalyptus globulus* and *Pinus pinaster* forest terrain in the Águeda Basin, Portugal”, *Catena*, Vol. 27(1), pp. 25-48, 1996.
- [12] R.A. Shakesby and S.H. Doerr, “Wildfire as a hydrological and geomorphological agent”, *Earth-Science Reviews* Vol. 74, pp. 269-307, 2006.
- [13] A.D. Thomas, R.P.D. Walsh and R.A. Shakesby, “Nutrient losses in eroded sediment after fire in eucalyptus and pine forests in the wet Mediterranean environment of northern Portugal”, *Catena*, Vol. 36, pp. 283-302, 1999.
- [14] F. Licciardello, G. Govers, O. Cerdan, M.J. Kirkby, A. Vacca and F.J.P.M. Kwaad, “Evaluation of the PESERA model in two contrasting environments”, *Earth Surface Processes and Landforms*, Vol. 34, pp. 629 – 640, 2009.



## Chemical characterization of *Terra Preta do Índio* soils, paleosols and a soil from the north of Galicia affected by forest fires.

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**Key-words:** Terra Preta do Índio, charcoal, elemental composition, organic carbon pools.

### Introduction

The average temperature of the surface of the Earth is growing, especially since 1950, being 2005 and 1998 the warmest years since 1850. The linear warming trend over the 50 years from 1956 to 2005 ( $0.13 \pm 0.03$  °C C per decade) is nearly twice that for the 100 years from 1906 to 2005 and there is a “high confidence” that the main reason is the increase of the concentration and emissions of greenhouse gases due to human activities. The atmospheric CO<sub>2</sub> concentration has grown since a preindustrial value of 280 ppm to 379 ppm in 2005, while in the previous 8000 years it grew just 20 ppm (1). The main CO<sub>2</sub> emissions come currently from the use of fossil fuels, gas flaring and cement production, so the responsibility of these sectors in reducing the consume of fuels and taking efficient measures can't be evaded. However, today, emissions of CO<sub>2</sub> related to agriculture practices and the change of soil use account still for the 25% of global emissions (2). This gives an idea of the magnitude of the organic C losses from soils and manifests the urgent need to invert this trend and promote them to act as a C sink. Efforts in this sense are increasing, focusing on organic C stability and recalcitrant C pools (permanence of around 50% of carbon inputs for a period of 100 years). Currently, there are some models that represent this objective, in particular: 1) those soils with high charcoal content, due to fire events 2) some kind of soils of human origin with burning episodes, such as Terra Preta soils (3,4,5), 3) making of technosols and 4) biochar production (6). A deep insight into the mechanisms behind the C stability in some of these models was the aim of this work.

### Objectives

The objective of this work was to compare the mechanisms of organic matter stabilization among two soils from Terra Preta (TP1 and TP2), in the Amazon Basin, two buried superimposed paleosols located in the cliffs from Arnela beach (A Coruña) (PaS1 and more aged PaS2) containing macroscopic charcoal particles and a soil from this place (S3), which is known to suffer continue fire episodes. Layers of sediments separate paleosols, and the most ancient sediment layer dates from preHolocene period of Wurm glaciation (7). For this purpose, chemical and thermal methods were used. Analysis included the quantifying of different carbon pools and differential scanning calorimetry.

### Methodology

Elemental analysis was done on a CHN analyzer (TrusPec, LECO Corp., St. Joseph, MI). The oxidability of soil organic C was determined with the warm dichromate acid method and back titrated against ferrous ammonium sulphate (8). Hot water extractable C (HWC, 80°C for 16 h) and water soluble carbon at 25°C (WSC) was determined following the



method of Ghani et al. (2003) by a extraction in a two sequential-step procedure (9). Dissolved organic carbon in both extracts was determined in an analyzer Shimadzu TOC-5000. Hydrolizable carbon (HC) was determined following Tan et al (2004) methodology(10). Samples were digested with 6 N HCl at 100 °C for 18 h. The residue was analysed on a CHN analyzer. Basal respiration was measured using a Micro-Oxymax Respirometer (Columbus Instruments, Columbus, OH). Samples were at 60% water holding capacity. Finally, Differential Scanning Calorimetry (DSC) was performed in a DSC Q100 TA with a heating rate of 10°C/min from 50 to 600°C and an air flow of 100 ml/min.

## Results and conclusions

Table 1 includes results of chemical analyses. TP1 and TP2 were analysed along the soil profile and they are ordered from *a* to *f* in growing deep. TP1-a has the highest levels of total organic carbon (TOC) with the exception of S3. TP1-a has a pH of 6.26, and a relation C/N of 12.08. C/N values for Terra Preta soils usually are in the range 12-40(11), what, in general, was confirmed in our samples, with the exception of TP2-c. The optimal C/N relation and the presence of labile organic compounds is probably the main reason why microbial activity is considerably higher in TP1-a than in the other samples, including S-3, despite having more TOC. Organic matter from S-3 will be probably dominated by organo-Al complexes, due to the low pH, what would make difficult microbial activity.

Water soluble carbon, indicated in Table 1 as HWC and WSC, generally is an index of readily bioavailable SOM, composed of small molecules to colloidal substances, generally associated to carbohydrates of microbial origin, with turnover times of weeks to months, but in soils with highly humified material or black carbon WSC is a bit more persistent (12). In our samples, this fraction accounts in a small proportion. In TP soils it diminishes along the profile and its value is smaller in the oldest PAS. The C determined as CO<sub>2</sub> evolved from respirometry is indicative of labile organic matter and it is also a small proportion with exception of the surface samples (TP1-a, TP2-a and S3).

**Table 1.** Ph, C/N and main carbon forms in percentage (per mass of dry soil)

	pH H <sub>2</sub> O	pH KCl	% TOC	% C Cr <sub>2</sub> O <sub>7</sub>	% HC	% HWC	% WSC	% C resp	C/N
TP1-a	6.26	5.89	4.88	3.96	1.93	0.070	0.0195	1.71	12.08
TP1-b	6.13	4.98	1.85	1.72	0.42	0.031	0.0081	0.13	29.73
TP1-c	5.67	4.60	0.89	0.65	0.34	0.034	0.0116	0.18	20.45
TP1-d	5.28	4.44	0.45	0.24	0.19	0.025	0.0167	n.d.	20.55
TP1-e	4.70	4.62	0.55	0.54	0.27	0.025	0.0070	n.d.	14.40
TP1-f	5.29	4.64	0.30	0.19	0.15	0.021	<LD	n.d.	18.34
TP2-a	3.69	3.26	1.56	1.55	0.72	0.078	0.0211	0.36	18.01
TP2-b	4.73	4.17	0.78	0.65	0.34	0.029	0.0072	0.19	30.69
TP2-c	4.62	4.14	0.43	0.25	0.20	0.025	0.0059	n.d.	21.94
TP2-d	4.76	4.17	0.36	0.19	0.14	0.026	0.0044	n.d.	>100
TP2-e	4.80	3.99	0.29	0.24	0.19	0.020	0.0030	n.d.	33.51
TP2-f	4.91	3.95	0.28	0.25	0.19	0.019	0.0043	n.d.	20.64
PAS-1	4.79	4.44	4.46	3.86	1.59	0.028	0.0071	0.10	24.01
PAS-2	5.30	5.18	3.53	3.24	2.11	0.022	<LD	0.08	24.97
S3	4.50	3.72	12.4	8.29	4.84	0.127	0.0116	0.54	14.74

Hydrolyzable carbon turns over faster than non hydrolyzable carbon (13). The hydrolysis reaction, through the process of protonation and hydration, solubilizes compounds with O- and N- containing functional sides (14), removing carbohydrates and protein materials. So, fatty acids, proteins and polysaccharides are susceptible to acid hydrolysis, while long-chain alkyls, waxes, lignin and other aromatics are resistant to such treatment. Thus, the fraction of oxidizable carbon by dichromate minus the fraction of hydrolyzable carbon refers to a fraction relatively persistent. Values for this pool are compiled in Table 2. Finally, the recalcitrant pool can be computed as all the organic carbon that resisted the dichromate treatment (15), also called Black Carbon (BC). Values for this pool are also reflected in Table 2.

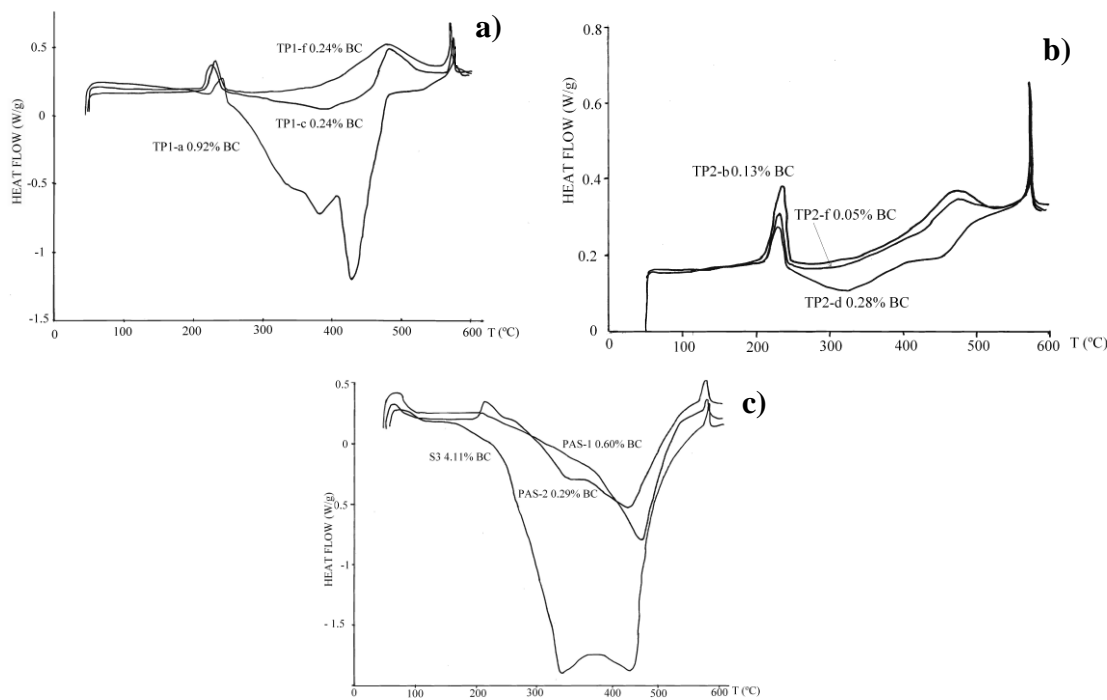
**Table 2.** BC, and main carbon forms in % ( per TOC)

	% BC	BC (g/kg soil)	BC (%TOC)	C Cr <sub>2</sub> O <sub>7</sub> <sup>-</sup> HC (% TOC)	HC (% TOC)	HWC (% TOC)	WSC (%TOC)	C resp (% TOC)
TP1-a	0.92	9.20	18.85	41.51	39.63	1.44	0.40	35.06
TP1-b	0.13	1.32	7.13	70.41	22.46	1.68	0.44	7.18
TP1-c	0.24	2.35	26.56	35.30	38.14	3.82	1.32	20.88
TP1-d	0.21	2.07	46.33	11.80	41.87	5.52	3.73	n.d.
TP1-e	0.01	0.05	0.99	48.74	50.27	4.64	1.28	n.d.
TP1-f	0.11	1.13	37.21	12.64	50.15	6.89	<L.D.	n.d.
TP2-a	0.01	0.1	0.64	53.03	46.33	4.97	1.35	22.96
TP2-b	0.13	1.32	16.86	39.52	43.62	3.69	0.92	24.78
TP2-c	0.18	1.84	42.41	12.50	45.09	5.76	1.37	n.d.
TP2-d	0.17	1.67	46.70	14.79	38.51	7.21	1.23	n.d.
TP2-e	0.05	0.53	18.06	16.34	65.60	6.91	1.02	n.d.
TP2-f	0.03	0.33	11.60	20.65	67.75	6.89	1.52	n.d.
PAS-1	0.60	6.00	13.45	50.96	35.59	0.62	0.16	2.24
PAS-2	0.29	2.90	8.22	31.97	59.81	0.64	<L.D.	2.34
S3	4.11	41.10	33.15	27.83	39.02	1.03	0.09	4.35

The distribution of BC contents in Terra Preta soils along the profile is probably related with particular practices of Amerindian population and different conditions of burning, but in general, as deep increases there is an enrichment in the BC fraction with values such as 80.17% and 57.57% for the most deep samples. Enrichment of BC respect TOC in paleosols is less than TP soils, but values in g/kg of soil can be compared. S3 has most BC than paleosols, probably due to the oxidation of BC along time (16).

Results of thermal analysis through Differential Scanning Calorimetry are examined in Figure 1. In graph a) can be clearly distinguished the second exothermic peak at a temperature of 430.19 °C for TP-1. The others TP soils don't show this peak, as can be seen in graph 2, with exception of TP-2, but with less intensity (results for all TP soils are not shown). This peak is probably due to recalcitrant carbon forms (17), indicating more aromaticity than the other TP soils (18). In paleosols an exothermic peak can be seen around 469.65°C for PAS-1 and 450.30 for PAS-2. The heat flow associated to these exothermic peaks for TP1-a, PAS-1 and PAS-2 is respectively 781 J/g, 713.9 J/g and 634.7. Barros et al 2010 showed that there was a positive and approximate correlation between the integral of the DSC curve, given in Joules per g, and the total carbon content of the soils they studied. Also higher contents in carbon are related with higher exothermic peaks (19). Looking at graph 3, S3 can be distinguished with a very intense signal around 432.18°C, that is overlapped with a previous exothermic peak of 342.43 °C with a heat flow of 2593 J/g, higher than the other soils. The first exothermic peak is probably related

to labile compounds and the second exothermic peak would be due to refractory compounds, made in recent fires. The high intensity of peaks and the heat flow associated is indicative of more aromaticity and labile carbon than the others soils, as chemical analyses confirm.



**Figure 1.** DSC for TP, PAS and S3

In conclusion, chemical analyses give information of the different carbon pools and notes the presence of BC in most samples. DSC analyses show BC especially in paleosols and the surface soil subjected to frequent fires, but not in TP soils with the exception of TP-1. It could be because of the high levels of BC in this sample or because there are different mechanisms of stabilization among TP soils and soils subjected to forest fires.

## References

1. IPCC,2007. Fourth assesment report (AR4).
2. Lal,R. 2001. SSSA special publication series number 57.
3. Neves et al., 2003. Chapter In Amazonian Dark Earths: Origin, Properties, Management , pp. 29-50
4. Sombroek, 1966. Amazon Soils. A Reconnaissance of the Soils of the Brazilian Amazon Region. Centre for Agricultural Publications and Documentations, Wageningen, pp. 12-283.
5. Glaser et al., 2000. Org Geochem, Vol 31: 669-678.
6. Macías & Arbestain, 2010. Mitig Adapt Strateg Glob Change. Vol.15, 6: 511-529
7. Pérez Alberti, 2010. Not published.
8. Sauerlandt & Berwecke, 1952. H. Z. Pflanz. Dung. Bodenk.. Vol 56, 204-226.
9. Ghani et al., 2003. Soil Biol Biochem, vol 35: 1231-1243
10. Tan et al., 2004. Soil Sci. Vol 169:423-433
11. Lehmann et al., 2003. Chapter: In Amazonian Dark Earths: Origin, Properties, Management, pp. 105-124



12. von Lutzow et al., 2007. *Soil Biol Biochem.* Vol 39:2183-2207
13. Six & Jastrow, Chapter In: *Encyclopedia of Soil Science*, pp.936-942
14. Barriuso et al. 1987. *Can J Soil Sci.* Vol. 67: 647-658
15. Hammes et al., 2007. *Global Biogeochemical Cy.* Vol 21:1-18
16. Cheng et al., 2006. *Org Geochem*, Vol 37-11: 1477-1488
17. López-Capel et al., 2006. *J Anal Appl Pyrolysis.* Vol 75:82-89
18. Dell abate et al., 2003. *J Sep Sci* Vol 26:433-440
19. Barros et al., 2010. *J Therm Anal Calorim.* DOI: 10.1007/s10973-010-1163-4





## Runoff rates, water erosion and water quality from a soil covered with different types of ash

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

### Introduction

The hydrological effects of an ash layer covering the soil after a fire are being explored. It is accepted that ash plays a role controlling post-fire runoff and erosion, but whether ash temporarily increases potential runoff and erosion by sealing the soil surface (Mallik, et al., 1984; Gabet and Sternberg, 2008; Onda et al., 2008) or reduces them by storing rainfall and protecting the underlying soil (Leighton-Boyce et al., 2007; Cerdà and Doerr, 2008; Woods and Balfour, 2008; Zavala et al., 2009) requires further investigation.

Recent studies clarify some of the reasons for these differences in observed ash effects on runoff and erosion. They are (i) the variable physical and mineralogical nature of ash depending on the temperature and condition of combustion and specie burned, e.g. size, porosity, calcium carbonate content, water repellency (Kinner and Moody, 2007; Larsen et al., 2009; Woods and Balfour, 2010; Bodí et al., 2011), (ii) changes in ash nature after interacting with the atmosphere or water (Etiegni and Campbell, 1991), (iii) the thickness of the ash layer (Woods and Balfour, 2010) and (iv) differences in geology and associated soil types of the sites (Larsen et al., 2009; Woods and Balfour, 2010). However more work is required to establish the link between ash characteristics and ash effects, particularly to enable predicting its behaviour for different ecosystems and wildfires.

In addition, differences in ash nature also can lead in differences in the chemical nature of runoff such as its nutrient content. The most common measurement method for nutrients in ash is the leaching test that involves extraction of an ash sample (Etiegni and Campbell, 1991; Pereira and Ubeda, 2010). However, this method quantifies the potential soluble nutrients in the ash, but not the actual nutrients dissolved during a rainfall event when the ash is covering the soil. Few experiments have been done on runoff quality, although the highest nutrient and suspended sediment contents in streams often occur during the first storms following a wildfire event (Hauer and Spencer, 1998; Lane et al., 2006).

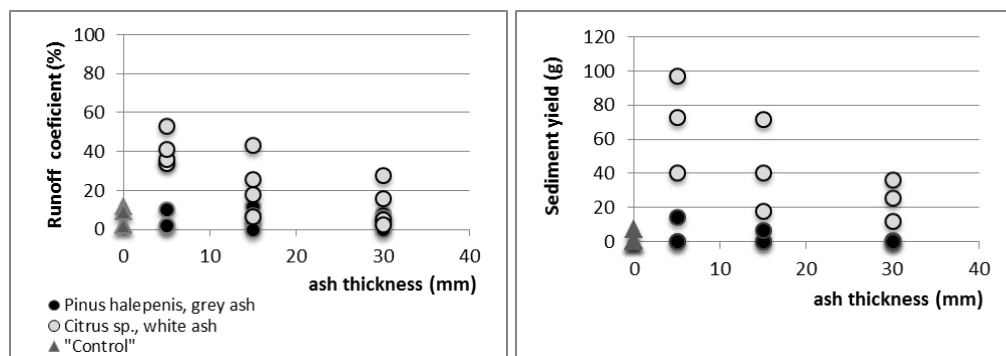
To address this research gap, we quantified the effects of ash type and the thickness of the ash layer on (i) overland flow generation, and soil and ash losses, and (ii) on the chemical constituents of the overland flow generated, using a series rainfall simulations over ash-treated field plots. Differences in these parameters were also measured with time by examining the first storm after a fire and a second storm a week later.

## Methods

A series of rainfall simulations were conducted in SE Spain, on an abandoned crop field with a 5° slope. We used a rainfall intensity of 50 mm h<sup>-1</sup> and a duration of 60 min. The plots (0.22 m<sup>2</sup>) were covered with two different ash types with three thicknesses: 5 mm, 15 mm and 30 mm. Control plots were also included with no ash cover. Two types of ash were used, one from *Pinus halepensis*, a grey ash collected from a low intensity wildfire, and the other a very white ash made from *Citrus sp.* litter and wood made in the laboratory at very high temperature. Ash physical and chemical characteristics (particle size, bulk density, porosity, sorptivity, particle density and total cation content) were analysed to characterise any differences between ashes. A second rainfall simulation was carried out after a week. Three replicates were made for all the treatments and a fourth replication was included to allow a destructive examination of the soil profile after the first simulation. The total number of simulations conducted was 70. Overland flow was collected at 1-min intervals and a sample retained every 10 min to allow determination of sediment concentrations, yield, erosion rates and water quality. Water samples were analysed for pH, electrical conductivity and cation content (Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, Na<sup>+</sup>).

## Results and discussion

The ash from *Citrus sp.* produced at high temperature generated more runoff than the one from *Pinus halepensis* produced at lower temperatures. The effects also were different depending on the depth of the ash. A layer of 5 mm of *Citrus sp.* ash generated a runoff coefficient of 41 ± 8 %, while 15 mm produced 23 ± 15 % and 30 mm 12 ± 11 %. The runoff coefficient of the plot covered with *Pinus halepensis* ash at the same above depths was 12 ± 15%, 5 ± 5% and 5 ± 3% respectively and the average of the control plots was 6 ± 5 % (Figure 1a). Sediment yield was also higher in the white *Citrus sp.* ash than in the *Pinus halepensis* ash (figure 1b). In all cases the sediment was composed almost entirely of ash.



**Figure 1a and 1b.** Runoff coefficient (%) and sediment yield (g) of the plots covered with a layer of *Pinus halepensis* ash produced at low temperature and *Citrus sp.* ash produced at high temperature for ash depths of 5, 15 and 30 mm, for the first rainfall simulation.

For the second rainfall simulation, runoff coefficient values were reduced to 10% for *Citrus sp.* ash for the three depths and to nearly to 0% for the *Pinus halepensis* ash covered plots. Sediment yield did not exceed 20 g for *Citrus sp.* ash and was zero for *Pinus halepensis* ash.

The reason for the differences between the ash types is suggested to be due to the nature of each one. It was observed that the *Citrus sp.* ash covering the plot was crusted after the first rainfall simulation. This may be due to the hydration of this ash produced at high temperature and its high contents of calcium carbonate (Balfour and Woods, 2006).



Respect the pore clogging phenomena, Larsen et al. (2009) and Woods and Balfour (2010), studied it by examining soil thin sections or determining the porosity of the soil. They explained that clogging would occur if the fine fraction of ash is enough to clog the soil pores (if there are). The only evidence we have up to now to refuse pore clogging for this experiment, is that percentage of sample finer than 2  $\mu\text{m}$  was only  $5.624 \pm 1.32$ ,  $0.50 \pm 0.05$  for the *Citrus sp.* ash and the *Pinus halepensis* ash respectively, compared with the 23% clay fraction of the soil. However, this aspect should be better studied. In addition, the lower runoff rates for *Pinus halepensis* ash can be associated to the lower bulk density, higher porosity and hence a greater capacity to hold the water. This effect increases with the thickness of the ash layer, as there will be more capacity to hold and store the water, leading to lower runoff rates (Woods and Balfour, 2010). After the second rainfall simulation, the thickness of the ash layer did not make any different effect on the water storage capacity because it become cracked and apparently more permeable. The differences between replicates were due to variations between plots. The plots did not have the same rock fragment content and macropore distribution, and also in some of them the underlying soil exhibited slight water repellency. Nevertheless, the trends in overland flow and sediment yield within the ash types were consistent between plots. Concerning the water quality, the runoff collected from *Citrus sp.* ash had pH values of 12 and the electrical conductivity exceeded  $1000 \mu\text{S cm}^{-1}$ , whereas pH of *Pinus halepensis* was 8 and electrical conductivity around  $500 \mu\text{S cm}^{-1}$ . These values were similar for the three thicknesses. The most abundant cation type in both ashes was  $\text{K}^+$  followed by  $\text{Ca}^{2+}$ ,  $\text{Na}^+$  and  $\text{Mg}^{2+}$ .  $\text{Na}^+$  and  $\text{K}^+$  were higher in *Citrus sp.* ash runoff and the levels of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  were similar in runoff of both ashes. However, the quantities measured here were not as high as the reported in leaching tests. Quantities reported are of the order of thousand  $\text{mg L}^{-1}$  (Etiegni and Campbell, 1991; Soto and Diaz-Fierros, 1993; Pereira and Úbeda, 2010), and here the highest value of  $\text{K}^+$  was no more than  $500 \text{mg L}^{-1}$ . This may be due to not all cations being washed away in the overland flow. Some would be expected them to have been lixiviated or incorporated into the soil. Also, some of them may need more water to allow full dissolution, such as  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  (Khanna et al. 1994).

In the second rain the quantity of cations in solution were lower, in part because the sediment concentration was lower than in the first rain, but also due to most of the cations were already washed and probably soil and ash interaction occurred during a week.

## Conclusion

In this study, the different types of ash (due to either specie or temperature of combustion) and their thickness when covering the soil led to markedly different responses in overland flow, quantity of sediment washed away and water quality.

As the thickness of the ash layer increased, the water storage capacity increased as well, reducing the total runoff produced. However, in the second rainfall event, thickness did not make any difference in the overland flow, which was reduced in both cases. Regarding the type of ash, some ash types, specially the porous one, may contribute to the infiltration of water into the soil, but more dense and packed ash will increase overland flow and at the same time lead to more ash being carried within the flow. In this case, more cations contained in ash will be entrained in the runoff from burned sites.

Because of the great variety of ash types in every ecosystem with different characteristics and different underlying soil type, care should be taken in predicting ash effects on runoff rates and nutrient losses following wildfires.



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## References

- Balfour V. and Woods S. (2006). Causes of variability in the effects of vegetative ash on post-fire runoff and erosion. Paper presented at Eos Trans. AGU, Fall Meeting.
- Bodí, M. B., Mataix-Solera, J., Doerr, S. H., and Cerdà, A. (2011). The wettability of ash from burned vegetation and its relationship to Mediterranean plant species type, burn severity and total organic carbon content. *Geoderma*, 160, 599-607.
- Cerdà, A., and 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.
- Etiengni, L., and Campbell, A. G. (1991). Physical and chemical characteristics of wood ash. *Bioresource Technology*, 37, 173-178.
- Gabet, E. J., and Sternberg, P. (2008). The effects of vegetative ash on infiltration capacity, sediment transport, and the generation of progressively bulked debris flows. *Geomorphology*, 101, 666-673.
- Hauer, F. R., and Spencer, C. N. (1998). Phosphorus and Nitrogen Dynamics in Streams Associated With Wildfire: a Study of Immediate and Longterm Effects. *International Journal of Wildland Fire*, 8(4), 183-198.
- Khanna, P. K., Raison, R. J., and Falkiner, R. A. (1994). Chemical properties of ash derived from *Eucalyptus* litter and its effects on forests soils. *Forest Ecology and Management*, 66, 107-125.
- Kinner, D. A., and Moody, J. A. (2007). *Infiltration and runoff measurements on steep burned hillslope using a rainfall simulator with variable rain intensities*: U.S. Department of the Interior U.S. Geological Survey.
- Lane, P. N. J., Sheridan, G. J., and Noske, P. J. (2006). Changes in sediment loads and discharge from small mountain catchments following wildfire in south eastern Australia. *Journal of Hydrology*, 331(3-4), 495-510.
- Larsen, I. J., MacDonald, L. H., Brown, E., Rough, D., Welsh, M. J., Pietraszek, J. H., et al. (2009). Causes of post-fire runoff and erosion: water repellency, cover, or soil sealing? *Soil Science Society American Journal* 73, 1393-1407.
- Leighton-Boyce, G., Doerr, S. H., Shakesby, R. A., and 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 agents on in situ soils. *Hydrological Processes*, 21(17), 2337-2345.
- Mallik, A. U., Gimmingham, C. H., and Rahman, A. A. (1984). Ecological effects of heater burning. I. Water infiltration, moisture retention and porosity of surface soil. *Journal of Ecology*, 72, 767-776.
- Onda, Y., Dietrich, W. E., and Booker, F. (2008). Evolution of overland flow after a severe forest fire, Point Reyes, California. *Catena*, 72, 13-20.
- Pereira, P., and Úbeda, X. (2010). Spatial distribution of heavy metals released from ash after a wildfire. *Journal of env. engineering and landscape man.*, 18(1), 13-22.
- Soto, B., and Diaz-Fierros, F. (1993). Interactions between plan ash leachates and soil. *International Journal of Wildland Fire*, 3(4), 207-216.
- Woods, S. W., and Balfour, V. (2008). The effect of ash on runoff and erosion after a forest wildfire, Montana, U.S.A. *International Journal of Wildland Fire*, 17(5), 535-548.



- Woods, S. W., and 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*, 393, 274-286.
- Zavala, L. M., Jordán, A., Gil, J., Bellinfante, N., and Pain, C. (2009). Intact ash and charred litter reduces susceptibility to rain splash erosion post-wildfire. *Earth Surface Processes and Landforms*, 34, 1522-1532.



## Characterizing the hydrological properties of wildfire ash

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**Key-words:** wildfire, ash, hydrology, hydraulic conductivity, porosity.

### Introduction and objectives

The hyper-dessicated ash and soil layers making up the near surface profile in recently burned areas respond very differently to rainfall than the litter and unburned soil that existed prior to the fire. Limited knowledge regarding the hydrological properties of the ash-soil profile, and the ash layer in particular, currently limits efforts to model the infiltration process in burned areas and hence predict the location and magnitude of post fire runoff and erosion events. The objectives of the work presented here were to: 1) determine the fundamental hydrologic properties of ash: particle size, bulk density, particle density, porosity, hydraulic conductivity, intrinsic permeability, sorptivity and water retention characteristics, and 2) explain the observed hydrologic properties of ash in terms of factors such as the particle size and shape and particle packing relative to mineral soils.

### Methodology

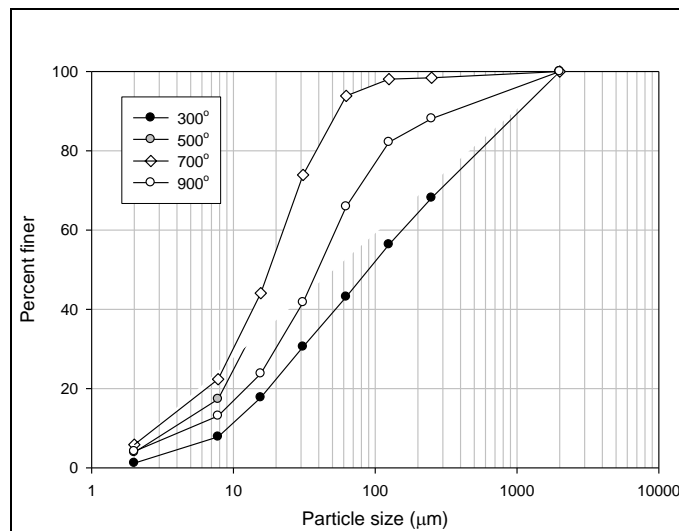
Particle size was determined using laser diffractometry and scanning electron microscopy for lab ash samples produced from Lodgepole pine (*Pinus contorta*), Ponderosa pine (*Pinus Ponderosa*) and Douglas fir (*Pseudotsuga menziesii*) at temperatures of 300, 500, 700 and 900 °C. Bulk density, particle density and porosity were measured in ash samples collected following two 2009 wildfires in Spain. Bulk density was measured in the field and in re-packed samples after transport to the lab. Particle density was measured using the pycnometer bottle method (Flint and Flint, 2002a). Porosity was calculated from the field bulk and particle densities and using the vacuum saturation method (Flint and Flint, 2002b). The water retention characteristics of the six wildfire ash samples were determined using the hanging column and pressure plate methods at 0.01, 0.02, 0.03, 0.04 and 0.05, 0.2, 0.3, 1.0, 2.0 and 5.0 bars. Hydraulic conductivity (K) was determined using the falling head method for both the lab ash and wildfire ash samples. Hydraulic conductivity, intrinsic permeability to air ( $k_{air}$ ), and sorptivity (S) were determined for the wildfire ash samples using the mini-disc infiltrometer (K, S), air permeametry ( $k_{air}$ , K) and sorptivity probe (S) methods. Falling-head K values were used to determine the intrinsic permeability to water ( $k_{water}$ ) and the ratio  $k_{air}:k_{water}$ . The same methods were used to determine the properties of a fine silica sand to validate the results of the analyses.

### Results and Conclusions

#### *Particle size and shape*

Ash produced at 300°C had the coarsest particle size distribution, with a  $D_{50}$  of ~90µm (Figure 1). The particle size distribution shifted to the left for the 500 and 700°C samples, indicating an overall decrease in particle size. SEM analysis indicated that this decrease reflects increasing structural breakdown associated with more complete combustion and a transition from primarily organic fragments in the ash to primarily crystalline fragments

of calcite and other minerals in the higher temperature ash. In the 900°C samples there was a 5-fold increase in the proportion of sand sized particles and a doubling of the  $D_{50}$  relative to the 700°C samples. SEM analysis indicates that coarsening in the 700 to 900°C range was due to sintering.



**Figure 4.** Particle size distribution of lab ash samples produced at 300, 500, 700 and 900°C. Particle size decreases in the 300-700°C range and then increases for the 900°C samples.

*Bulk density, particle density and porosity*

Field bulk densities ranged from 0.10 to 0.38 g cm<sup>-3</sup> (Table 1). These values are similar to those previously reported for wildfire ash (Bookter, 2006; Cerda and Doerr, 2008, Woods and Balfour, 2008, Zavala et al., 2009) but they are considerably lower than the typical range of values for mineral soils. Bulk densities for ash samples repacked in the lab were higher than those measured in the field, ranging from 0.33 to 0.53 g cm<sup>-3</sup>, indicating the difficulties associated with reproducing the delicate structural characteristics of ash in the laboratory.

**Table 1.** Median particle size ( $D_{50}$ ), bulk density ( $\rho_b$ ), particle density ( $\rho_p$ ), porosity ( $\Phi$ ), hydraulic conductivity (K), intrinsic permeability (k) and sorptivity (S) of six ash samples and silica sand.

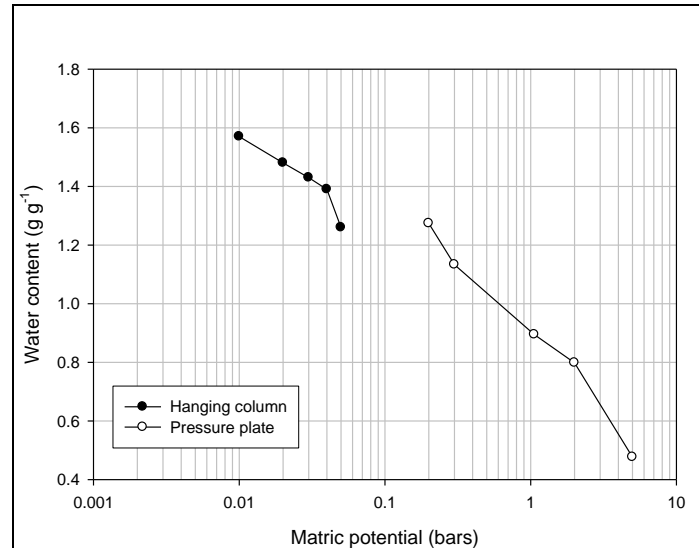
Sample	$D_{50}$	Field $\rho_b$	Lab $\rho_b$	$\rho_p$	$\Phi$ from $\rho_b$ and $\rho_p$	$\Phi$ by saturation	$K_{sat}$ falling head	$K_{sat}$ mini disc	$K_{air}$	$K_{air} : K_{water}$	S mini disc	S sorptivity probe
Units	$\mu m$	g cm <sup>-3</sup>			-		cm s <sup>-1</sup>		m <sup>2</sup>	-	mm s <sup>-0.5</sup>	
REM-1	123	0.18	0.33	2.36	0.93	0.80	1.33E-03	ND	1.36 E-12	5.35	0.75	1.97
REM-2	17	0.108	0.43	2.05	0.95	0.67	6.02E-04	ND	6.14 E-13	6.44	0.87	1.63
REM-3	26	ND	0.35	2.27	ND	0.74	7.56E-04	ND	7.73 E-13	4.86	0.71	1.08
SON-1	18	0.38	0.53	2.49	0.85	0.64	1.61E-03	ND	1.65 E-12	4.79	ND	1.95
SON-2	23	0.30	0.38	2.41	0.88	0.71	1.83E-03	ND	1.87 E-12	3.05	2.02	2.35
SON-3	134	ND	0.42	2.52	ND	0.77	1.33E-03	1.89 E-03	1.36 E-12	4.78	1.39	ND
Silica sand	ND	-	1.34	2.62	0.49	0.47	3.26 E-02	1.52 E-02	3.33 E-11	0.53	1.14	2.23

Particle densities for the wildfire ash samples ranged from 2.05 to 2.40 g cm<sup>-3</sup>, or 9 to 23 percent less than the 2.65 g cm<sup>-3</sup> value used to estimate total porosity in soils, and occasionally in ash (e.g Bookter, 2006). The reduced particle density reflects the fact that ash contains low-density char particles as well as mineral material.

Total porosity estimates based upon the field bulk density and measured particle density ranged from 85 to 95%, which is within the range previously reported for wildfire ash samples (Cerdeira and Doerr, 2008, Woods and Balfour, 2008) but more than twice the typical range for mineral soils of comparable texture. Porosity estimates obtained using the saturation method, which ranged from 64 to 89%, were consistently lower than those obtained using the bulk density method. This is to be expected, as the bulk density method estimates the total porosity whereas the saturation method measures the effective porosity. However, some of the difference between the two estimates may also reflect settling and internal densification during transport to the lab. Given the high effective porosity values seen in these samples, it is clear that ash has an exceptionally high saturated water holding capacity compared to mineral soils with a similar texture.

#### *Water retention*

The water retention curve developed for one of the six samples (SON3) using the hanging column and pressure plate methods in combination is shown in Figure 2. In general, the results obtained with the two methods are consistent, and indicate that the tested ash retains about half of its saturated water content at field capacity (0.3 bars). This is similar to a sandy loam mineral soil, which on average retains 46 percent of its saturation water content at field capacity.



**Figure 5.** Water retention curve for ash sample SON-3

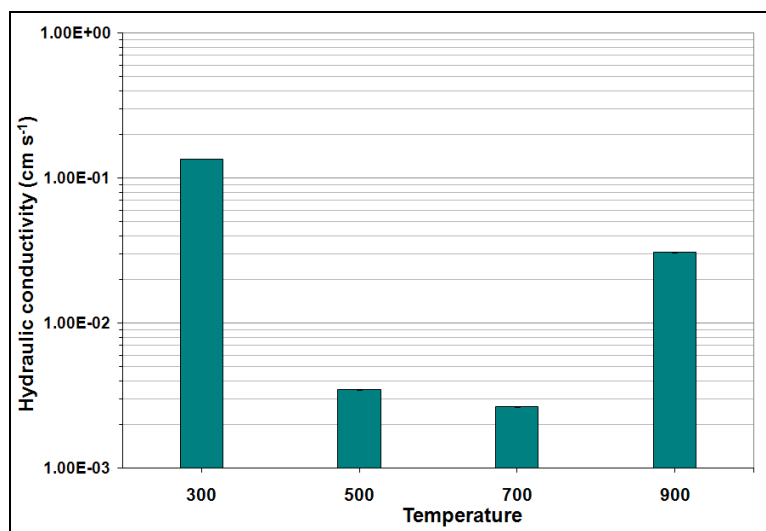
#### *Hydraulic conductivity, intrinsic permeability and sorptivity*

Falling head hydraulic conductivity values for lab ash samples decreased with increasing temperature in the 300-700°C range but then increased in the 900°C ash (Figure 3); this is consistent with the observed variability in ash texture in these samples. K values for wildfire ash samples ranged from 6.0 x 10<sup>-4</sup> to 1.8 x 10<sup>-3</sup> cm s<sup>-1</sup>, which is within the range seen in the 500-700°C lab ash and within the range expected for mineral soils with the same silty to sandy texture (Table 1).



The ratio  $k_{\text{air}}:k_{\text{water}}$  was closest to 1.0 for silica sand, indicating that wetting had little or no effect on the internal structure and the hydraulic conductivity (Table 1). The fact that  $k_{\text{air}}:k_{\text{water}}$  was  $< 6$  for all the ash samples indicates that structural changes associated with wetting were minimal; thus air permeametry may provide a relatively easy way to obtain order of magnitude estimates for  $K_{\text{sat}}$  for ash samples.

In five of the six ash samples tested using the mini-disc infiltrometer, the coefficient for the term representing the effect of  $K$  in the polynomial equation used to calculate  $K$  and  $S$  was negative, resulting in a physically unrealistic negative value for  $K$ . This was due to the fact that the sorptivity term was large relative to the hydraulic conductivity term, so that the best fit to the data was obtained with a linear model relating  $S$  to  $\sqrt{t}$ . Moody et al., (2009) noted a similar problem with this method when applied to burned soils and ash samples.



**Figure 6.** Hydraulic conductivity of lab ash samples produced at 300, 500, 700 and 900°C.

Ash sorptivity values obtained using the tension infiltrometer and sorptivity probe methods (Table 1) were within the range seen in mineral soils, which varies from  $0.1 \text{ mm s}^{-0.5}$  for fine textured soils to  $4 \text{ mm s}^{-0.5}$  for coarse textured soils (Leeds Harrison et al., 1994). Values obtained using the sorptivity probe method were up to 2.6 times higher than those obtained from the tension infiltrometer. This may reflect the fact that the tension infiltrometer method used here measured one dimensional infiltration whereas the sorptivity probe measured three dimensional infiltration. Three dimensional tension infiltrometer measurements require a much larger volume of ash material than was available for the samples tested here. The sorptivity probe offers a useful alternative method for determining the sorptivity of ash when only a limited sample volume is available.

## References

- Bookter, A., 2006. Erosional processes after wildfires: the impact of vegetative ash and the morphology of debris flows. M.S. Thesis, Department of Geology, University of Montana, Missoula, Montana. 69 p.
- 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



- Flint A.L., Flint L.E., 2002a. Particle density, Ch. 2.2 In Dane J.H. and Topp G.C. (eds), 2002. *Methods of Soil Analysis, Part 4 Physical Methods*. Soil Science Society of America Inc., Madison, Wisconsin USA.
- Flint L.E., Flint A.L., 2002b. Porosity, Ch. 2.3 In Dane J.H. and Topp G.C. (eds), 2002. *Methods of Soil Analysis, Part 4 Physical Methods*. Soil Science Society of America Inc
- Moody J.A., Kinner D.A. and Úbeda X., 2009. Linking hydraulic properties of fire-affected soils to infiltration and water repellency. *Journal of Hydrology* 379, 291-303
- Woods, S.W., Balfour, V., 2008. Effect of ash on runoff and erosion after a severe forest wildfire. Montana, USA. *International Journal of Wildland Fire* 17, 1-14
- Zavala, L.M., Jordán, A., Gil, J., Bellinfante, N., Pain, C., 2009. Intact ash and charred litter reduces susceptibility to rainsplash erosion post-wildfire. *Earth Surface Processes and Landforms* 34, 1522-1532.



## Depositional characteristics of post-fire flooding following the Schultz Fire, San Francisco Peaks, Arizona

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**Key-words:** Wildfire; erosion; sediment distribution; alluvial fan; infiltration.

### Introduction

During the summer of 2010 the northern Arizona mountain town of Flagstaff experienced three fires all blazing the same week in late-June, the height of the fire season for this region. By July 1<sup>st</sup>, all three were extinguished, but that was only the first phase of disturbance. The largest and most detrimental of these fires was the Schultz Fire. From June 20<sup>th</sup> to July 30<sup>th</sup> 2010, the Schultz Fire burned 6,100 ha on the eastern slopes of the San Francisco Peaks, a dormant Middle Pliocene to Holocene aged stratovolcano (Figure 1). This was a wind driven fire, consuming approximately 60% of the total burn area in the first day. Ponderosa pine and mixed conifer forest on steep to moderate slopes of the mountain front and upper piedmont zone of 11 watersheds were impacted.

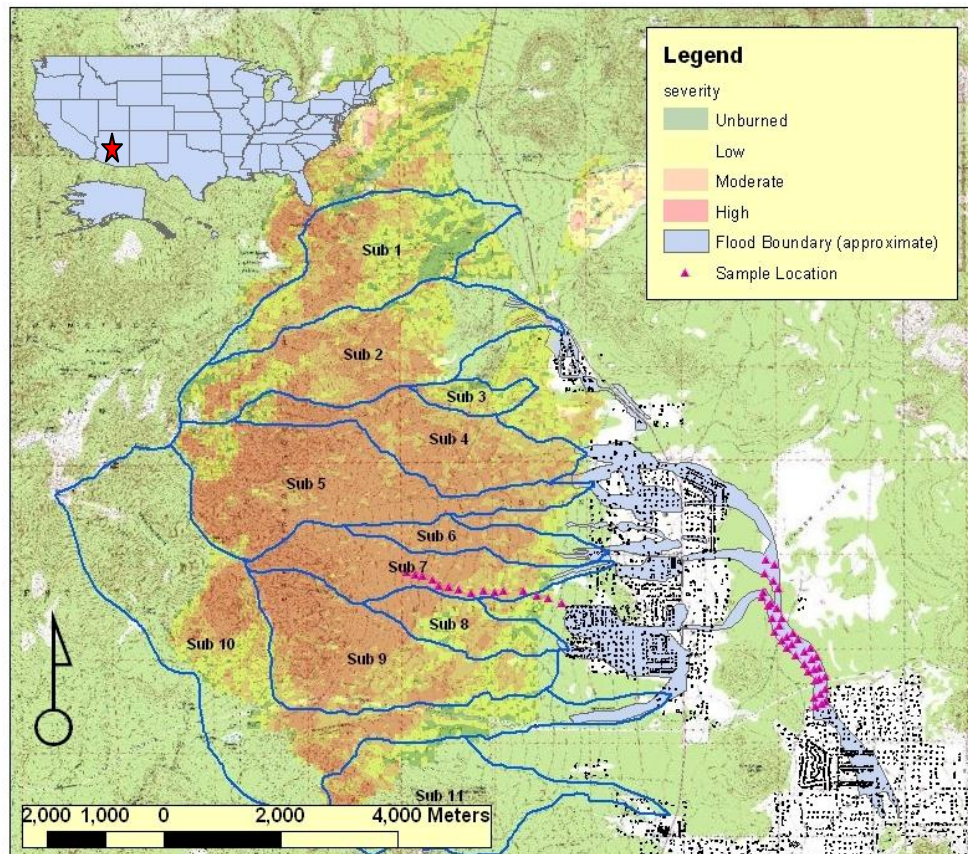
The US Forest Service Remote Sensing Application Center (RSAC) estimated the burn severity of the Schultz Fire using Burned Area Reflectance Classification (BARC). The BARC process combines Normalized Burn Ratio (NBR) data derived from Landsat satellite imagery with National Land Cover Database vegetation layers to accurately estimate burn severity across different vegetation types within the burn (Hudak et al. 2004). 70% of the Schultz Fire was classified as high to moderate severity, while 25% was classified as low severity, and another 8% was unburned. The high severity burned areas are concentrated on the steep mountain face with slopes greater than 30% and in places exceeding 100% (USDA Forest Service 2010).

Prior to the fire and subsequent flooding, the upper mountain had few defined channels consisting largely of ridge-swale topography with thick mixed-conifer forest cover and a well-developed O horizon (10-30 cm). These swales become more defined channels in the ponderosa pine-dominated piedmont zone. Prior to the fire they rarely carried flows. The slope varies from 60 to >100% on the upper mountain face to 30 to 60% in the piedmont zone and to 5 to 7% at the head of the alluvial fans. Scattered housing developments, most of which are less than 40 years old, occupy the fans.

The onset of summer monsoon precipitation in mid-July 2010, the 4<sup>th</sup> wettest on record, resulted in debris deposition on the alluvial fan with a series of discrete flood events over the following 6-weeks of summer precipitation. Over 1000 residents in this area were evacuated from their homes during the fire itself and several hundred experienced damages to property due to repeated flooding.

Post-fire debris flows scoured the swales on the upper slopes of most watersheds 1-4 m to expose bedrock channels. Well-defined channels in the piedmont zone were

simultaneously filled with coarse material from debris flows and flood-flow bedloads in less confined reaches, and incised over a meter beneath the previous channel surface in confined reaches. The piedmont channels coalesce and diverge on an alluvial fan surface that was constantly being reworked by multiple flood events. As defined channels emerge onto fan heads, flood flows fan out into sheet flows across the alluvial fans, passing through Coconino National Forest lands and several residential developments.



**Figure 1.** Schultz Fire boundaries with severity classification, watershed delineation, post-fire flood flow boundaries, and sediment sample locations.

## Objectives

The intent of this study is to examine the hydrologic and depositional processes from the piedmont zone, across the alluvial fan, to the outwash plain by determining the variability in grain size. Data from the steep channels of the mountain front are excluded from this analysis because currently these steep channels are predominantly erosive supplying the material that is deposited below. The purpose of this research is to better inform land and civic managers of long-term impacts from post-fire sedimentation and depositional processes, and to assist efforts managing post-fire flows and recovery.

## Methodology

The depositional characteristics of post-Schultz Fire flooding were evaluated by sampling sediments across landscape features to capture variability in grain size of material transported by the flows. Sampling techniques were based on landscape position within two primary zones: the confined channels of the piedmont zone, and the outwash plain of the depositional fan where flood-impacted developments are situated. Though there were widespread debris flows resulting from two high-intensity rainfall events on the 20<sup>th</sup> of



July and the 16<sup>th</sup> of August, the sampling of grain size described herein is of material that was transported by hyperconcentrated flood flows and fluvial processes (Pierson and Costa 1987).

*Study Area Selection:* Due to the extensive coverage of post-fire flooding from eleven watersheds across the eastern slopes of the San Francisco Peaks, one watershed was selected for initial study. Basin 7 (Figure 1), was sampled to determine sediment characteristics and availability for future transport in the piedmont zone. This watershed was chosen because it had direct impact on the developments downstream of the burn area. It is one of the smaller basins within the burn area (4<sup>th</sup> of 11), facilitating comprehensive sampling coverage in limited time. The entire basin was surveyed but the focus of this analysis is from the piedmont zone downstream. Basin 7 also ranks high (2<sup>nd</sup> of 11) in the percentage of high-severity burn, and has had debris flows in every tributary, providing ample sediment source for fluvial transport. Basin selection was also based on the availability of post-fire precipitation data due to the placement of two emergency rain gauges in the watershed.

The second landscape zone sampled was the depositional fan across the flood area between several developments that were inundated (Figure 1). Sampling was restricted to public lands to limit disturbance of flood deposits from human activities (e.g. the removal or reorganization of material), and the ability to determine what was indeed a recent flood deposit.

*Sampling & Analytical Procedures:* Sediment samples within the piedmont channel of Basin 7 were taken at randomly selected cross-section locations. The data from ten cross-section locations presented here (Figure 1) consist of samples collected downstream of the 2316.5 m (7600ft) topographic contour line. This contour was selected as the piedmont threshold because the slope becomes gradual, grading into the depositional fan. At each cross-section location the depth of the recently disturbed layer (flood deposited material) was determined at the channel thalweg and a sediment sample was taken. The depth of the flood deposit and the associated sediment sample were determined by excavating the channel bed until small intact tree roots (<1mm diameter) were present, indicating the boundary of the flood deposit and the preexisting material. At each cross-section location 1-2 sediment samples were taken.

Sheet flow flood deposits on the fan were sampled along twelve randomly selected transects situated perpendicular to the direction of flow (Figure 1). On each transect 3-4 points across the flood deposit were sampled at undisturbed locations. The depth of the fresh deposit was measured down to the previous ground surface, as indicated by the presence of cinders and organic matter, and a sediment sample was taken.

Sediment samples from within the channel of the piedmont zone and from the sheet flow deposits on the fan were all analyzed for grain size using sieve analysis. Eleven sieves were used with screen sizes ranging from 50.8 to 0.074 mm. Samples were shaken for 15 min to sort grain sizes and the mass of residual sediment in each screen taken.

## **Results and conclusions**

Grain size analysis of samples taken from post-fire flood deposits in the piedmont zone of Basin 7, and the alluvial surface and outwash plain between downstream housing developments indicate a reduction in particle diameter from coarse cobble and gravel to fine sands and clay. At the transition between the piedmont zone and the head of the alluvial fan the slope is 5 to 7%. On the alluvial fan the slope lessens to 2 to 4%, and



decreases further in the outwash plain to less than 2%. Channel confinement also decreases with slope. There are no channels extending from the alluvial fan to the outwash plain. The decrease in slope and lack of confinement caused flow velocity to drop off substantially driving differential deposition between landscape features. Extensive deposition of fine sediments on the toe of the fan and outwash plain created an impermeable layer on the alluvial surface easily observed before, during and after flood events. The scouring of channels on the mountain face and piedmont zone paired with fine grained deposition in the outwash plain has effectively reduced infiltration.

The burnt slopes of the San Francisco Peaks lost a substantial amount of material during the 2010 monsoon season following the Schultz Fire. Debris flows scoured material from the channel beds of several watersheds across the burn area supplying coarse sediments to the piedmont channels below. Hillslope erosion, facilitated by rill and gully formation across the landscape, supplied fine sediments and ash to form hyperconcentrated flows. Initial flood events of hyperconcentrated flow transported fine grained sediments and ash across the alluvial fan and outwash plain effectively sealing the previous surface of cinders. Surface flood deposits of fine sediments across the 750+ ha flood area of the alluvial fan and outwash plain, along with the scoured channels of the basins above caused secondary flood events to respond more quickly with increased sensitivity to precipitation.

The effects of fire on hydrologic response is well documented in DeBano et al. (1998) and Neary et al. (2008). The hydrologic impacts of the Schultz Fire will likely continue for several years, though it is unlikely flooding will be as extensive and detrimental as witnessed during the monsoon season of 2010. This is due to several actions taken by local land managers and civic planners to mitigate the effects of post-fire watershed response on the residents in the flood path. Continued research is needed to understand the efficacy of these mitigation efforts and the landscape changes during the post-fire recovery. Across the alluvial fan and outwash plain, research is needed on the depositional history of the basin by coring sample locations where surface properties have been described and dating samples when possible.

## References

- DeBano, L.F.; Neary, D.G.; Ffolliott, P.F. 1998. *Fire's effects on ecosystems*. New York, NY: John Wiley and Sons. 333 p.
- Hudak, A.T.; Robichaud, P.R.; Evans, J.B.; Clark, J.; Lannom, K.; Morgan, P.; Stone, C. 2004. *Field validation of Burned Area Reflectance Classification (BARC) products for post fire assessment*. In: Remote Sensing for Field Users, Proceedings of the Tenth Forest Service Remote Sensing Applications Conference, Salt Lake City, Utah, April 5-9, 2004. 13 p.
- Neary, D.G.; Ryan, K.C.; DeBano, L.F. 2005. (Revised 2008). *Wildland Fire in Ecosystems: Fire effects on soil and water*. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42, Volume 4: Fort Collins, CO.
- Pierson, T.C.; Costa, J.E. 1987. *A rheological classification of subaerial sediment-water flows*. In: J.E. Costa, J.E.; Wicczorek, G.F. Editors. Debris Flows/Avalanches: Process, Recognition, and Mitigation, Reviews in Engineering Geology **vol. VII**, Geological Society of America, Boulder, CO (1987), pp. 1–12.
- USDA Forest Service. 2010. *Burned Area Emergency Response Report, July 8, 2010*. Coconino National Forest, Flagstaff, Arizona. 167 p.



## Hydrological response of a small catchment burned by experimental fire

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**Key-words:** catchment-scale; scale effects; hydrology; soil moisture; interception.

### Introduction

Fire can considerably change hydrological processes, increasing the landscape's vulnerability to major flooding and erosion events (Shakesby and Doerr 2006). By removing vegetation cover, changing soil properties and inducing soil water repellency, fire can increase runoff which can lead to floods and erosion (Cerdà and Robichaud 2009). The impact of fire is however largely affected by scale. Despite this scaling challenge, which is universal across all hydrological problems (Blöschl and Sivapalan 1995), catchment-scale studies on the hydrological impact of fire are scarce. Even though controlled fire experiments can give valuable insight into the drivers of fire-induced hydrological changes and effects of scale, to date catchment-scale controlled fire experiments have not been performed and particularly nested approaches are rarely used (Ferreira et al. 2008). This paper presents a catchment-scale experimental fire study that assesses fire impact on hydrology using paired catchments and a nested approach.

### Objective

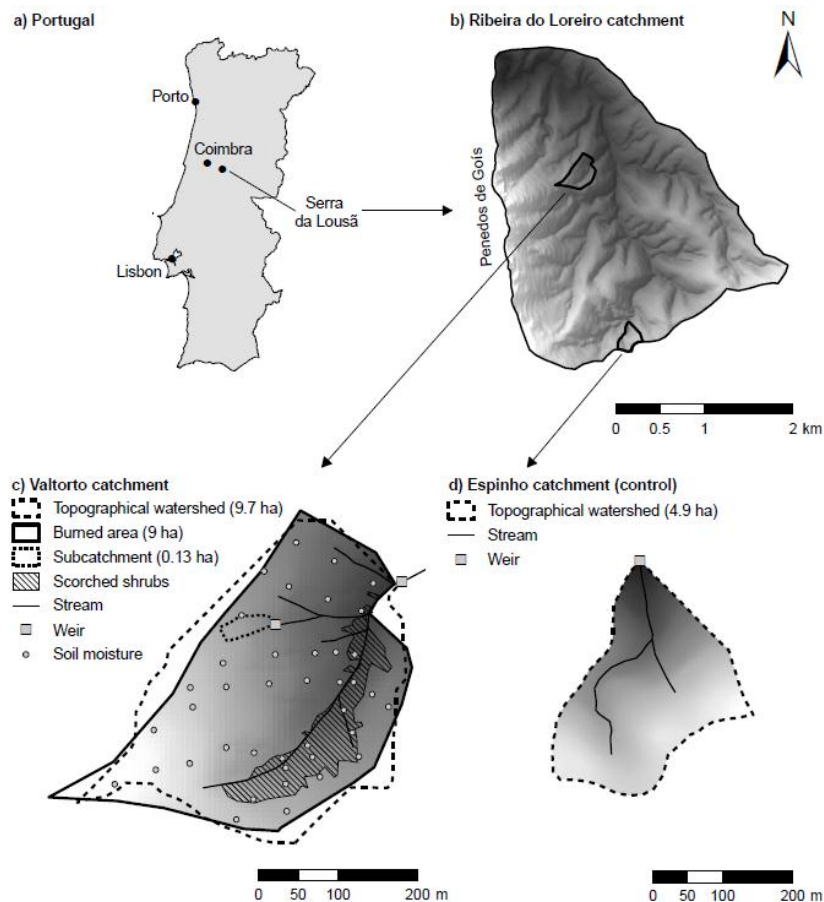
The objective of this study was to evaluate the short-term ( $\leq 1$  yr) impact of fire on hydrological processes and the causes of any changes different scales.

### Methodology

#### *Research catchments and experimental fire*

The paired catchments Valtorto (burned, 600-750 m a.s.l.) and Espinho (control, 695-800 m a.s.l.) are located on the northeastern slopes of the Serra da Lousã in north-central Portugal (Fig. 1). Climate is Mediterranean with an annual precipitation of 1050 mm, and soils and vegetation are typical for the region. Soils are shallow, developed from schist and quartzite, and covered by dense heathland dominated by *Erica* spp. and *Pterospartum tridentatum* regenerated after wildfire burned both catchments in the summer of 1990 and a prescribed fire burned the Valtorto catchment in April 1996.

The Valtorto catchment was burned by a high-intensity experimental fire on 20 Feb 2009 (Stoof et al. 2011). Despite the high fire intensity, shrubs were not completely consumed throughout the catchment (Fig. 1c), and soils remained below 100°C in the majority of the catchment. As a result, soil hydrologic properties such as saturated hydraulic conductivity and soil porosity did not change significantly. However, overland flow resistance and soil surface roughness decreased significantly because of the fire and the post-fire exposure of the soil (Stoof et al. 2011).



**Fig. 1** Location of the Valtorto and Espinho catchments, showing the sampling design. Grey shading in graphs b, c and d represents elevation, enhanced using hillslope shading in ArcGIS.

### *Hydrological monitoring*

Pre- and post-fire time series of rainfall and streamflow were collected in both the burned and the unburned control catchment. A nested approach was used, in which streamflow in the Valtorto catchment was monitored at the outlet of the main catchment and a small unbounded subcatchment halfway up the southeast slope (Fig. 1c). Additionally, soil moisture and canopy interception was monitored in the Valtorto catchment alone. Rainfall, streamflow and soil moisture data was managed through a MySQL database and analyses were done in R (R Development Core Team 2010). For details regarding the experimental design or data management, please refer to Stoof et al. (2011).

Fire effects were assessed by comparing pre- and post-fire rainfall, streamflow and moisture parameters. Streamflow changes were furthermore statistically analyzed using ANCOVA's, which evaluated the effects of fire while taking into account autocorrelation and changes in the rainfall distribution. Because of the effects of scale on the delay between rainfall and streamflow response, the catchment response was analyzed at a weekly basis, while the subcatchment response was analyzed at a daily basis.

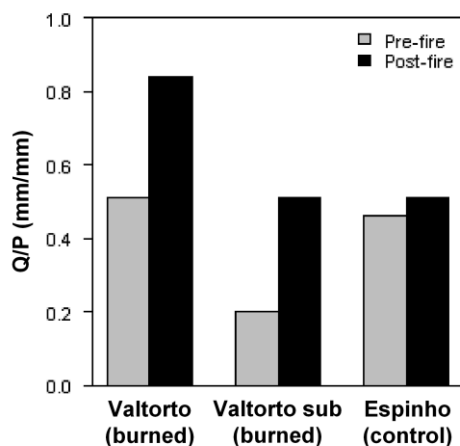
### **Results and conclusions**

Although pre- and post-fire daily rainfall amounts were not significantly different, there was an increased occurrence of large rain events ( $> 20$  mm) after the fire. Moreover, the post-fire occurrence of streamflow (fraction of days with streamflow  $> 0$ ) was higher for all three sites (Valtorto and Espinho catchments and Valtorto subcatchment), resulting in

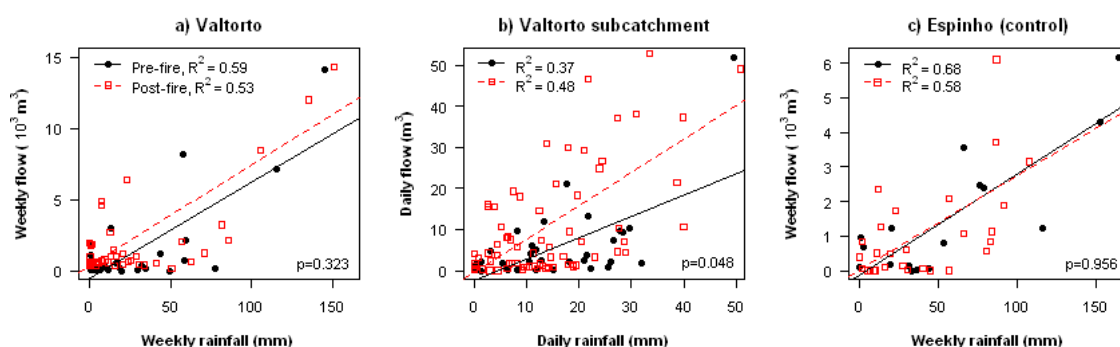


almost year-round streamflow in the main Valtorto catchment after the fire. In addition, daily streamflow increased for all three sites, but the increase was only significant in the burned catchment.

Because of the pronounced effects on rainfall distribution on streamflow patterns (Beven 2001), attributing observed hydrological changes to the effects of fire must be treated with caution. Since the rainfall changes also affected streamflow in the control catchment, it is reasonable to assume that at least part of the observed changes in streamflow in the burned catchment should be attributed to the change in rainfall. However, the runoff coefficient (Fig. 2) changed more in the burned catchment than in the unburned control, clearly suggesting that fire did have a role in changing streamflow response in the burned catchment. Moreover, separation of rainfall and fire effects using ANCOVA (Fig. 3) showed that while fire did not appear to change the rainfall-streamflow relationship in the control Espinho catchment ( $p=0.955$ , based on weekly data), it did shift the rainfall-streamflow relationship in the burned Valtorto catchment (Fig. 3). Effects were greatest at the subcatchment-scale, where changes were also significant ( $p=0.048$  vs  $p=0.323$  for subcatchment and catchment-scale, respectively). Fire therefore changed the rainfall-streamflow relationship causing an increase in streamflow, and thus flooding risk, in the Valtorto subcatchment and possibly in the whole catchment.



**Fig. 2** Runoff coefficient (Q/P) in the Valtorto catchment (1.7-fold increase), the Valtorto subcatchment (sub, 2.5-fold increase) and the Espinho catchment (1.1-fold increase), for the entire pre- and post-fire monitoring periods.

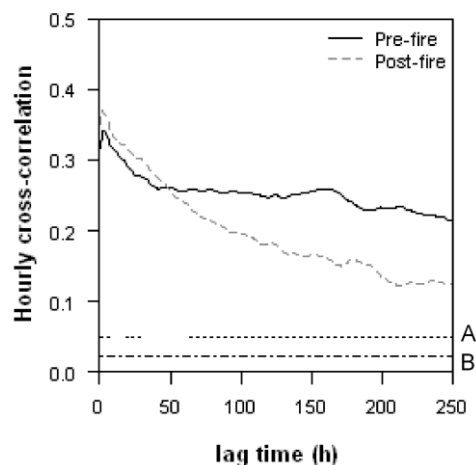


**Fig. 3** Rainfall-streamflow relationships in Valtorto (burned) and Espinho (control). P-values indicate whether pre- and post-fire regression lines were significantly different

Increases in streamflow after fire have also been observed by others (Scott 1993; Seibert et al. 2010), and are often attributed to decreased plant transpiration and canopy

interception storage (e.g. Scott and Van Wyk 1990). Canopy throughfall in the winter before the fire averaged  $51.3 \pm 17.8\%$  of total rainfall, resulting in an estimated canopy interception of  $48.7 \pm 17.8\%$ . This value is fairly high compared to the few data available on shrub interception (Dunkerley 2000), but can likely be attributed to the dense canopy cover ( $80 \pm 18\%$ ) and the rapid drying of the upper canopy between rain events. Because of the high interception storage, removal of vegetation by fire nearly doubled the effective rainfall.

While reduced canopy interception was certainly a factor in this study, additional data suggest that there are more contributing factors. Reduced water storage at the soil surface also played a role (Stoof et al. 2011). Furthermore, while soil water repellency was abundant before the fire, the fire did increase the temporal dynamics of soil moisture content – an important driver of soil water repellency. Cross-correlation analysis between rainfall and soil moisture content (Fig. 4) illustrated after the fire, soil moisture responded more strongly to rainfall than before (higher peak at lag=0). However, for greater lag times, the correlation between rainfall and soil moisture decreased for all sites, resulting in a catchment average change depicted in Fig. 4. The initial increased response of soil moisture to rainfall was therefore followed by a long period of decreased response, suggesting that the burned soil dried out more quickly after rain events. This more rapid drying and wetting is in line with findings by Stoof et al. (2011) who observed more rapid development and elimination of soil water repellency after the Valtorto fire.



**Fig. 4** Cross-correlation between hourly rainfall and catchment average soil moisture content in Valtorto, indicating the timing and the strength of the soil moisture response to the occurrence of rainfall. The dotted line (A) indicates for which lag times post-fire cross correlation is significantly different from the pre-fire value ( $p < 0.05$ ), while the dashed line (B) indicates the confidence interval.

Since soil physical changes due to fire were not apparent, we suggest that changes resulting from vegetation removal played an important role in increasing erosion (Shakesby et al. 2010) and streamflow (Fig. 3) after fire, namely: 1) increased effective rainfall and decreased transpiration – increasing the amount of water available for (sub)surface runoff, 2) more rapid development of soil water repellency and decreased surface water storage – increasing overland flow risk, 3) more rapid breakdown of post-fire soil water repellency – increasing infiltration during extended rain events. Results stress that fire impact on hydrology is largely affected by scale, and emphasize the risk of overestimating fire impact when upscaling plot-scale studies to the catchment-scale. Finally, they increase understanding of the processes contributing to post-fire flooding and erosion events.



## References

- Beven, K. J. (2001). *Rainfall-runoff modelling: the primer*. Chichester, UK, Wiley.
- Blöschl, G. and M. Sivapalan (1995). *Scale issues in hydrological modelling: A review*. *Hydrological Processes* 9(3-4): 251-290.
- Cerdà, A. and P. Robichaud (2009). *Fire effects on soils and restoration strategies*. Enfield, NH, USA, Science Publishers.
- Dunkerley, D. (2000). *Measuring interception loss and canopy storage in dryland vegetation: a brief review and evaluation of available research strategies*. *Hydrological Processes* 14(4): 669-678.
- Ferreira, A. J. D., C. O. A. Coelho, C. J. Ritsema, A. K. Boulet and J. J. Keizer (2008). *Soil and water degradation processes in burned areas: Lessons learned from a nested approach*. *Catena* 74(3): 273-285.
- R Development Core Team (2010). *R: A language and environment for statistical computing*. Vienna, Austria, R Foundation for Statistical Computing.
- Scott, D. F. (1993). *The hydrological effects of fire in South African mountain catchments*. *Journal of Hydrology* 150(2-4): 409-432.
- Scott, D. F. and D. B. Van Wyk (1990). *The effects of wildfire on soil wettability and hydrological behaviour of an afforested catchment*. *Journal of Hydrology* 121: 239-256.
- Seibert, J., J. J. McDonnell and R. D. Woodsmith (2010). *Effects of wildfire on catchment runoff response: a modelling approach to detect changes in snow-dominated forested catchments*. *Hydrology Research* 41(5): 378-390.
- Shakesby, R., C. Ferreira, R. Walsh, E. Urbanek, A. Ferreira and C. Stoof (2010). *Temporal changes in sediment, organic matter and nutrient losses following an experimental fire in Atlantic-Mediterranean heath, central Portugal. VI International Conference on Forest Fire Research*. D. X. Viegas. Coimbra, Portugal.
- Shakesby, R. A. and S. H. Doerr (2006). *Wildfire as a hydrological and geomorphological agent*. *Earth-Science Reviews* 74(3-4): 269-307.
- Stoof, C. R., A. J. D. Ferreira, W. Mol, J. Van den Berg, A. De Kort, S. Drooger, E. C. Slingerland, A. U. Mansholt, C. S. S. Ferreira, T. C. J. Esteves and C. J. Ritsema (2011). *Soil surface changes increase erosion risk after low-severity fire (in review)*. *International Journal of Wildland Fire*.
- Stoof, C. R., D. Moore, C. J. Ritsema and L. W. Dekker (2011). *Natural and fire-induced soil water repellency in a Portuguese shrubland (in review)*. *Soil Science Society of America Journal*.
- Stoof, C. R., R. W. Vervoort, J. Iwema, E. Van den Elsen, A. J. D. Ferreira and C. J. Ritsema (2011). *Hydrological response of a small catchment burned by experimental fire (accepted)*. *Hydrology and Earth System Sciences Discussions*.



## Soil water repellency persistence after recurrent forest fires, Mt. Carmel, Israel

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**Key-words:** Forest fire, Long term, Mediterranean, Mt. Carmel, Water repellency.

### Introduction

Changes in the fire regime may play a key role in affecting the natural rates and patterns of: (a) vegetation-community structure and revegetation rates, (b) soils - physical and chemical property changes, and consequently (c) geomorphic processes - runoff processes and sediment yield changes (Delitti et al., 2005; Eugenio, 2006; Herman, 2009).

Mt. Carmel in northwestern Israel (35°W, 32°N) is a prominent triangular mountain ridge, covering approximately 250 km<sup>2</sup>. The climate is Mediterranean, with short, rainy, cool winters and long, dry, hot summers. The lithology is composed of Upper Cretaceous carbonate rocks, mainly limestone, dolomite, chalk, usually overtopped by nari crusts, marl, and local exposure of volcanic tuff (Wittenberg et al., 2007). The dominant soil taxa are mainly Rendolls, Haploxerolls and Rhodoxeralfs (Soil Survey Staff, 2006).

Fire on Mt. Carmel, as in other parts of the Mediterranean basin, is caused mainly by human activity, and has played an ecological role ever since the adoption of fire by Mankind (Naveh, 1990; Pausas and Vallejo 1999).

Repeated burnings can lead to long-term cumulative effects on some ecosystem properties, such as vegetation regeneration (Delitti et al., 2005) and soil resilience (Zedler et al., 1983; Herman, 2009). However, few studies have attempted to address the role of recurrent fires on forest ecosystems (e.g. Ferran et al., 2005; Eugenio et al., 2006; Herman, 2009). If cumulative effects are evident at plant community level, it is likely that they also occur in soils. The loss of plant productivity caused by a reduced availability of nutrients in mineral soils would result in reduced organic matter inputs to soil organic horizons (Eugenio et al., 2006). Moreover, the increasing area and frequency of fires nowadays in some Mediterranean areas create a new ecological situation that can enhance desertification processes (Vallejo and Alloza, 1998).

Among the fire-induced changes in the physical environment, soil water repellency (WR) is a property with major repercussions for plant growth, surface and subsurface hydrology, and for soil erosion. It is also a common property in fire-affected soils (Doerr et al., 2000). In semi-arid areas, where water supply is limited, even a slight WR may significantly affect infiltration rates, runoff and erosion (DeBano, 2000). Soil properties may experience short-term, long-term or permanent fire-induced changes, mainly depending on the type of property, severity and frequency of fires, and post-fire climatic conditions (Kutiel and Shaviv, 1992). The longevity of fire-induced WR depends on some of the factors that affect its formation. Water repellency produced by low-to-moderate severity fires is usually of shorter duration than that produced by high severity fires (DeBano 2000). Most studies indicate that the increase in soil WR due to burning

disappears within a few months to a couple of years (Tessler et al., 2008; Doerr et al., 2009; Malkinson and Wittenberg, 2010).

## Objectives

The research aims at analyzing temporal and spatial changes in soil WR after recurrent forest fires. Methods included: 1) performing Water Drop Penetration Time (WDPT) tests in situ in field conditions on the soil surface, in various sites with different fire histories; 2) soil sampling from the soil surface (0-5 cm) at the same sites, to analyze the influence of recurrent fires on organic matter (OM); 3) laboratory analyses to estimate organic matter content and some other nutrients, and 4) statistical analysis with one way non-parametric ANOVA Kruskal-Wallis and Mann-Whitney tests to estimate the effect of recurrent fires on WR, and to see if there is a correlation between WR and organic matter.

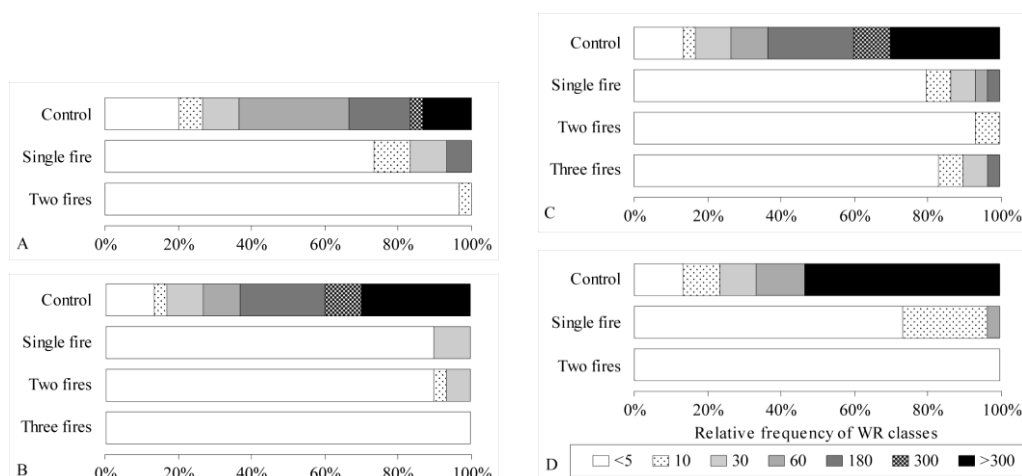
## Methodology

Recurrent fire effects were examined during the summers of 2009 and 2010. Measurements were taken in ten different sites that were burnt during 1989, 1999, 2005 and 2006, and in three control (unburnt) areas. Four categories were addressed: ‘single-fire’ sites, ‘two-fire’ sites, and ‘three-fire’ sites, in addition to the control areas. All samples were taken from open patches in the soil surface (without vegetation cover).

## Results and conclusions

### *General water repellency, seasons 2009–2010:*

Water repellency results from soil surface tests in all fire sites (1989, 1999, 2005, 2006) showed significant differences between the control site and the burnt sites (Kruskal-Wallis test,  $p < 0.001$ ). WR in the control areas that represent the 1999 and 2005 fires was much higher than the burnt samples, indicating natural strong water repellency (>300 s class). 30% of WR values in the control site had a strong repellency (>300 s class), 33% of WR values were in the 180 s - 300 s classes, and 13% were classed as wettable. At the second control site (representing the 1989 area), 13% of WR values observed had a strong repellency: >300 s class, 47% of results were in the 60 s – 180 s class, while 20% were wettable. The same tendency was demonstrated in the 2006 fire control area (Fig. 1).



**Figure 1.** Relative frequency of WR classes at ‘single-fire’ sites, ‘two-fire’ sites and ‘three-fire’ sites in four areas: A- last burnt in 1989, B- last burnt in 1999, C- last burnt in 2005, D- last burnt in 2006; n=30 per site.

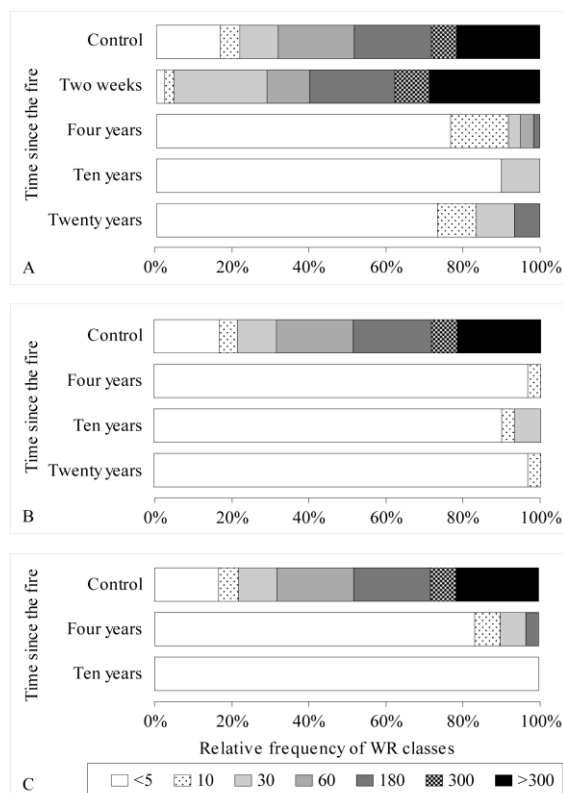
Generally, soil WR is a natural phenomenon that can be intensified by soil heating during fires (Varela et al., 2005). A previous study in Mt. Carmel showed the development of WR after a ‘single fire’, when WR values were higher for several weeks immediately after the fire, and decreased rapidly a few months afterwards (Tessler et al., 2008). The present study shows that 4, 10 and 20 years after single and recurrent fires the WR values were lower than in the control sites. Although there are differences between the soil types that can cause different natural water repellencies, the general trend of WR was the same for a long period after the fires.

### *Long-term changes in water repellency*

Data on long-term WR changes from the burnt and control sites were combined into three groups: a) ‘single-fire’ sites, b) ‘two-fire’ sites and c) ‘three-fire’ sites.

Two weeks after a ‘single fire’ more than 25% of measurements were classified in the >300 s class, while more than 22% were classified into the WR categories of 60 s and 180 s. Four years after a ‘single fire’, WR had decreased, and only 2% of the results were classified into the 60-180 s category. 77% of the samples were classified as wettable soil; other results showed lower values of WR (10-60 s). Ten years after the ‘single-fire’, 90% of the results were classified as wettable. Twenty years after the ‘single-fire’ WR started to increase: 7% of the results were classified with moderate repellency of 60-180 s, and 10% results show low WR (10-30 s).

In the ‘two-fire’ group, the results show very low WR values 4, 10 and 20 years after the recurrent fires. 3% of the results show low WR of 10-30 s in all sites. In the ‘three-fire’ group, after 4 years 83% were classified as wettable soil, while after 10 years 100% were classified as wettable soil. All results are lower than at the control sites (Fig. 2).



**Figure 2.** The influence of numbers of fires and time since the last fire on WR: A- ‘single-fire’ sites, B- ‘two-fire’ sites, C- ‘three-fire’ sites, n = 435.



The effects of fire on WR have been well studied (Doerr et al., 2000), but relatively little work has been done on long-term recovery. Comparing our results from the ‘single-fire’ sites and the control sites to the Tessler et al. (2008) data (two weeks after the 2005 fire) (Fig. 2A), showed the tendency of WR values in the last 20 years at the Carmel region: in the first few weeks after the fire the WR values increase; 4 and 10 years after the fire there is almost no WR on the soil surface, and 20 years after the 1989 ‘single-fire’, WR starts to increase again, and WR is moderate. This tendency has been attributed to increased biological activity and the accumulation of organic matter (Malkinson and Wittenberg, 2010). After recurrent fires, WR values remain low for more than 20 years, and the recovery rate is probably controlled by vegetation and organic matter recovery.

### ***Water repellency and its relationship to soil organic matter***

The OM results showed recurrent fire effects on OM rehabilitation. OM content in the control sites (13%) is consistently higher than in the burnt areas. Moreover, OM in the recurrent fire sites is lower than in the ‘single fire’ sites. For example, in the 1999 ‘single-fire’ site mean OM was 9.7%, whereas only 8.5% and 8.2% were recorded in the ‘two-fire’ and ‘three-fire’ sites, respectively. In Spain, Eugenio et al., (2006) showed a similar tendency, with recurring fires decreasing the amount of soil organic dry mass.

Correlation between soil organic matter (OM) content and WR from all burnt sites shows significant results: WR is higher when the OM content is higher ( $r_s = 0.345$ ,  $n = 100$ ,  $p < 0.001$ ); this tendency increasing with the combination of the control data ( $r_s = 0.561$ ,  $n = 130$ ,  $p < 0.001$ ). These significant results indicate that soil OM controls WR values: when OM values are higher than 10%, WR values increase, particularly in the control areas.

Previous studies indicated that after forest fires some soil properties, such as OM, P, pH, N, texture etc., could be used as indicators for recovery trends. This study supports this approach (Seybold et al., 1999).

The development and nature of fire-induced WR following forest fires in various environments has been widely investigated. Its long-term dynamics, however, are not well understood relative to evaluating hillslope response to fires. Natural WR in the Mediterranean maquis of Mt. Carmel is particularly common, in part due to the coarse-textured soils and the high content of organic matter.

Our results indicate that in the long term, WR in the burnt sites is generally low, and the soil maintains its wettability for more than a decade. After recurrent fires, the rehabilitation process is more complicated, and may take a long time (>30 years). Increase in WR is facilitated by the restoration of the organic matter. When OM is higher than 10% the WR value is also moderate to high. The recovery of natural WR may serve as an indicator for site rehabilitation. These processes may cause a delay in recovery of other soil properties such as carbon stock, pH, phosphorus content, electrical conductivity, etc, and can cause a decrease in the quality and productivity of the site for a long period.

### **References**

- DeBano, L.F. 2000. Water repellency in soils: a historical overview. *Journal of Hydrology*. 231-232: 4–32.
- Delitti, W.A., Ferran, L., Trabud, L., and Vallejo, V.R., 2005. Effects of fire recurrence in *Quercus coccifera* L. shrublands of the Valencia region (Spain): I: plant composition and productivity. *Plant Ecology* 177: 50-70.



- 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., and Huffman, E.L., 2009. Soil water repellency: A key factor in post-fire erosion? In Cerda, A. and Robichaud, P. (Editors) *Fire Effects on Soils and Restoration Strategies*: 197-224.
- Eugenio, M. G., 2006. Fire recurrence effects on *Pinus halepensis* Mill. communities of Catalonia. Thesis submitted for degree Doctor of Philosophy, University of Barcelona.
- Eugenio, M., Lloret, F., Alcaniz J.M., 2006. Regional patterns of fire recurrence effects on calcareous soils of Mediterranean *Pinus halepensis* communities. *Forest Ecology and Management* 221: 313–318
- Ferran, A., Delitti, W., and Vallejo V. R., 2005. Effects of fire recurrence in *Quercus coccifera* L. shrublands of the Valencia Region (Spain): II. plant and soil nutrients. *Plant Ecology* 177: 71-83.
- Herman, J., 2009. Fire recurrence effects on aboveground plant and soil carbon in Mediterranean shrublands with Aleppo pine (*Pinus halepensis*). MSc Thesis, forest ecology and forest management group. Final report.
- Kutiel, P., Shaviv, A., 1992. Effects of soil type, plant composition and leaching on soil nutrients following a simulated forest fire. *Forest ecology and management*, 53: 329-343.
- Malkinson, D., Wittenberg, L., 2010. Post fire induced soil water repellency - modeling short and long-term processes. *Geomorphology* 125: 186-192.
- Naveh, Z., 1990. Fire in the Mediterranean - A landscape ecological perspective, in: Goldammer, J.G., Jenkins, M.J. (Eds.), *Fire in ecosystems dynamics: Mediterranean and Northern perspective*, 1–20. SPB Academic Publication, The Hague.
- Pausas, J.G. Vallejo, V.R., 1999. The role of fire in European Mediterranean ecosystems. In: Chuvieco E. (Ed.), *Remote sensing of large wildfire in the European Mediterranean basin*, Springer-Verlag, pp 3-16.
- Seybold, C.A., Herrick, J.E., Brejda, J.J., 1999. Soil resilience: a fundamental component of soil quality. *Soil Science* 1644: 224-234.
- Soil Survey Staff, 2006. *Keys to Soil Taxonomy*, 10th ed. NRCS, Washington, DC.
- Tessler, N., Wittenberg, L., Malkinson D., Greenbaum, N., 2008. Fire effects and short-term changes in soil water repellency – Mt. Carmel, Israel. *Catena*, Special Issue - Fire Effects on Soil 74: 185-191.
- Vallejo R., and Alloza J.A., 1998. The restoration of burned lands: the case of eastern Spain. In: Moreno J.M. (ed.), *Large Forest Fires*. Backhuys Publishers, Leiden, The Netherlands: 91–108
- Varela, M.E., Benito, E., de Blas, E., 2005. Impact of wildfires on surface water repellency in soils of northwest Spain. *Hydrological Processes* 19: 3649–3657.
- Wittenberg, L., Malkinson, D., Beerli, O., Halutzky, A., Tessler, N. 2007. Spatial and temporal patterns of vegetation recovery following sequences of forest fire in a Mediterranean landscape Mt. Carmel, Israel. *Catena* 71: 76-83.
- Zedler, P.H., Gautier, C.R., McMaster, G.S., 1983. Vegetation change in response to extreme events: the effect of a short interval between fires in California chaparral and coastal scrub. *Ecology* 64: 809–818.





## Impacts of wildfire on soil water repellency within obligate resprouter Eucalypt communities near Sydney, Australia

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**Key-words:** Soil water repellency; Eucalyptus; wildfire; soil.

### Introduction

Wildfire can either induce or enhance the amount of repellency within a soil body, depending on the temperature and wildfire intensity reached during the wildfire. (Keizer et al. 2008; Shakesby and Doerr 2006; Tessler et al. 2008; Zavala et al. 2009). Laboratory studies conducted by DeBano and Krammes (1966) found that little change occurs in water repellency when soils are heated to approximately less than 175 °C. Water repellency is induced when temperatures range between 175 and 200°C, whilst destruction of water repellency occurs at temperatures between 280 and 400 °C.

Similar studies were performed by Doerr et al (2004) and Zavala et al. (2010) which assessed soils under Eucalypt forests in Spain, Mexico and Australia. Results showed that soil water repellency did not change significantly with respect to unheated control samples between 100-150 °C. However, once temperature were increased to 250-300 °C, water repellency decreased and was completely destroyed when temperatures reached 400-450 °C.

Doerr et al. (2006) examined different effects of fire severity on soil water repellency in eucalypt forest catchments in the sandstone tablelands near Sydney, burnt in 2001 and 2003. All non-burnt soils were identified to be naturally repellent, whilst soils impacted by high severity levels witnessed destruction in their repellency levels within the soil surface (0-2.5 cm). Within 2 years post-wildfire, repellency levels had still not recovered to their pre-wildfire repellency levels.

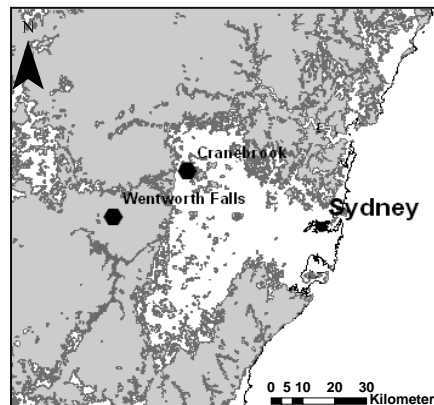
The objective of this paper is to:

- i) assess the impact of different wildfire severities on soil water repellency within two study sites near Sydney, Australia
- ii) assess the response of water repellency through time according to the different severity levels at two study sites near Sydney, Australia.

### Methods

We selected two study sites situated within the outer Sydney basin, Australia (Figure 1) that were burnt by wildfire in 2009/10 fire season. Cranebrook, is located on a lowland floodplain. The geology consists of Quaternary alluvium derived from Wianamatta Group shales (Bringelly shale), with smaller areas overlaid with Tertiary alluvial sediments. The lithology of the region is dominated by fine sand. Cranebrook was impacted by wildfire during December 2009 and has no other recent history of wildfire. The second site, Wentworth Falls, is situated within mountainous terrain. The underlying geology of Wentworth Falls consists of ancient Triassic sandstone plateau (Hawkesbury and Narrabeen sandstones) with Narrabeen mudstone embedded throughout it. The soils

within the region are dominated by coarse sands. Wentworth Falls was affected by wildfire in November 2009 and was previously burnt in January 2002. Both sites are dominated by resprouting *Eucalyptus* sp. with a dense shrubby understorey. Landsat 5 satellite imagery was collected for both pre- and post- wildfire for both study sites. At each site the differenced Normalised Burn Ratio (dNBR) was computed to determine the difference in images between pre- and post- wildfire across the study sites. The dNBR at each site was then classified into five classes to quantify the relative degree of fire severity that occurred across each study site. In this instance, 5 severity classes were used for each study site, ranging from unburnt to very high severity levels (see Chafer 2008).



**Figure 1.** Location of study sites

Field sampling was conducted at each site 6 months and 1 year post-wildfire. For each severity class, three sites were selected at random for each study site, except for the low severity class at Cranbrook due to restricted access allowing only 2 sites to be selected ( $n = 58$ ). At each site a ten metre transect was marked out and soil samples were collected at one metre intervals along the transect. At each sample site, data was collected for 0-2 cm depth and 2-5cm depth (total  $n = 580$ ). All sites were located at least 20 m from any human disturbance. Leaf litter and organic matter was removed from the top of each sample, gently using a brush. Unburnt sites were selected adjacent to the burnt areas and the same method was applied.

The soils were bulked over each transect and the particle size analysis was measured for each transect using the hydrometer method from Gee and Bauder (1986).

Water repellency was analysed in the laboratory through the Water Drop Penetration Time (WDPT) technique (Bisdorn 1993). The 10 samples from each transect were analysed separately. All samples were left to air dry at 27 °C until dried. Samples were sieved through a 2 mm sieve to remove excess material such as litter and rocks. Each soil sample was then placed into a petri dish at least 1 cm high and then was slightly compacted using a weight. All samples were left to equilibrate over night in controlled atmospheric conditions (20 °C). Using a standard eye dropper, 3 drops of distilled water were placed on the surface of each soil sample and the time for each droplet to penetrate into the soil into the soil was recorded. Each recorded was able to then be compared to the WDPT time intervals used by Bisdorn et al. (1993). Samples which infiltrated <5 seconds were classed as wettable, 5-60 seconds classed as slightly wettable, 60-600 seconds strong repellency, and 600-3600 seconds severe repellency. All sample recordings were terminated once the time reached 3600 seconds.



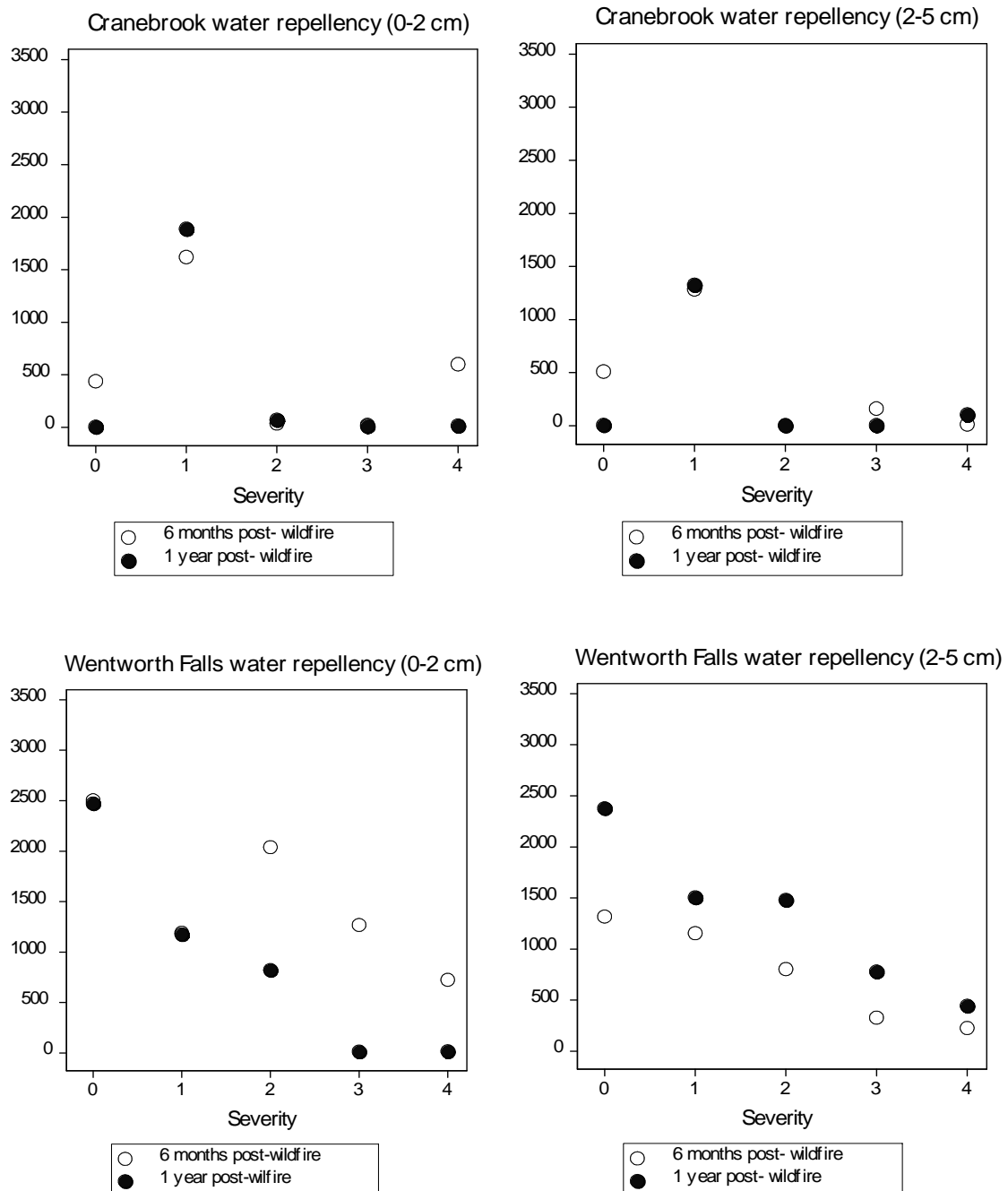
The average repellency time for each transect was recorded for each depth interval, the top 0-2 cm and bottom 2-5 cm. From this, the results for each transect were then categorised under the appropriate severity class and time period in which they were sampled (6 months or 1 year post-wildfire). Normality of data was assessed and if not normal it was transformed and logged, as seen in the case of Cranebrook. An analysis of variance (ANOVA) was used to determine if there was a significant difference ( $P < 0.05$ ) between:

- a) the water repellency levels across the different burn severity classes;
- b) the two time periods that were sampled; and
- c) the interaction between burn severity and time.

### Results and Conclusions

The particle size fractions at both study sites varied as a result of the local lithology. Cranebrook is dominated by fine sand at both 0-2 cm (31-63 %) and 2-5 cm (23-63 %) below the soil surface. Coarse sand occurs in the top 0-2 cm of soil (17-47 %), with a little more variation at 2-5 cm (18-58 %). Clay percentage at 0-2 cm of soil is 10-23 % and 2-5 cm of soil is 10-20 %. Silt ranges from 3-10% at 0-2 cm below soil surface and 6-10 % at 2-5 cm below soil surface. Wentworth Falls soil samples displayed a higher percentage of coarse sand ranging from 63-88 % at 0-2 cm and 62-89 % at 2-5 cm. Fine sand varies from 8-19 % at 0-2 cm and 4-23 % at 2-5 cm. Only 5-14 % of clay is present at 0-2 cm and 4-14 % at 2-5 cm. Silt attained the lowest percentage across the landscape ranging from only 1-8 % at 0-2 cm of soil and 2-6 % at 3-5 cm of soil.

At both time periods sampled for Cranebrook, a similar trend in the overall pattern of repellency levels at both 0-2 cm and 2-5 cm occurred (Fig. 2). Cranebrook experienced a sudden decline in repellency levels across unburnt sites between 6 months to 1 year post-wildfire (Fig 2). Soils went from experiencing strong water repellency at both 0-2 cm and 2-5 cm 6 months post-wildfire, to becoming wettable 1 year post wild-fire. Heavy rainfall occurring in the weeks before sampling took place 1 year-post wildfire could have resulted in this fluctuation in repellency levels. Similar findings have previously been observed in north-central Portugal (Keizer et al. 2008) and Australia (Doerr and Thomas, 2000). Low severity affected areas experienced the highest repellency levels increasing from 1620 seconds at 0-2 cm 6 months post-wildfire to 1889 seconds 1 year post-wildfire. At 2-5 cm, water repellency was slightly lower but still severe at 1285 seconds 6 months post-wildfire and 1326 seconds 1 year post-wildfire. Very high severity areas changed the most, with repellency times of 600 seconds 6 months post-wildfire at 0-2 cm falling to only 16 seconds at 1 year post-wildfire. For 2-5 cm samples, the repellency increased from 13 seconds to 105 seconds. This trend in the data agrees with the Findings of DeBano and Krammes (1966), which acknowledges that low temperatures may enhance repellency levels, whilst an increase in temperature will destroy it. Although variation occurred, Cranebrook did not encounter a significant difference in its soil water repellency across the 5 severities for both 0-2 cm of soil ( $p = 0.232$ ) and 2-5 cm of soil ( $p = 0.188$ ). Cranebrook also showed no significant difference in the data recorded over the two time periods sampled or the interaction of burn severity and results for each time period sampling occurred.



**Figure 2.** Average water repellency time for each severity class according to each study site at 0-2 cm and 2-5 cm, for each sampling time.

Wentworth Falls experienced a declining trend in repellency levels as the burn severity levels increased (Fig 2.) Naturally Wentworth Falls is identified to obtain severely repellent soils at both 0-2 cm and 2-5 cm. Such a high repellence could be a result of vegetation species as previous Australian studies conducted by Doerr et al. (2006) and Howell et al. (2006) have established that soil repellence is common in pre-fire drought conditions in Australia. However, such results could also be a reflection of the coarse sandy soil particles found within Wentworth Falls. Water repellency in sandy soils is known to develop as a consequence of sand particles being coated with organic substances produced by fungal activity (Chan 1992). Sites impacted by the 2009 wildfire experienced an overall decline in water repellency at 0-2 cm as the degree of burn



severity increased for both 6 months and 1 year post-wildfire. Overall, high burn severity at 0-2 cm experienced the greatest difference in repellency levels decreasing from 1268 seconds to 15 seconds, causing the soil to become slightly wettable. At 2-5 cm, low and moderate severities experienced severe water repellency levels at 6 months and 1 year post-wildfire. High and very high severities were identified to encounter strong repellency both 6 months and 1 year post-wildfire at 2-5 cm. Overall, there was a significant difference in the water repellency across the 5 burn severities at Wentworth Falls within the top 0-2 cm ( $p = 0.043$ ), whilst no significant difference occurred for the bottom 2-5 cm of soil ( $p = 0.057$ ). There was no significant difference in the data recorded over the two time periods sampled or the interaction of burn severity and results for each time period sampling occurred.

In conclusion, it was observed that Wentworth Falls has a naturally repellent soil with coarse sand particles dominating the region, whilst Cranebrook has slight to strong repellent soil. Although variation in repellency occurred, no significant difference in water repellency levels across the different burn severity classes at 0-2 cm and 2-5 cm was found at Cranebrook. Wentworth Falls only obtained a significant difference in repellency across burn severities at 0-2 cm. Both sites encountered no significant difference in the repellency times recorded over the two periods sampled or the interaction between burn severity and time.

## References

- Bisdorn, E.B.A. 1993. *Water repellency of sieve fractions from sandy soils and relationships with organic material and soil structure*. Geoderma 56, 105–118.
- Chafer, C.J. 2008. *A comparison of fire severity measures: An Australian example and implications for predicting major areas of soil erosion*. Catena 74, 235-245.
- Chan, K.Y. 1992. *Development of seasonal water repellence under direct drilling*. Soil Science Society of America Journal 56, 326–329.
- DeBano, L.F., Krammes, J.S. 1966. *Water repellent soils and their relation to wildfire temperatures*. Bulletin of the I.A.S.H., XI(2):14-19.
- Doerr, S.H., Blake, W.H., Shakesby, R.A., Stagnitti, F., Vuurens, S.H., Humphreys, G.S., Wallbrink, P. 2004. *Heating effects on water repellency in Australian eucalypt forest soils and their value in estimating wildfire soil temperatures*. International Journal of Wildland Fire 13, 157-163.
- Doerr, S.H., Shakesby, R.A., Blake, W.H., Chafer, C.J., Humphreys, G.S. and Wallbrink, P.J. 2006. *Effects of differing wildfire severities on soil wettability and implications for hydrological response*. Journal of Hydrology 319, 295-311.
- 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.
- Gee, G.W., Bauder, J.W. 1986. *Particle size analysis*. In *Methods of soil analysis: Physical and Mineralogical Methods*. 2nd edn. Agronomy Monograph 9. Part 1. Ed. A Klute. pp 383-411. ASA-SSSA, Madison, WI.
- Howell, J., Humphreys, G., Mitchell, P.B. 2006. *Changes in soil water repellence and its distribution in relation to surface microtopographic units after a low severity fire in eucalypt woodland, Sydney, Australia*. Australian Journal of Soil Research 44, 205–217.
- Keizer, J.J., Doerr, S.H., Malvar, M.C., Prats, S.A., Ferreira, R.S.V., Oñate, W.G., Coelho, C.O.A., Ferreira, A.J.D. 2008. *Temporal variation in topsoil water*



- repellency in two recently burnt eucalypt 7stands in north-central Portugal. Catena 74, 192-24.*
- Shakesby, R.A., Doerr, S.H. 2006. *Wildfire as a hydrological and geomorphological agent. Earth-Science Reviews, 74, 269-307.*
- Tessler, N., Wittenberg, L., Malkinson, D., Greenbaum, N. 2008. *Fire effects and short-term changes in soil water repellency- Mt. Carmel, Israel. Catena 74, 185-191.*
- Zavala, L.M., González, F.A., Jordán, A. 2009. *Fire-induced soil water repellency under different vegetation types along the Atlantic dune coast-line in SW Spain. Catena 79, 153-162.*
- Zavala, L.M., Grangedm A.J.P., Jordán, A., Bárcenas-Moreno, G., 2010. *Effect of burning temperature on water repellency and aggregate stability in forest soils under laboratory conditions. Geoderma 158, 366-374.*



## The relative importance of soil water repellency in determining runoff-infiltration processes in burned Mediterranean forest soils

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**Key-words:** Water repellency, forest fire, rainfall simulation.

### Introduction

Ecosystem properties undergo considerable changes following wildfires, which include modifications to the vegetation (Keeley, 2009) and the soil structure/texture (Certini, 2005), and consequently soil infiltration and water storage capacities are reduced (Robichaud, 2000) facilitating a general increase in overland flows and sediment yields (Coelho et al., 2004). Fire induced water repellency (WR) has been suggested to be a process changing the hydrological response of burned sites (Doerr et al., 2000), although its role is somewhat controversial (Larsen et al., 2009), partially, as the direct effects of WR under field conditions have been difficult to isolate. The soil and vegetation respond in a complex manner to burning, and soil WR is only one of several processes affecting soil hydrology. Several factors, including fire severity, soil and vegetation type and soil moisture content affect the degree and the spatial distribution of WR.

### Objectives

The objectives of this study were twofold. First we evaluated *in situ* the effects of burnt pine trees on generating spatial patterns of hydrophobicity. Second, we conducted a complementary controlled experiment in which we assessed the effects of burned pine needles on hydrophobicity and runoff generation.

### Methodology

During July 2009 a 60 ha stand of *Pinus halepensis* located in the Byria forest in northern Israel was consumed by a forest fire. The forest, located in a mountainous region characterized by a Mediterranean climate, is dominated by afforested pine stands which were planted during the 1950s. The soils of the region are composed of reddish-brown clay loam forest soil, terra rossa on limestones and greyish light rendzina on the marl and chalk exposures.

In the field segment of the research we studied the spatio-temporal distribution of WR, generated by the fire event, in relation to tree stumps which burned during the fire. We measured *in situ* hydrophobicity one week, a month and five months following the fire event, using the WDPT test. Measurements were taken in two concentric circles around the burned trees (0.5 m, 1 m) at two soil depths, (surface and 5 cm depth), yielding 16 drop locations around each tree. At each drop locations, three drops were applied, and the measurements were carried out during three time periods after the fire (2, 15 and 28 weeks after the fire).



Additionally, we conducted a series of laboratory rainfall simulations in order to evaluate the effect of the fire in a controlled manner on the formation of WR. Four treatments were applied to 30x50 cm trays containing unburned soils collected from the Byria forest: (a) non-burned soil, (b) non-burned soil + pine needles, (c) burned soil without ash (300<sup>0</sup>C/15 min. after adding pine needles) and (d) burned soil with the residue ash (300<sup>0</sup>C/15 min. after adding pine needles). The trays were sub-divided with a 5x5 cm grid, and in the centre of each cell WR was assessed. The unsorted soil was dried at 60 °C for 24 h and sieved in portions of two aggregate sizes: 0-4 mm and 0-15 mm to estimate differences in hydrophobicity for coarse and finer aggregates.

To assess runoff response to the different treatments constant rainfall intensity of 32-33 mm/hr was simulated. The duration of the first run was 4.5 hours, and extended for the time period in order to achieve equilibrium in through flow. For the following runs simulation lasted only 2 hours, though the final infiltration rate was not attained. Following the first session the experimental trays were oven dried and the effects of a second rainstorm were studied.

## Results

Soil hydrophobicity measurements are extremely variable over short distances. Additionally, time measurements are highly skewed due to the long infiltration time associated with the hydrophobicity. Therefore, in order stabilize the variance associated with the database we log-transformed the data and averaged the three WDPT measurements taken in each location. We conducted a 2X2X4 ANOVA to assess whether differences in WR can be attributed to the distance of measurement from the tree (0.5, 1m), the depth (soil surface, 5 cm below surface), the interaction between these two factors, and the time since the fire. The overall analysis yielded a significant model ( $F = 4.48, p < 0.001, 239 d.f.$ ). The distance from the tree in which measurements were applied was not found to be a significant explanatory variable, whereas the depth of the measurement was ( $F = 17.4, p < 0.001, 1 d.f.$ ). Also, a significant that an interaction term exists between distance and depth, ( $F = 6.03, p = 0.015, 1 d.f.$ ), indicating that WR responds differently to distance from the tree, in the two measured depths. At a distance of 0.5 m from the burned trees higher WR values were observed at a depth of 5 cm below soil surface while at a distance of 1 m higher WR values were observed at the surface (Table 1).

**Table 1.** mean WDPT 0.5 and 1 m from the burnt trees, at the soil surface and subsurface

	Depth	
Distance	surface	subsurface
0.5 meter	35.2	64.5
1 meter	25.2	17.5

Time since fire also appeared to be a significant factor affecting WR, although not monotonically. Two weeks after the fire highest WR values were observed (mean WDPT = 50.0 seconds) compared to a mean value of 11.7 in the control plots. WR values decreased 15 weeks after the fire event, but 28 weeks after the event mean WR values increased back almost to the 2-week post fire values (Table 2).





**Table 2.** mean WDPT 2, 15 and 28 weeks following the fire

<b>weeks after fire</b>	<b>Mean WDPT</b>
2	50.05
15	21.68
28	47.26
control	11.74

### WR- laboratory results

Following the combustion of app. 1 kg of pine needles, uniformly distributed over the soil surfaces of the experimental trays, between 11-16% of the tray's surface revealed slight-strong water repellency. Nonetheless, the spatial distribution of the hydrophobic patches appeared to be randomly distributed in the trays.

### Runoff

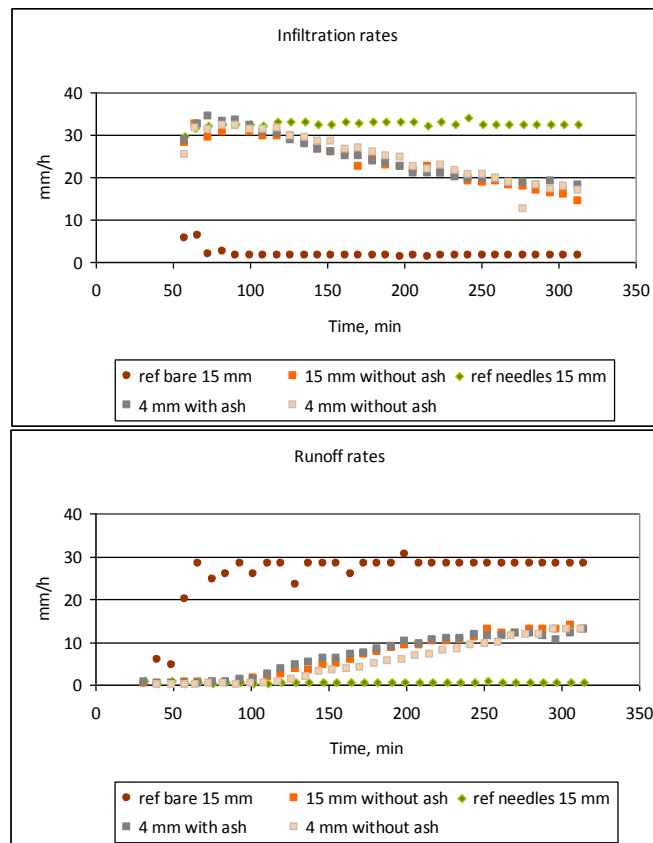
For all treatments, burned and control, runoff starts in run 1 following accumulative amount of 13 to 16 mm of simulated precipitation. Three main clusters of hydrologic responses are evident (figures 1-2):

- A steady high level of runoff rates (25 - 28 mm h<sup>-1</sup>) which was reached after 40 mm during which the runoff rate increased.
- Intermediate, runoff rates for all burned soils. After a period of very low runoff rates, the soils (at 35 mm) impeded drainage and runoff rates gradually increased.
- Low runoff rates for the samples with the needle cover, where on average runoff rates did not exceed 0.5 mm h<sup>-1</sup>.

In the second run, transportation of water and sediments were observed following a lower amount (in comparison to the first run) of only 7 mm for all treatments. Nonetheless, for 4mm and 15mm *cover* (with ash) trays the runoff rates remained at the stable low level of 0.5 mm h<sup>-1</sup>, whilst runoff rates in the burned treatment increased to 20-25 mm h<sup>-1</sup>.

### Infiltration

Non burnt soils exhibited the uppermost (bare soil) and the lowest (covered soils) fairly constant infiltration rates, whereas intermediate values were observed at the burnt samples no matter the aggregate size (4mm or 15mm) or the type cover of the soils. A decreasing trend was observed during the rainfall simulation as was also reflected in the complementary increase in runoff rates.



**Figure 1-2.** Infiltration and runoff rates of the various treatments, rainfall simulations RUN1

## Conclusions

In the burnt *Pinus halepensis* forest, fire induced high water repellency values were found 6 months after the burning, even after several rainfall events. While WR is exceedingly spatially heterogeneous nonetheless, a complex but persistent pattern of hydrophobicity is observed. At a distance of 0.5 m from the trunks the higher WR values were observed at the subsurface, whereas at a distance of 1m higher degrees of WR developed at the surface. It has been established that maximum fire-generated hydrophobicity peaks at temperatures of approximately 170-200°C, and decreases at higher temperatures (Doerr et al. 2000). The large pine trees present in the study area provide an important fuel source for the fire, and most likely are consumed by higher temperature flames. A strong temperature gradient exists from the soil surface, which burns at temperatures of several hundred deg. Celsius, towards the deeper strata of the soil, resulting in the formation of WR layers in the subsurface. With increasing distances from the trees flame temperatures drop, leading to the migration of the hydrophobic soil layer upwards. Our study design may not have captured the maximum WR rates in the different location, but reflects the exiting patterns.

The attempt to create homogeneous hydrophobic layer under controlled laboratory conditions yielded a scattered pattern of repellency, similar to the patterns observed in the field. In contrast to expected, the bare soil and bare soil covered by needles exhibited the highest and lowest infiltration rates, respectively, while the burned soils demonstrated transitional intermediate rates. It is thus suggested that in some soils, WR might enhance infiltration capacity by creating a complex mosaic of runoff-generating and runoff-absorbing micro-patches. Rapid crusting of non-burned soil provided lateral connectivity



(=increased runoff) whilst the accumulation of litter and organic matter blanket the surface and enhance the vertical conductivity (=infiltration). Equilibrium runoff rates are independent of the degree of water repellency and converge to a constant runoff-infiltration ratio, presumably, due to the spatial structure of the connectivity among the WR patches. Repellency generating mechanisms may be fire-induced hydrophobicity coupled with physical soil sealing whereas the specific role of each of these components is utterly unpredictable.

## References

- Certini, G., 2005. Effects of fire on properties of forest soils: a review. *Oecologia* 143, 1-1.
- 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 Hydrology*, 37: 233-240.
- Doerr, S.H., Shakesby, R.S., Walsh, R.P.D., 2000. Soil water repellency: its characteristics, causes and hydro-geomorphological consequences. *Earth Science Reviews*, 51:33–65.
- Keeley, J.E., 2009. Fire intensity, fire severity and burn severity: a brief review and suggested usage. *International Journal of Wildland Fire*, 18(1): 116-126.
- Larsen, I.J. et al., 2009. Causes of Post-Fire Runoff and Erosion: Water Repellency, Cover, or Soil Sealing? *Soil Sci Soc Am J*, 73(4): 1393-1407.
- Robichaud, P.R., 2000. Fire effects on infiltration rates after prescribed fire in Northern Rocky Mountain forests, USA. *Journal of Hydrology*, 231-232: 220-229.



## Variability of the soil thermal properties after a prescribed fire

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

### Introduction

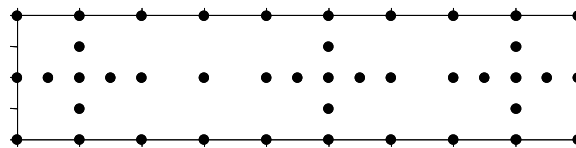
Prescribed fires are used in Catalonia since 1999 as a tool, among others, for managing forested areas with large amounts of fuel in order to prevent high intensity fires. The Montgrí prescribed fire main objective was reduced the scrubland in an ancient and abandoned pine plantation. On the whole of 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  $\mu\text{m}$  and a device by dispersion laser beams (Malvern Mastersizer/E) for particles smaller than 50  $\mu\text{m}$ . 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  $\lambda$ ,  $\alpha$  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  $\lambda$ ,  $\alpha$  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

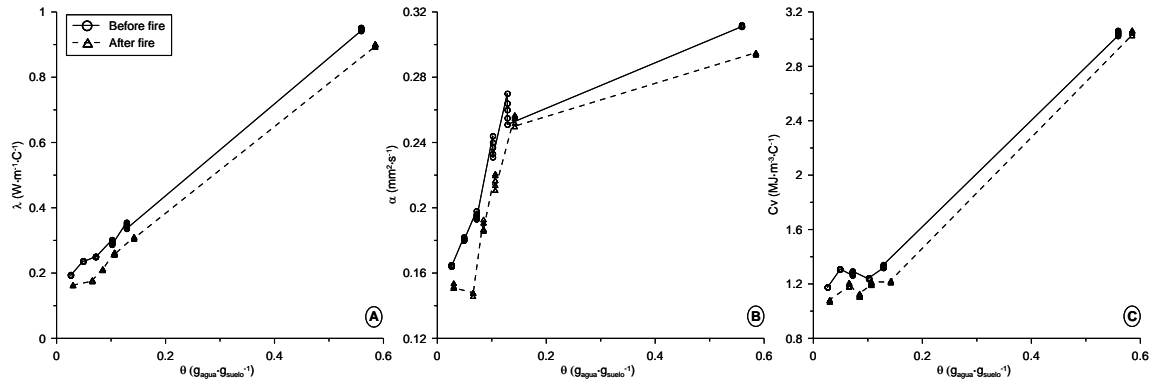
The soil from this plot in the Montgrí massif was classified according to USDA as loam textural class (SSS, 1998). Mean bulk density was around 1.1  $\text{g}\cdot\text{cm}^{-3}$ . The chemical and physical properties values before and after prescribed fire were, respectively: mean total organic carbon 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;  $\text{CaCO}_3$  = 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
$\text{CaCO}_3$ (%)	<3	<3
Hw (%)	1.8	1.9

Respect to soil thermal properties, all of them  $\lambda$ ,  $\alpha$  and  $C_v$  showed changes in their values. Indeed, in all cases the values of soil  $\lambda$ ,  $\alpha$  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

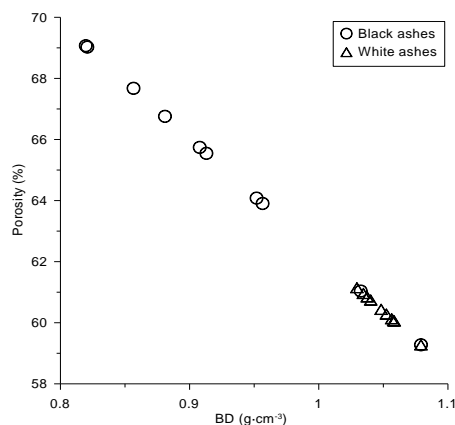
changes in the variables. Also, the mean temperature values for the soil samples before and after fire during the experiment were about 21.5°C and 18.5°C, respectively. The difference between both values did not affect the soil thermal properties measurements. Finally, a new experiment using the black 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.



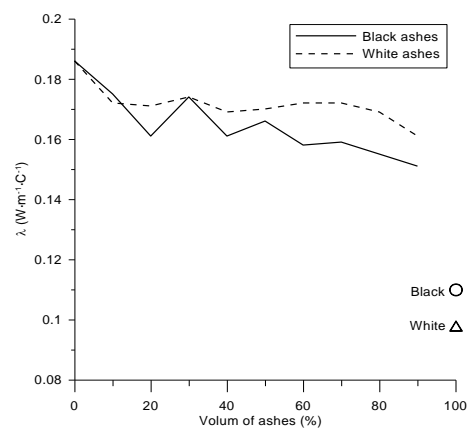
**Figure 2.** Dry-out curves of the relationship between **A:** thermal conductivity, **B:** thermal diffusivity, **C:** volumetric heat capacity and gravimetric water content.

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  $\lambda$ . 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  $\lambda$  (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

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**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 post-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.

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### 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, AK., 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)

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**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<sup>-2</sup> of straw mulch; d) burnt soil with a mixture of seeds at a rate of 45 g m<sup>-2</sup> (*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  $\beta$ -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<sub>i</sub>) 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 <sup>-1</sup> )	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 <sup>-1</sup> h <sup>-1</sup> )	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 <sub>4</sub> <sup>+</sup> g <sup>-1</sup> h <sup>-1</sup> )	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 <sup>-1</sup> h <sup>-1</sup> )	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.

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

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**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 20<sup>th</sup> and 30<sup>th</sup>, 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 m<sup>3</sup> 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 20<sup>th</sup>, 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 30<sup>th</sup>. 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 20<sup>th</sup> (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 20<sup>th</sup> 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 20<sup>th</sup> 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 20<sup>th</sup> 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  $1 \text{ m s}^{-1}$  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

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**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/m<sup>2</sup>, 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/m<sup>2</sup> 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.

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## 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)

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**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<sup>-2</sup> (B+S), burnt soil with 250 g m<sup>-2</sup> 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.

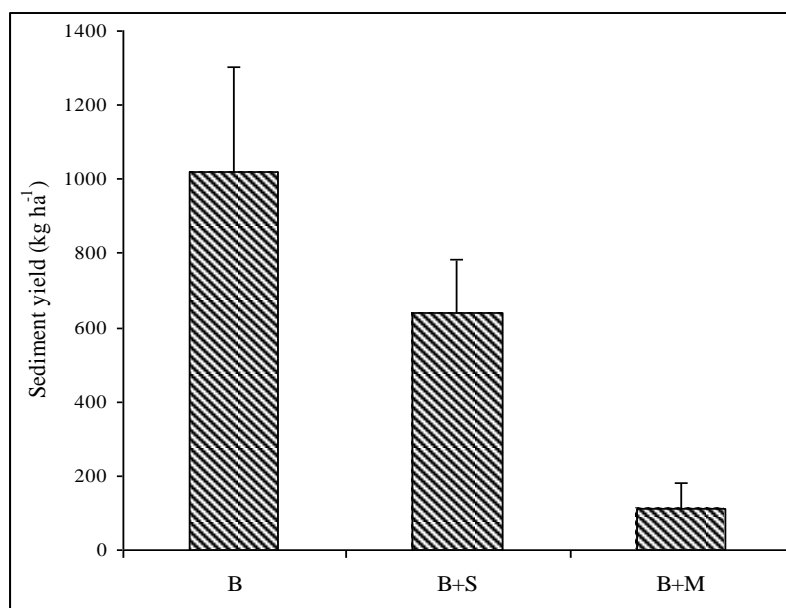
**Table 1.** Soil properties in the different soil treatments immediately and 4 months after the wildfire (mean values $\pm$ SD of three field replicates). Treatments: U, unburnt soil; B, burnt soil; B+S, burnt soil plus seeding; B+M, burnt soil plus straw addition.

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 repelence	0	Very severe	Very severe	Very severe	Very severe
Water field capacity (g water kg <sup>-1</sup> )	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 <sub>water</sub>	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 <sub>KCl</sub>	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 ( $\mu$ S cm <sup>-1</sup> )	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 <sup>-1</sup> )	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, unburnt 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 <sup>-1</sup> )
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.

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## 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 alter 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

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**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 20<sup>th</sup> and 30<sup>th</sup>. 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<sup>-1</sup>) 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 4<sup>th</sup> 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.

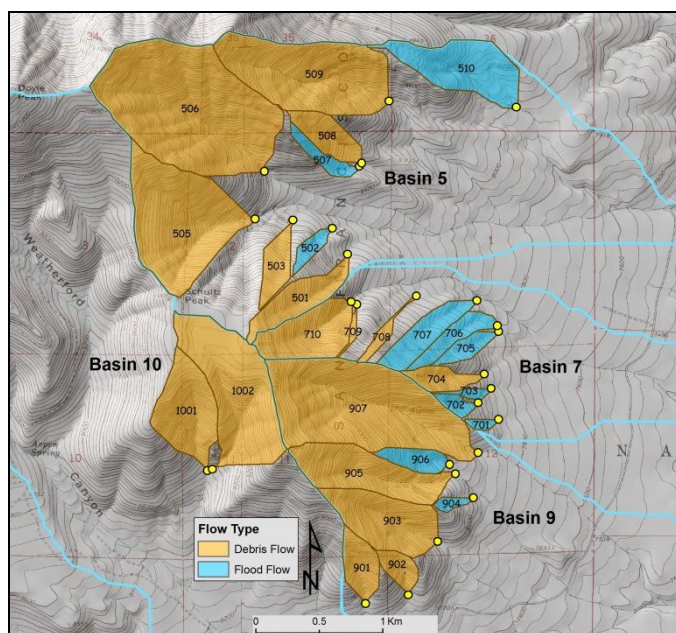
### **Objectives**

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 km<sup>2</sup> with an average area of 0.08 km<sup>2</sup>. Debris-flow basin areas ranged from 0.01-1.11 km<sup>2</sup> with an average area of 0.34 km<sup>2</sup>. 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<sup>-1</sup> yr<sup>-1</sup> 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<sup>-1</sup> yr<sup>-1</sup>. 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

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**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 europaeus*. 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 20-30cm (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 cm<sup>3</sup> 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<sup>-3</sup> (Ekinici, 2006; Hubert 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 ± standard deviation)

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

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 ± standard deviation)

Depth (cm)	Burned				Unburned			
	Sand	Silt	Clay	Textural classes	Sand	Silt	Clay	Textural classes
0-5	44.0 ± 3.4 <sup>a</sup>	34.8 ± 1.9 <sup>b</sup>	21.2 ± 2.7 <sup>a</sup>	Loam	48.8 ± 2.8 <sup>b</sup>	30.5 ± 2.3 <sup>a</sup>	20.7 ± 2.3 <sup>a</sup>	Loam
5-20	44.7 ± 3.6 <sup>a</sup>	34.5 ± 2.7 <sup>a</sup>	20.8 ± 1.4 <sup>b</sup>	Loam	45.4 ± 3.1 <sup>a</sup>	31.9 ± 2.5 <sup>a</sup>	22.7 ± 2.0 <sup>a</sup>	Loam
20-30	40.6 ± 2.5 <sup>a</sup>	39.2 ± 3.5 <sup>b</sup>	20.2 ± 5.2 <sup>a</sup>	Loam	47 ± 2.3 <sup>b</sup>	30.6 ± 1.8 <sup>a</sup>	21.9 ± 2.3 <sup>a</sup>	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 <sub>2</sub> O)	SOM (%)	Total N (%)	Extractable P (mg kg <sup>-1</sup> )	Extractable K (mg kg <sup>-1</sup> )	Sum exchange bases (cmol (+) kg <sup>-1</sup> )
Burned						
0-5	4.78 $\pm$ 0.32 <sup>a</sup>	7.55 $\pm$ 3.36 <sup>b</sup>	0.12 $\pm$ 0.14 <sup>b</sup>	14.25 $\pm$ 4.90 <sup>a</sup>	147.13 $\pm$ 39.49 <sup>a</sup>	3.92 $\pm$ 0.78 <sup>a</sup>
5-10	4.69 $\pm$ 0.27 <sup>a</sup>	4.03 $\pm$ 0.84 <sup>a</sup>	0.06 $\pm$ 0.09 <sup>a</sup>	9.17 $\pm$ 7.39 <sup>a</sup>	118.88 $\pm$ 25.12 <sup>a</sup>	3.10 $\pm$ 0.42 <sup>a</sup>
10-15	4.69 $\pm$ 0.28 <sup>a</sup>	3.28 $\pm$ 0.46 <sup>a</sup>	0.02 $\pm$ 0.02 <sup>a</sup>	8.23 $\pm$ 7.12 <sup>a</sup>	112.63 $\pm$ 20.74 <sup>a</sup>	2.96 $\pm$ 0.26 <sup>a</sup>
15-20	4.74 $\pm$ 0.28 <sup>a</sup>	2.05 $\pm$ 0.79 <sup>a</sup>	0.01 $\pm$ 0.01 <sup>a</sup>	10.67 $\pm$ 8.91 <sup>a</sup>	102.88 $\pm$ 17.99 <sup>a</sup>	3.03 $\pm$ 0.27 <sup>b</sup>
20-30	4.70 $\pm$ 0.23 <sup>a</sup>	1.25 $\pm$ 0.97 <sup>a</sup>	0.01 $\pm$ 0.01 <sup>a</sup>	8.03 $\pm$ 4.52 <sup>a</sup>	83.13 $\pm$ 8.34 <sup>a</sup>	2.88 $\pm$ 0.26 <sup>a</sup>
Unburned						
0-5	5.18 $\pm$ 0.38 <sup>b</sup>	4.84 $\pm$ 0.54 <sup>a</sup>	0.03 $\pm$ 0.02 <sup>a</sup>	34.26 $\pm$ 25.18 <sup>b</sup>	164.88 $\pm$ 50.67 <sup>a</sup>	4.50 $\pm$ 0.59 <sup>a</sup>
5-10	4.85 $\pm$ 0.18 <sup>a</sup>	3.40 $\pm$ 0.62 <sup>a</sup>	0.14 $\pm$ 0.18 <sup>b</sup>	20.71 $\pm$ 24.12 <sup>a</sup>	105.75 $\pm$ 52.42 <sup>a</sup>	3.08 $\pm$ 0.31 <sup>a</sup>
10-15	4.87 $\pm$ 0.28 <sup>a</sup>	3.02 $\pm$ 0.66 <sup>a</sup>	0.03 $\pm$ 0.01 <sup>a</sup>	23.20 $\pm$ 22.90 <sup>a</sup>	92.75 $\pm$ 54.16 <sup>a</sup>	2.83 $\pm$ 0.20 <sup>a</sup>
15-20	4.84 $\pm$ 0.19 <sup>a</sup>	3.01 $\pm$ 0.92 <sup>b</sup>	0.02 $\pm$ 0.01 <sup>a</sup>	16.24 $\pm$ 17.04 <sup>a</sup>	87.75 $\pm$ 51.98 <sup>a</sup>	2.70 $\pm$ 0.19 <sup>a</sup>
20-30	4.75 $\pm$ 0.09 <sup>a</sup>	2.87 $\pm$ 0.61 <sup>b</sup>	0.09 $\pm$ 0.09 <sup>a</sup>	11.98 $\pm$ 9.44 <sup>a</sup>	84.63 $\pm$ 45.62 <sup>a</sup>	2.82 $\pm$ 0.30 <sup>a</sup>

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

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**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 Lupoia and Jilţ 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.

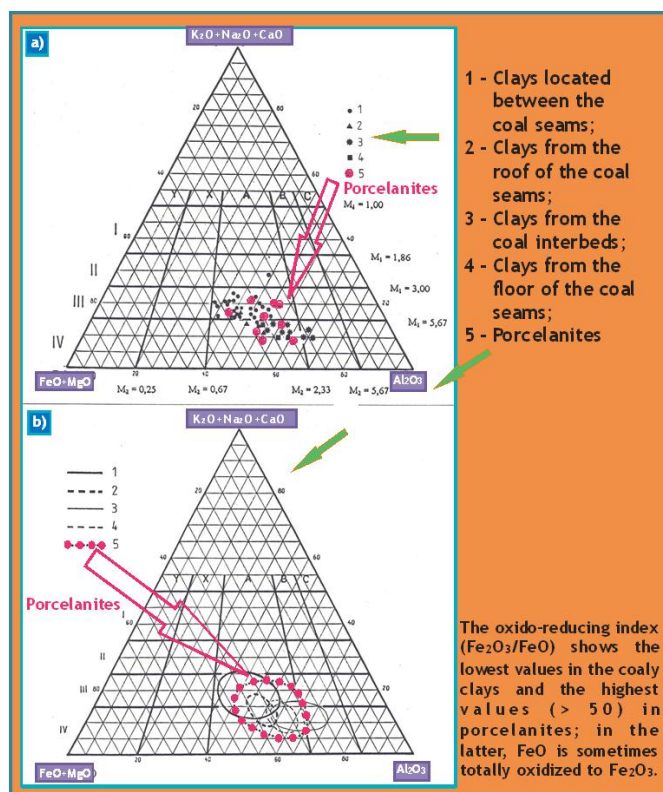
“Original” (not-affected by burning) clays, as well as “baked clays” (*i.e.* porcelanites and clinkers) were analysed by X-ray diffractometry and the thermo-mineralogical characteristics were identified; besides, thin sections were analysed. A geochemical investigation was performed, as well.

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

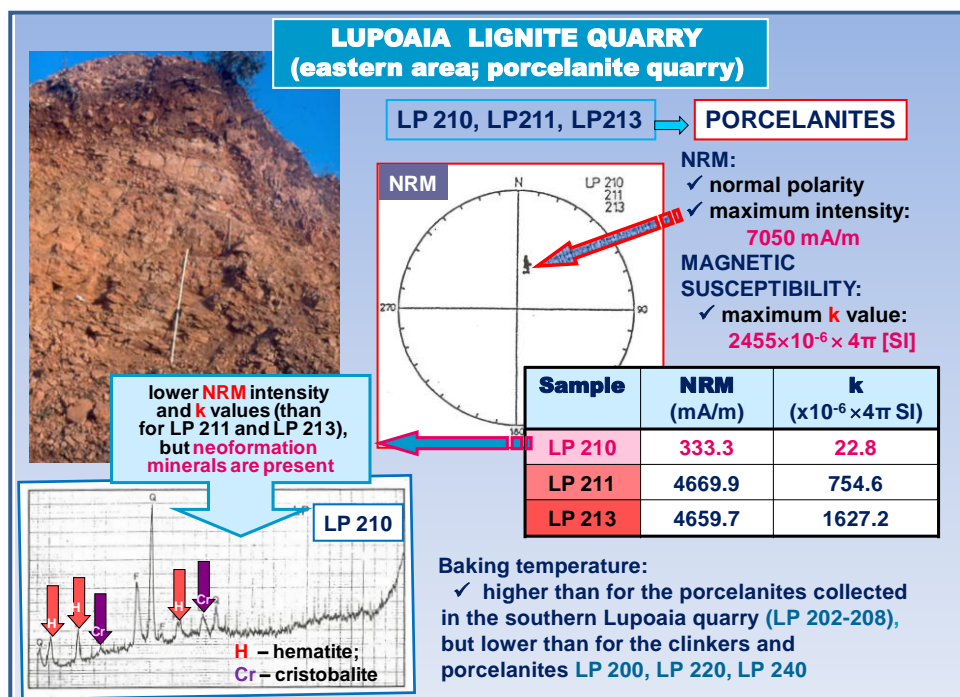
On the basis of the analyses performed by X-ray diffractometry and thin sections, the “original” clays (not-affected by heating) were characterised by clay mineral assemblages (illite, smectite, kaolinite, chlorite) and non-clay minerals (angular quartz and quartzite grains, feldspars/plagioclases, calcite, 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.

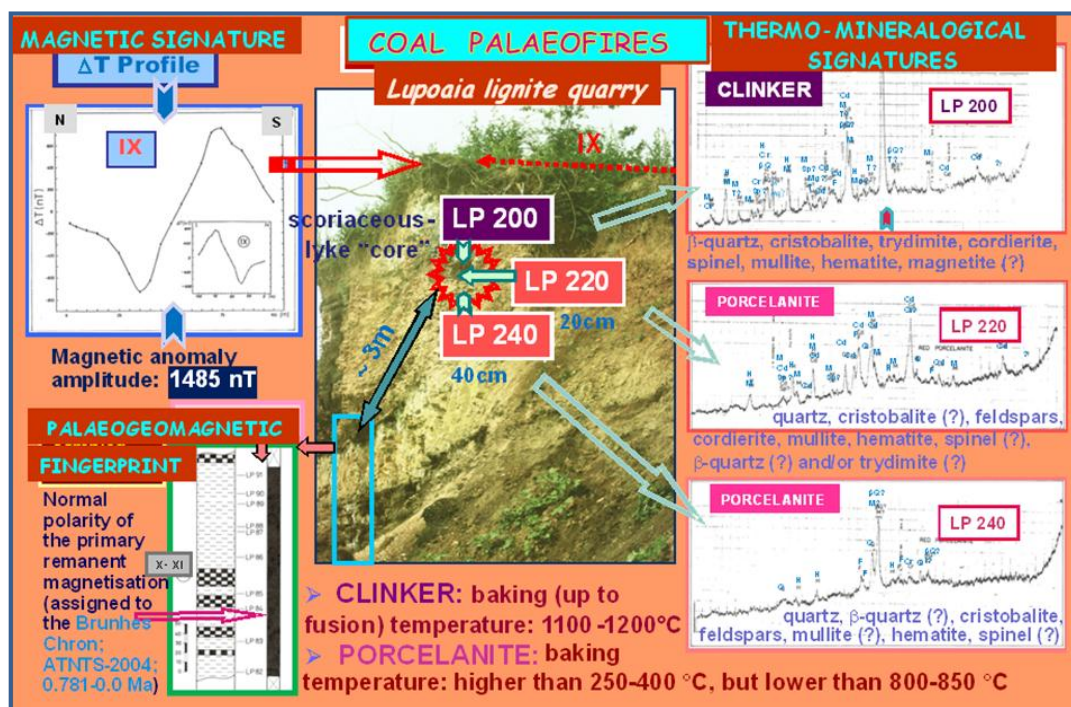
The geochemical data, based on bulk sample analyses, Englund-Jorgensen classification diagrams (two examples, in Fig. 1), the oxido-reducing index ( $\text{Fe}_2\text{O}_3/\text{FeO}$ ), point out changes comparable to thermal metamorphism, providing interesting information related to the mineralogical 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 ( $\text{MS}$ ;  $k_{\text{in}}$ ) has considerably increased. High and very high  $\text{MS}$  amplitudes were recorded for porcelanites and porcelanite-like clays: the  $k_{\text{in}}$  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  $\text{MS}$  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 ( $\text{TRM}$ ) (other details, in Rădan, 1998). The remanent magnetisation records high and very high intensity values ( $I_{\text{r}}$ ), mostly between 1 - 7 A/m, occasionally reaching 7982 A/m (see in Fig. 2 porcelanites defined by  $I_{\text{r}}$  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, București, 111-141.



## Contrasting effects of fire on forest and agricultural soils

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**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

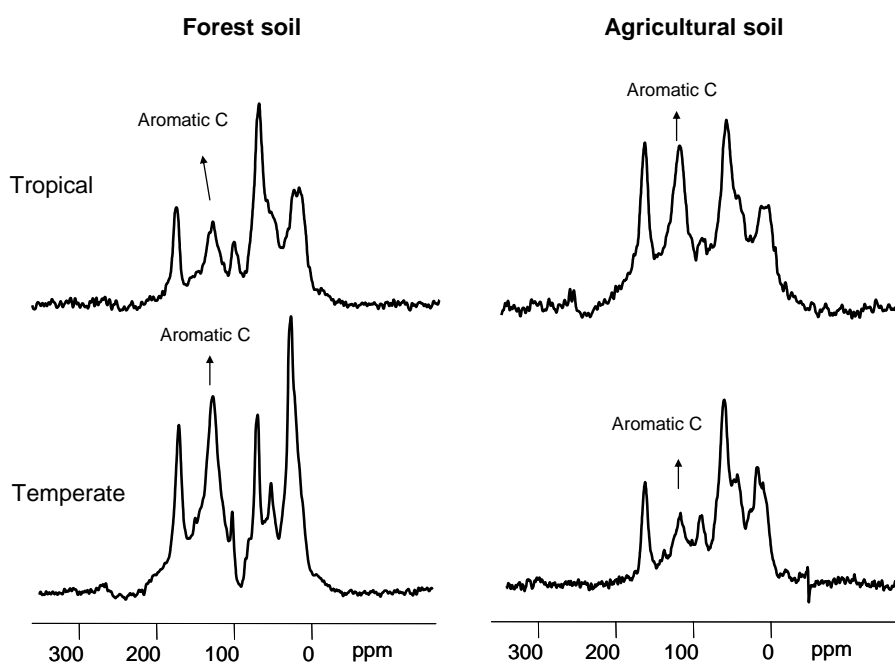
This study compiles data from burned sites under different management in contrasting climatic regions. We hypothesized that fire in different management systems affects differently the organic matter compartment of soil and that these differences would be similar in different climatic regions. The objective 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 <sup>13</sup>C 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

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### 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

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**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

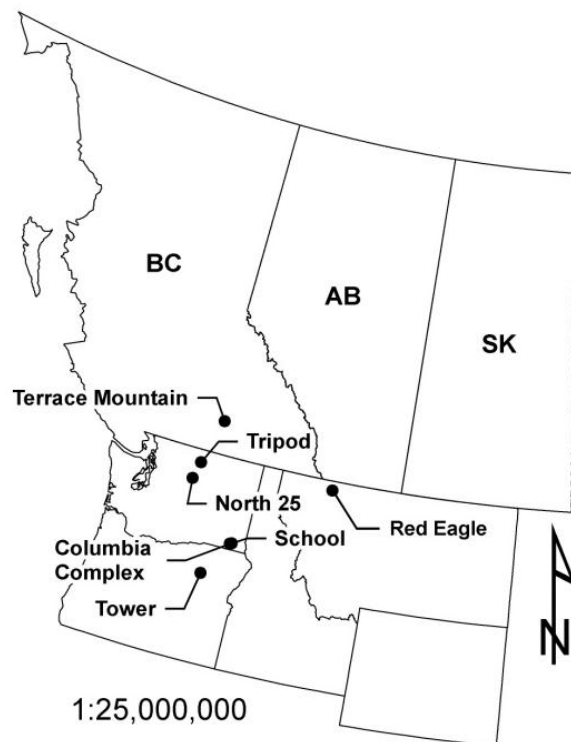
The goal of this study was to compare runoff rates, sediment flux rates, and rill erodibility parameters from simulated rill experiments among burned hillslopes in the western U.S. and Canada. The objectives were to: 1) Determine if the runoff rates or sediment flux rates varied by location or within 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<sup>-1</sup>) 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<sup>-1</sup> (n = 4) with values ranging from 12 to 20 L min<sup>-1</sup> (Table 1). The runoff rates were lower in the first post-fire year (n = 6), when the mean value was 12 L min<sup>-1</sup>, but ranged from 4 to 18 L min<sup>-1</sup>. The means continued to decrease in the second and third post-fire years to 8 and 5.6 L min<sup>-1</sup>, but the ranges were also relatively large (3 to 15 L min<sup>-1</sup> [n = 4] and 1 to 10 L min<sup>-1</sup> [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<sup>-1</sup>) (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  $2.4 \text{ g s}^{-1}$  and ranged from  $0.8$  to  $4.6 \text{ g s}^{-1}$  among the 4 sites in the year of the fire. In the first post-fire year, the mean sediment flux increased to  $3.8 \text{ g s}^{-1}$ , 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  $9.2 \text{ g s}^{-1}$ . The mean sediment flux decreased to  $1.6 \text{ g s}^{-1}$  in the second post-fire year, and the 4 site values were between  $0.2$  and  $6.6 \text{ g s}^{-1}$ . There was no change in sediment flux in the third post-fire year, when the mean for the 2 sites was  $1.7 \text{ g s}^{-1}$  (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 ( $0.013 \text{ g s}^{-1}$ ) (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 ( $\text{L min}^{-1}$ )	Sed. flux ( $\text{g s}^{-1}$ )	Erodibility ( $\text{s m}^{-1}$ )
North 25	0	20	1.7	++
Columbia Complex	0	17	4.6	$1.1 \times 10^{-5}$
Tripod	0	20	2.7	$7.0 \times 10^{-6}$
Terrace Mountain	0	12	0.76	$8.8 \times 10^{-6}$
Columbia Complex	1	9.5	3.1	$1.0 \times 10^{-3}$
Tripod	1	17	2.1	$6.3 \times 10^{-6}$
Terrace Mountain	1	8.7	0.29	$1.1 \times 10^{-5}$
Tower	1	18	9.2	$5.7 \times 10^{-4}$
School	1	16	7.2	$4.7 \times 10^{-5}$
Red Eagle	1	4.3	0.54	$4.3 \times 10^{-5}$
Columbia Complex	2	5.1	0.20	$1.8 \times 10^{-6}$
Tripod	2	15	1.6	$2.0 \times 10^{-4}$
School	2	9.1	4.5	$1.0 \times 10^{-4}$
Red Eagle	2	2.8	0.27	$1.4 \times 10^{-5}$
School	3	10	3.2	$3.3 \times 10^{-5}$
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

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**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 3<sup>rd</sup> 2008. An experimental fire was carried out on February 20<sup>th</sup> 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 m<sup>2</sup>. 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 m<sup>2</sup>). 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 m<sup>2</sup> 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 (H<sub>2</sub>O) (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 m<sup>2</sup> 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.



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

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**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<sup>-2</sup> (B+S), burnt soil with 250 g m<sup>-2</sup> 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<sup>-1</sup> and burnt soil had a slightly higher pH (4.2) and lower organic matter content (93 g kg<sup>-1</sup>). 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 $\omega$ 9, 16:1 $\omega$ 7c, i17:0, a17:0, cy17:0, 18:1 $\omega$ 7 and cy19:0), was used as an index of the bacterial biomass (bactPLFAs), and the quantity of the 18:2 $\omega$ 6, 18: $\omega$ 19, 18:3 $\omega$ 3 and 16:1 $\omega$ 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 $\omega$ 7c and 18:1 $\omega$ 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, unburnt 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 <sup>-1</sup> )	358 $\pm$ 46	189 $\pm$ 24	256 $\pm$ 80	223 $\pm$ 47
FungPLFA (nmol g <sup>-1</sup> )	84.2 $\pm$ 12.1	38.8 $\pm$ 4.8	50.7 $\pm$ 19.0	44.7 $\pm$ 8.4
BactPLFA (nmol g <sup>-1</sup> )	123 $\pm$ 15	64.8 $\pm$ 8.9	87.6 $\pm$ 26.8	76.2 $\pm$ 16.1
Gram <sup>-</sup> bactPLFA (nmol g <sup>-1</sup> )	70.6 $\pm$ 9.4	35.6 $\pm$ 4.7	45.3 $\pm$ 14.5	40.5 $\pm$ 6.8
Gram <sup>+</sup> bactPLFA (nmol g <sup>-1</sup> )	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 <sup>-</sup> /Gram <sup>+</sup>	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<sup>-</sup>/Gram<sup>+</sup> 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

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### 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 $\omega$ 6,9 and 18:1 $\omega$ 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)

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**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<sup>-2</sup> (B+S), burnt soil with 250 g m<sup>-2</sup> 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<sup>-1</sup> and burnt soil had a slightly higher pH (4.2) and lower organic matter content (93 g kg<sup>-1</sup>). 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 CO<sub>2</sub> 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  $\beta$ -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 <sup>-1</sup> )	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 ( $\mu$ g p-nitrophenol g <sup>-1</sup> h <sup>-1</sup> )	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 ( $\mu$ g NH <sub>4</sub> <sup>+</sup> g <sup>-1</sup> h <sup>-1</sup> )	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 ( $\times 10^{-17}$ mol Leu ml <sup>-1</sup> h <sup>-1</sup> )	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 <sup>-1</sup> )	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.

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## 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

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**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 <sup>a</sup>	Tm <sup>b</sup> (°C)	Pm <sup>b</sup> (mm)	Soil type (SSS, 2006)	Texture <sup>c</sup> (% sand, silt, clay)	OM <sup>d</sup> (%)	pH	CaCO <sub>3</sub> (%)
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

<sup>a</sup> PI: Sierra de Pinoso; M: Sierra del Maigmo; A: Sierra de Aitana.

<sup>b</sup> Tm: Mean annual temperature; Pm: Mean annual precipitation.

<sup>c</sup> 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.

<sup>d</sup> 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<sup>-1</sup>. 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

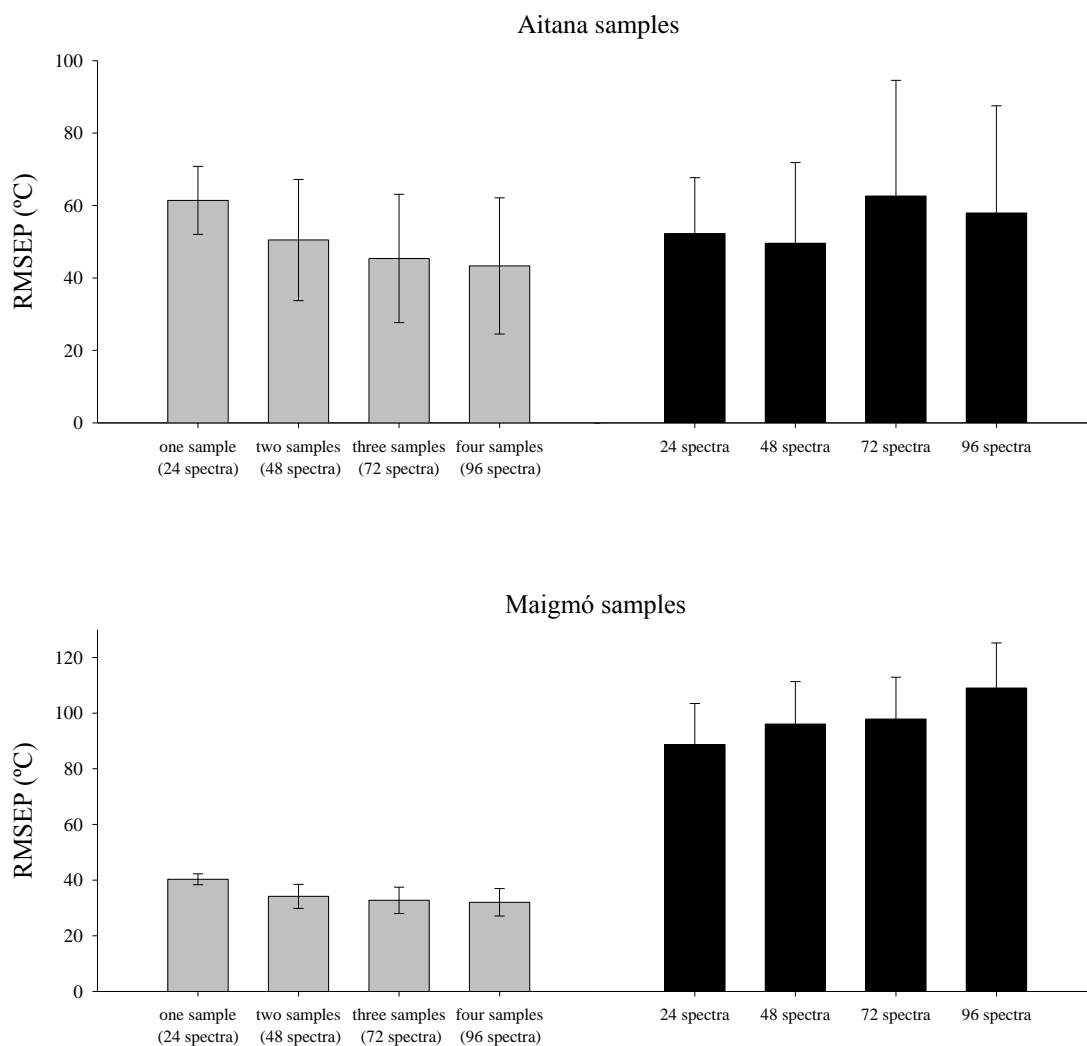
All of the models were constructed using the same conditions and procedures, ie: the rank of temperatures was the same in all the models, they were constructed using the entire spectral region, the same preprocessing of the spectra, and the same rank (number of PLS included in the model).

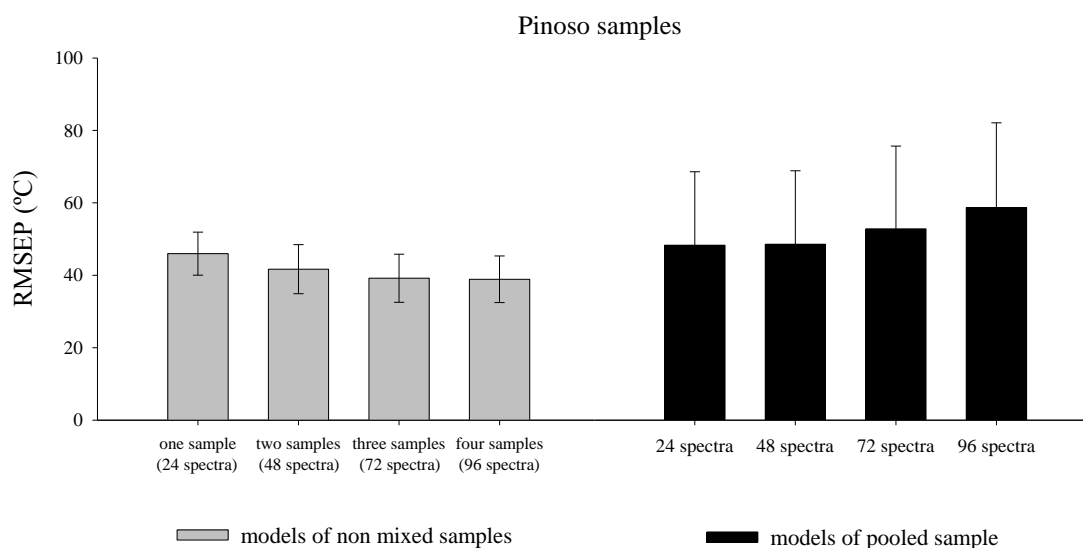
To assess differences between the two groups of models (models of pooled sample and models of non-mixed samples), a comparison among the mean error of prediction (RMSEP) was done. To do this, an average of the prediction results of models of non-mixed samples for each category (24, 48, 72 and 96 samples)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



## **ADAPTA CLIMA - Adaptation to the effects from climate change in the AVE**

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**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 “ADAPTA CLIMA - Adaptation to the effects from climate change” (InterReg Sudoeste) 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 SUDOESTE, that can be implemented in the participating areas. Among the challenges facing SUDOESTE to combat climate change, two of them represent the strategic objectives of the project ADAPTA CLIMA: on the one hand, the alert the populations of the SUDOESTE 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 ADAPTA CLIMA, 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.

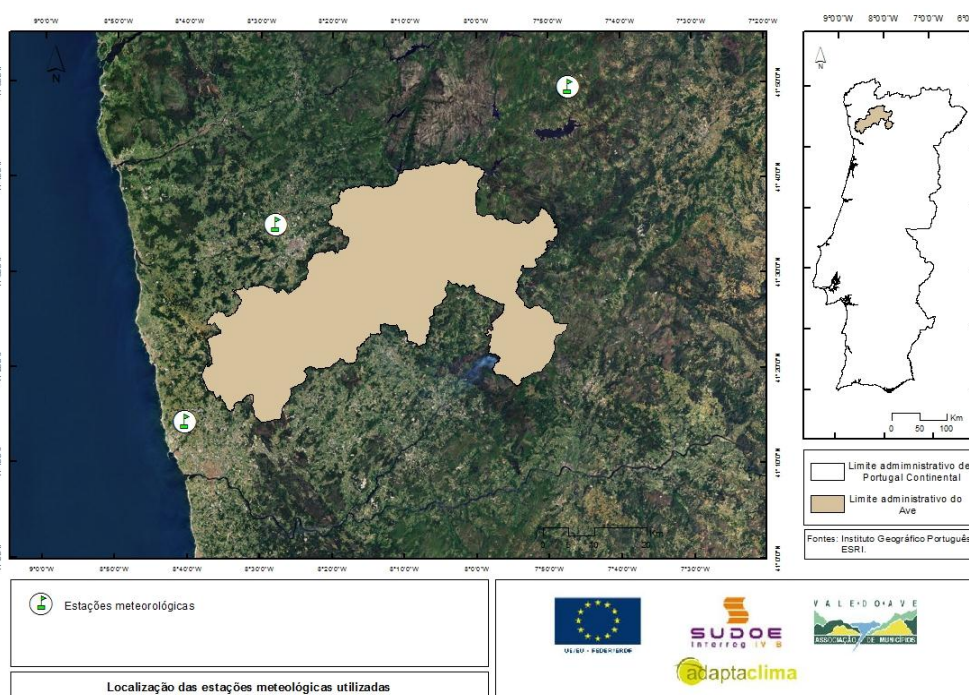
These projections were made by different institutions using different meteorological European regional climate models based on global model HadAM3H, which is one of the global models used in IPCC (Intergovernmental Panel on Climate Change) and one that offers better results for the current climate.



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.

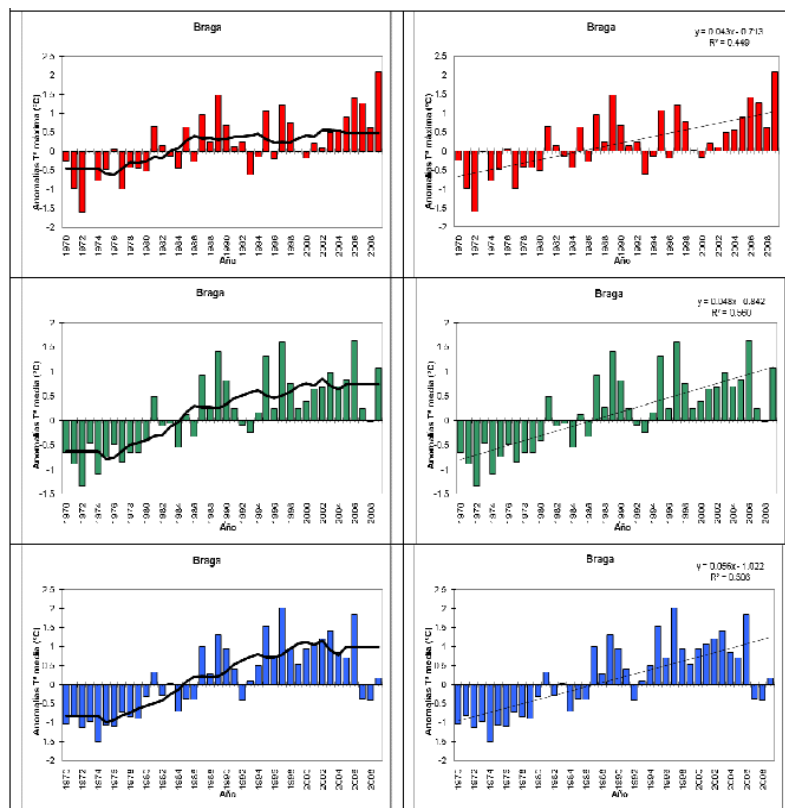
**Table II.** Weather stations used for rainfall

	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.

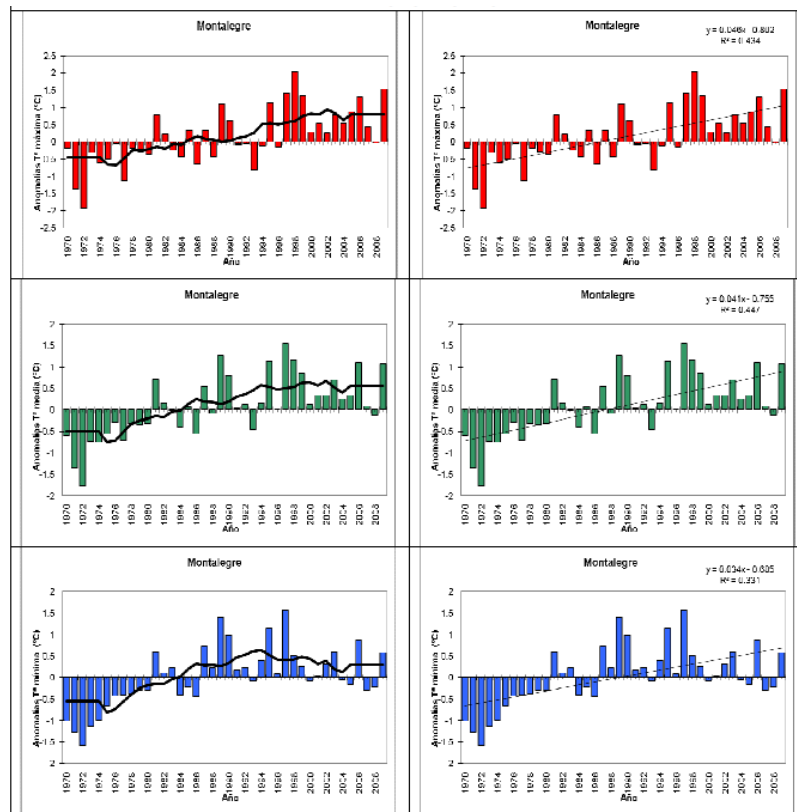
### Results and conclusions

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).



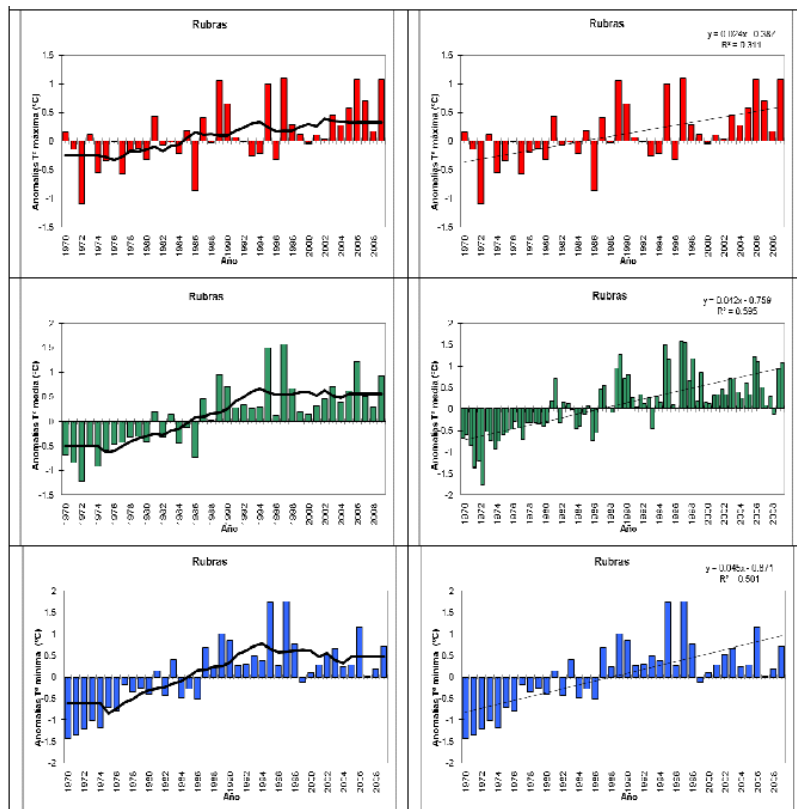
Source: Consellería de Medio Ambiente Territorio e Infraestruturas. MeteoGalicia.

**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).

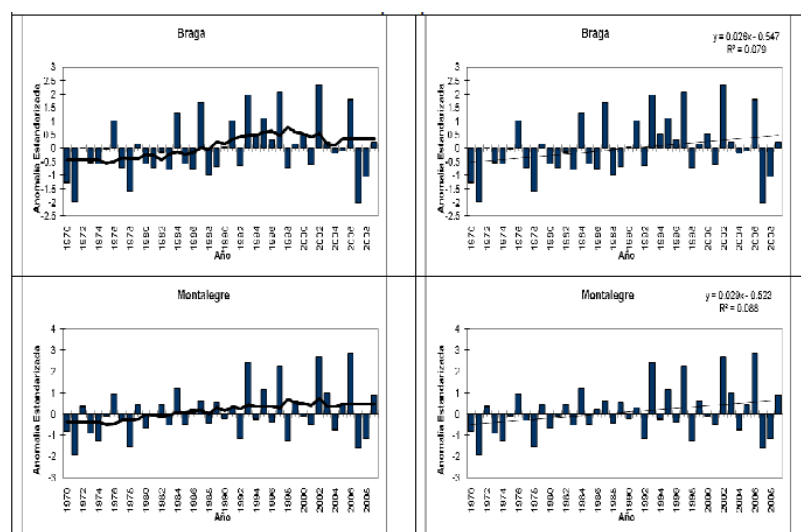


Source: Consellería de Medio Ambiente Territorio e Infraestruturas. Meteogalicia.

**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

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**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 Protec<sup>1</sup> (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.

<sup>1</sup> Funded by CEGOT – Centro de Estudos em Geografia e Ordenamento do Território.

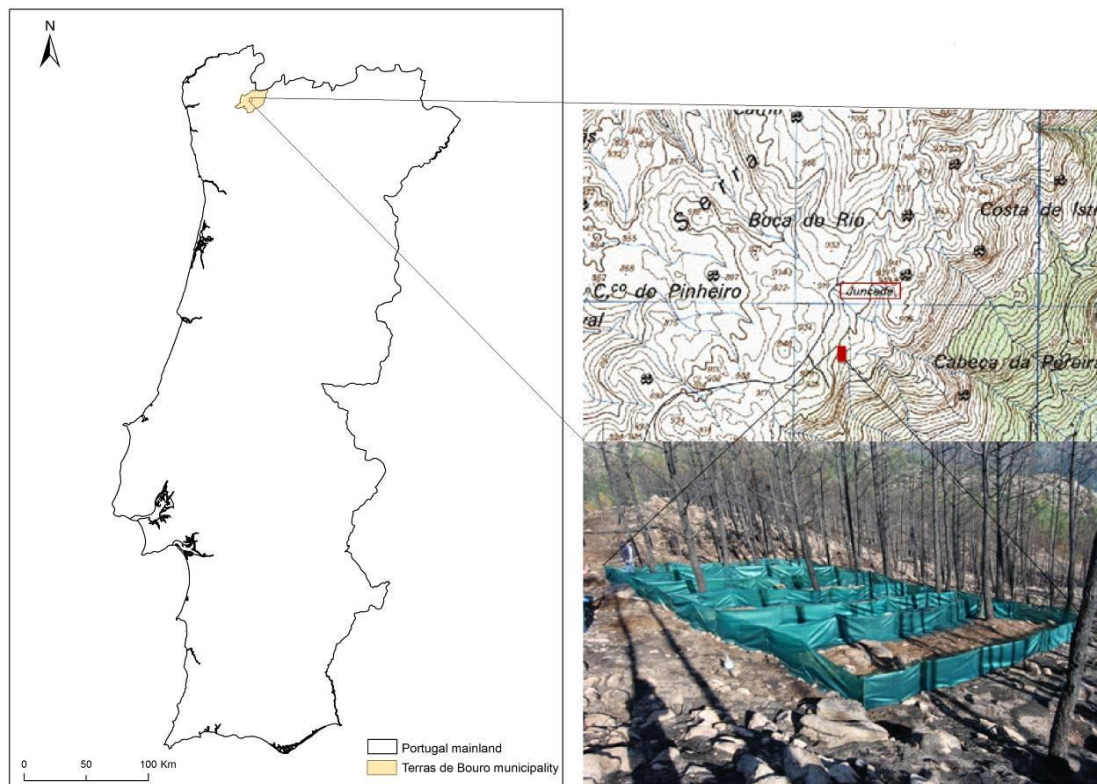
We aim to test the role of pine needles available at the actual site of the fire - which are partly due to them falling after the fire of low/medium intensity - as a protective agent against soil erosion (photos 1 and 2) and, also, compared with the role of straw.



**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.

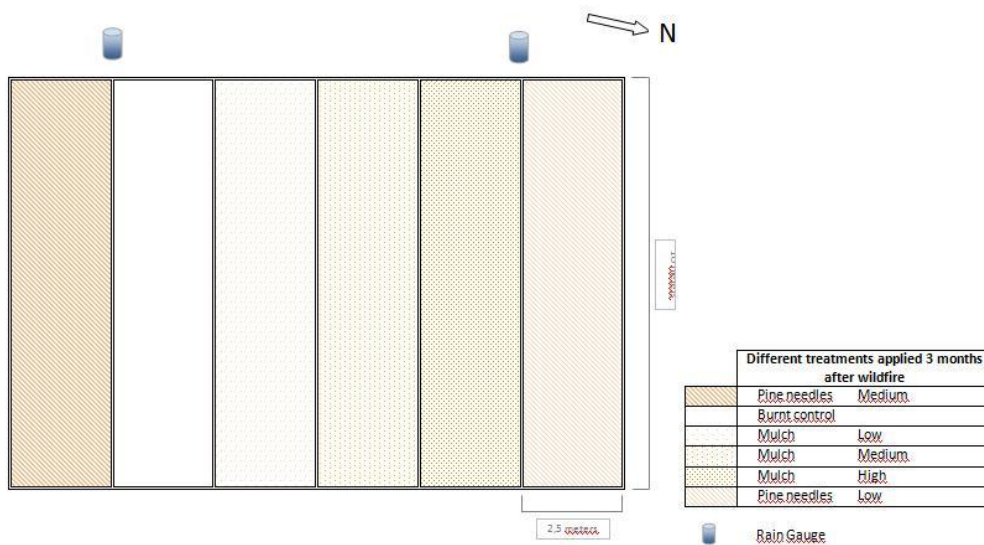


**Photo 3.** Burnt control plot;



**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., Terman, 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 III* (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 Andalucía”. *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

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**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.

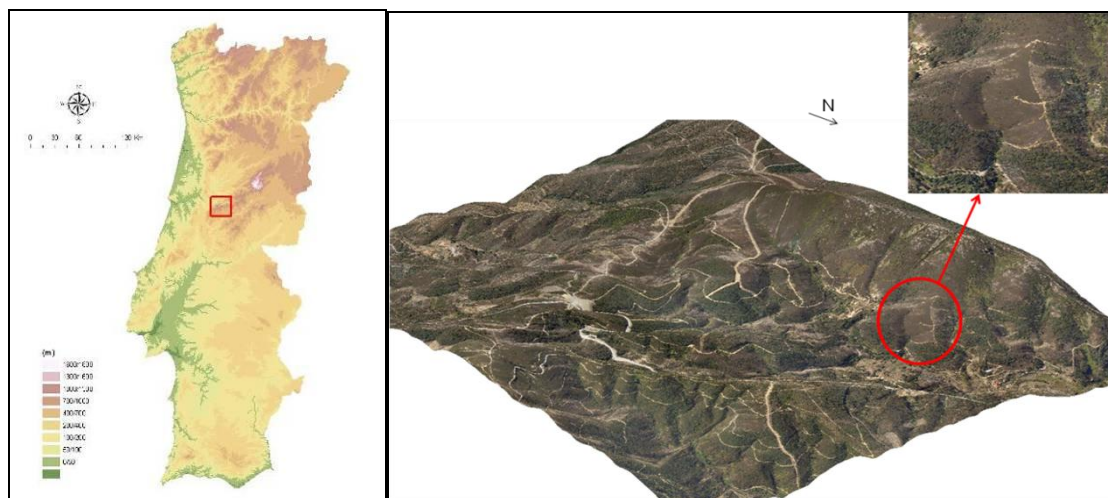


Figure 1. Study area – Vale Torto (Penedos de Góis) in Açor Mountain

### 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.

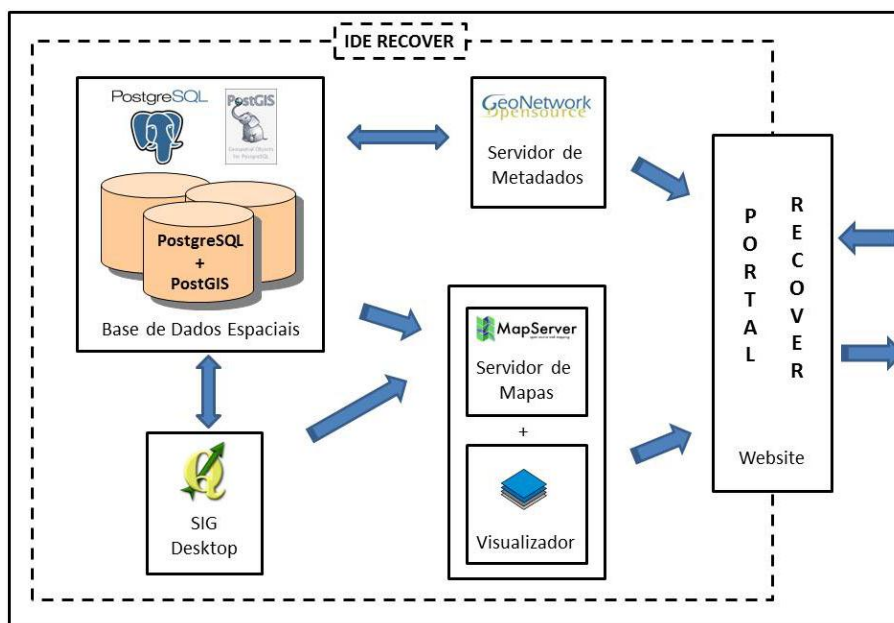
Given the intimate relationship between geomorphological processes and the area in which they are triggered, we consider it appropriate to apply the methodologies of modeling provided by GIS spatial analysis of erosion processes operated in the aftermath of forest fires.

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.

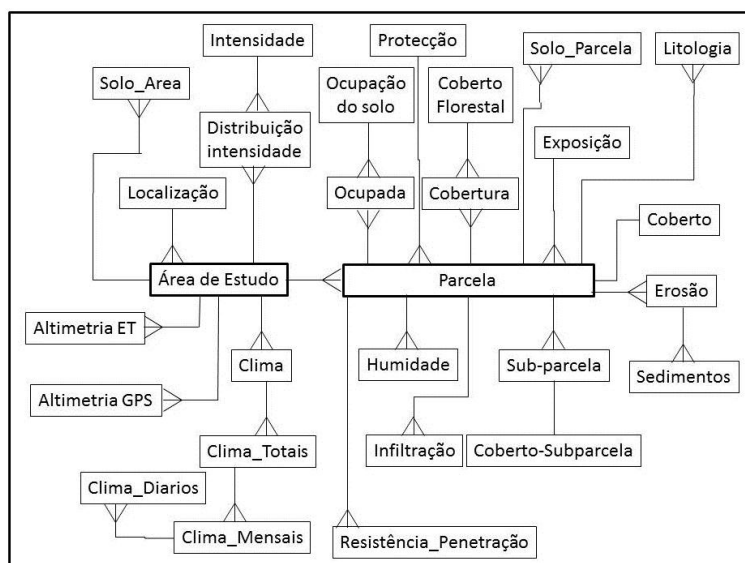


Source: Vieira *et al.*, 2009

**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.



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## 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

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

### Introduction

The Burned Areas Restoration Project (RAA)<sup>2</sup>, 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).

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<sup>2</sup> 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 projects<sup>3</sup> 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	Sediment		Water turnouts	
Strips	Fences			

## 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,

<sup>3</sup> 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-line<sup>4</sup> 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

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### References

- Pinho, J., Louro, G., Paulo, S. (2005). Recuperação das áreas ardidas em 2003. Orientações estratégicas. Actas das Comunicações do 5<sup>o</sup> 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.

<sup>4</sup> [http://www.phoenixefi.org/uploads/tecnicas\\_rel.pdf](http://www.phoenixefi.org/uploads/tecnicas_rel.pdf)



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

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**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 ( $\text{cm h}^{-1}$ ),  $K_{wl}$ =hydraulic conductivity of the water repellent layer ( $\text{cm h}^{-1}$ ),  $h_0$ =depth of ponded water at surface (cm),  $\psi$ =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  $40 \text{ mm h}^{-1}$ ) 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

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**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 m<sup>2</sup> 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

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**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 m<sup>2</sup> 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

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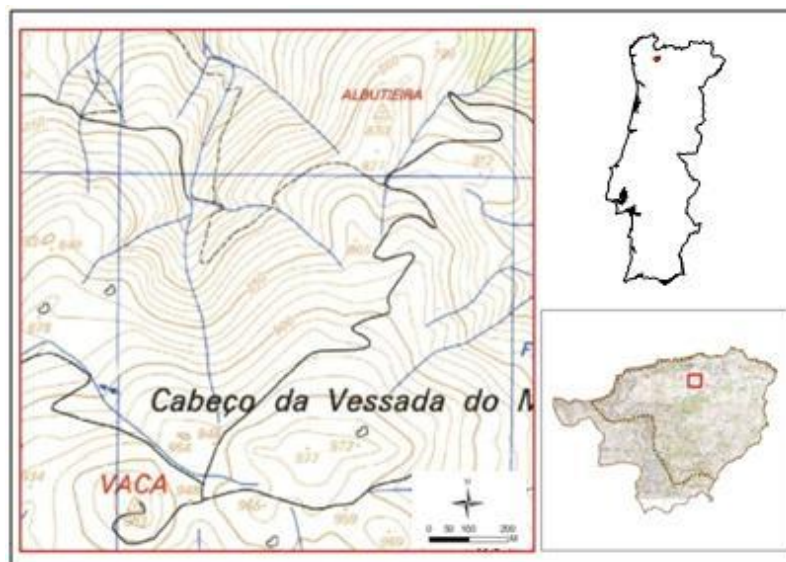
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**Key-words:** Cabreira mountain, forest fires, recurrence interval, soil degradation

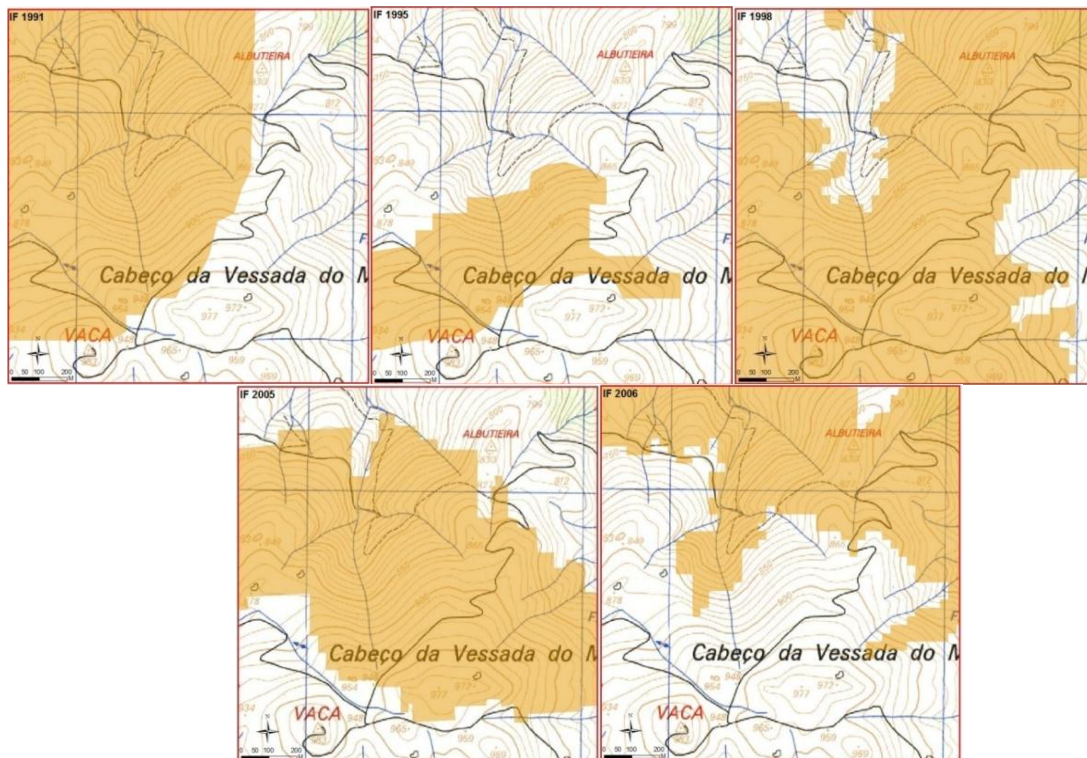
### Introduction

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
Zebraal	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>		
<i>Genista falcata</i>		
<i>Ulex parviflorus</i>		
<i>Cytisus multiflorus</i>		

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 fires<sup>5</sup>, 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 Alentejo”

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<sup>5</sup> 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

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**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.

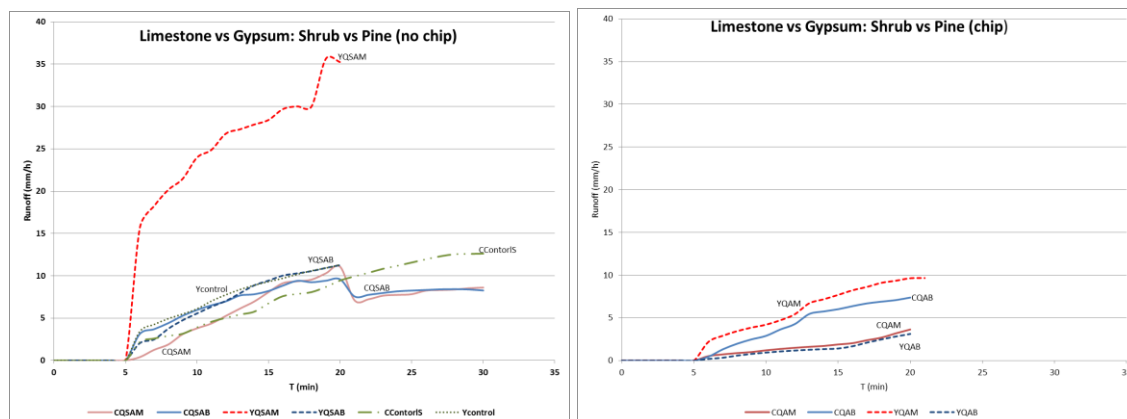
### *Rainfall simulation experiment:*

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-m<sup>2</sup>-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<sup>-1</sup>, with a mean drop-size of 0.5·1 mm (D<sub>50</sub>), and a Kinetic energy of 4.16 J m<sup>-2</sup> mm<sup>-1</sup>. 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 Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup> and Na<sup>+</sup>. 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.

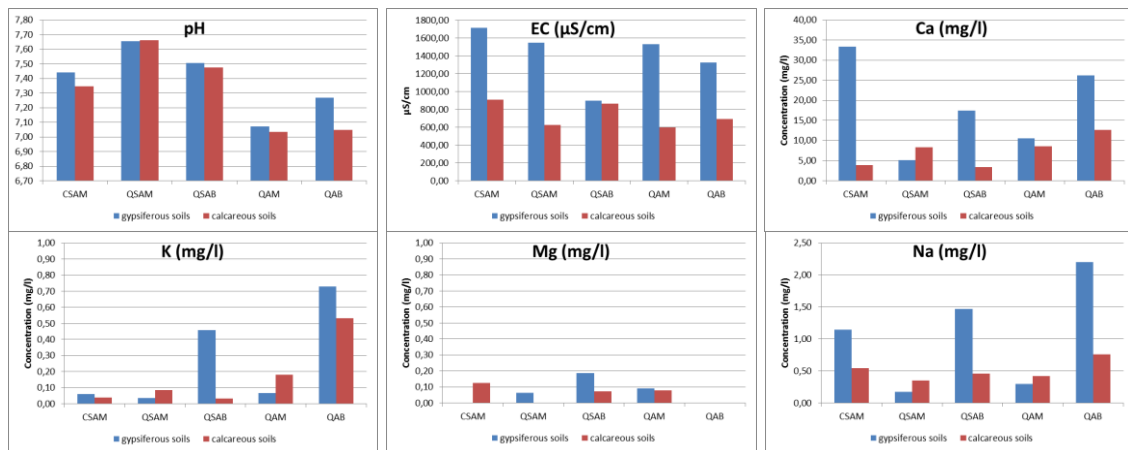
**Table 1.** Field values. (T) type: (C) unburnt; (Q) burnt; (T<sub>tm</sub>) treatment: (SA) no chip; (A) chip; (T<sub>veg</sub>) vegetation type: (M) shrub; (B) pine.

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

**Table 2.** Field values. (T) type: (C) unburnt; (Q) burnt; (T<sub>tm</sub>) treatment: (SA) no chip; (A) chip; (T<sub>veg</sub>) vegetation type: (M) shrub; (B) pine.

GYPSUM			Ponding time	Runoff Coef	Runoff Ratio	Sediment	Infiltration Coef
T	T <sub>tm</sub>	T <sub>veg</sub>	(min)	(%)	(mm/h)	(gm <sup>-2</sup> h <sup>-1</sup> )	(%)
C	SA	M	3,87 ±0,6	21,77 ±6,1	10,89 ±3,0	149,22 ±284,9	78,23 ±6,1
Q	SA	M	3,31 ±1,0	59,73 ±18,6	29,87 ±9,3	911,72 ±394,6	40,27 ±18,6
Q	SA	B	4,62 ±1,6	21,16 ±5,2	10,58 ±2,6	137,69 ±21,3	78,84 ±5,2
Q	A	M	5,65 ±1,1	19,49 ±13,5	9,75 ±6,7	128,89 ±116,3	80,51 ±13,5
Q	A	B	6,36 ±1,6	6,24 ±0,8	3,12 ±0,4	51,02 ±4,8	93,76 ±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<sup>2+</sup>, decreases with the effect of fire, this is higher on gypsiferous soils than on limestone. But the amount of K<sup>+</sup> 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 gypsumiferous 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 (µS/cm)	Na <sup>+</sup> (mg/l)	Mg <sup>2+</sup> (mg/l)	K <sup>+</sup> (mg/l)	Ca <sup>2+</sup> (mg/l)
T	Ttm	Tveg						
C	SA	M	7,35 ±0,15	907,61 ±639,5	0,55 ±0,7	0,13 ±0,18	0,04 ±0,06	3,88 ±5,4
Q	SA	M	7,66 ±0,43	624,83 ±26,1	0,35 ±0,6	0,00 ±0,00	0,08 ±0,15	8,33 ±14,4
Q	SA	B	7,47 ±0,44	864,94 ±278,2	0,46 ±0,9	0,07 ±0,15	0,03 ±0,07	3,45 ±6,9
Q	A	M	7,03 ±0,03	595,22 ±59,5	0,42 ±0,3	0,08 ±0,14	0,18 ±0,16	8,53 ±7,4
Q	A	B	7,05 ±0,03	690,39 ±24,1	0,76 ±1,0	0,00 ±0,00	0,53 ±0,75	12,65 ±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 (µS/cm)	Na <sup>+</sup> (mg/l)	Mg <sup>2+</sup> (mg/l)	K <sup>+</sup> (mg/l)	Ca <sup>2+</sup> (mg/l)
T	Ttm	Tveg						
C	SA	M	7,44 ±0,26	1713,49 ±228,7	1,15 ±1,9	0,00 ±0,0	0,06 ±0,1	33,34 ±57,7
Q	SA	M	7,65 ±0,06	1544,58 ±182,5	0,17 ±0,3	0,06 ±0,1	0,03 ±0,06	5,08 ±8,7
Q	SA	B	7,51 ±0,11	899,15 ±129,8	1,47 ±1,2	0,19 ±0,3	0,46 ±0,5	17,46 ±13,5
Q	A	M	7,07 ±0,15	1528,88 ±110,6	0,30 ±0,5	0,09 ±0,1	0,07 ±0,1	10,54 ±18,2
Q	A	B	7,27 ±0,05	1323,50 ±195,8	2,20 ±3,1	0,00 ±0,0	0,73 ±1,0	26,15 ±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.
- Moriassi, 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.

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### 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

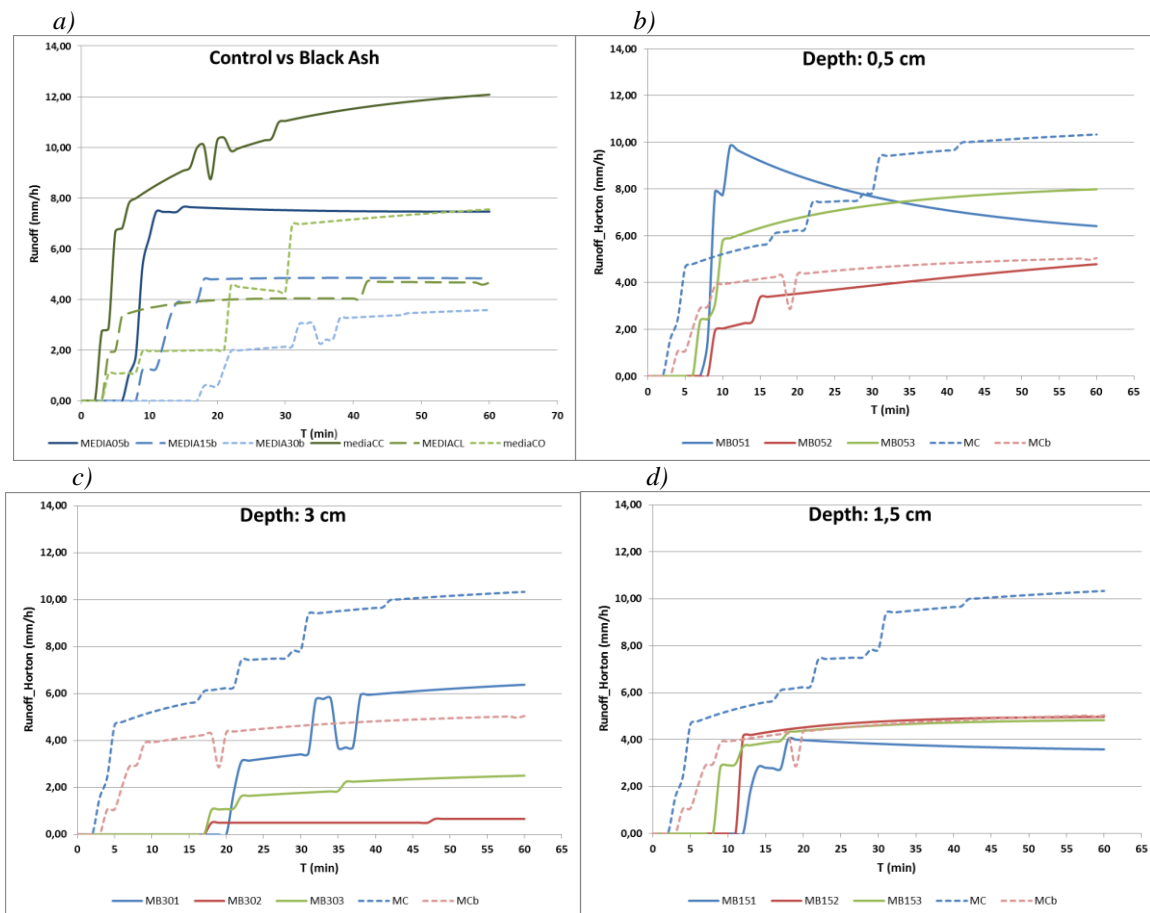
### *Study area*

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 m<sup>2</sup> sub-plot, and runoff was collected from a bordered circular 0,24 m<sup>2</sup> area in the center of the sub-plot. Simulated rainfall duration was 1 h at a rate of 55 mm h<sup>-1</sup>, 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<sup>-1</sup>, with a mean drop-size of 2,53 mm (D<sub>50</sub>), mean drop velocity of 3,4 m s<sup>-1</sup>, and a Kinetic energy of 7,1 J m<sup>-2</sup> mm<sup>-1</sup>. 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, Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, Na<sup>+</sup> and Cl<sup>-</sup>. 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):



**Figure 1.** (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 <sup>-1</sup> )	f <sub>0</sub> (mm/h)	f <sub>c</sub> (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 <sup>2+</sup> (mg/l)	Mg <sup>2+</sup> (mg/l)	K <sup>+</sup> (mg/l)	Na <sup>+</sup> (mg/l)	Cl <sup>-</sup> (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<sup>+</sup> and Na<sup>+</sup> 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<sup>+</sup>, Na<sup>+</sup> and Cl<sup>-</sup>, show greater values in the control plots were than on the ash covered plots. The K<sup>+</sup>, Na<sup>+</sup> and Cl<sup>-</sup> 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.
- Moriassi, 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

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**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 <sup>13</sup>C 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<sub>tot</sub> 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<sup>-1</sup> organic C without any evidence of PyOC, 16 and 19 years a clear increase of C<sub>tot</sub> (10-15 mg g<sup>-1</sup>) with a considerable contribution of PyOC (12% of C<sub>tot</sub>) was revealed. Although the absolute concentration of PyOC did not decrease in the lower depths, its relative contribution to C<sub>tot</sub> 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

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**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<sup>-1</sup>. 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 <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	S	CEC	V
	(cmol(+)/Kg)	(cmol(+)/Kg)	(cmol(+)/Kg)	(cmol(+)/Kg)	(cmol(+)/Kg)	(cmol(+)/Kg)	%
<b>Control</b>	0.37	0.79	2.07	0.74	3.97	25.50	15.24
<b>200°C</b>	0.26	0.68	1.78	0.55	3.27	17.50	18.80
<b>400°C</b>	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)
<b>Control</b>	Surface	5.97	7.33	1.22	0.95
	Subsurface	6.30	7.88	0.90	0.89
<b>200°C</b>	Surface	12.04	10.06	19.76	5.15
	Subsurface	5.36	7.56	5.60	1.77
<b>400°C</b>	Surface	8.34	12.45	31.60	5.32
	Subsurface	8.72	13.44	15.11	3.94



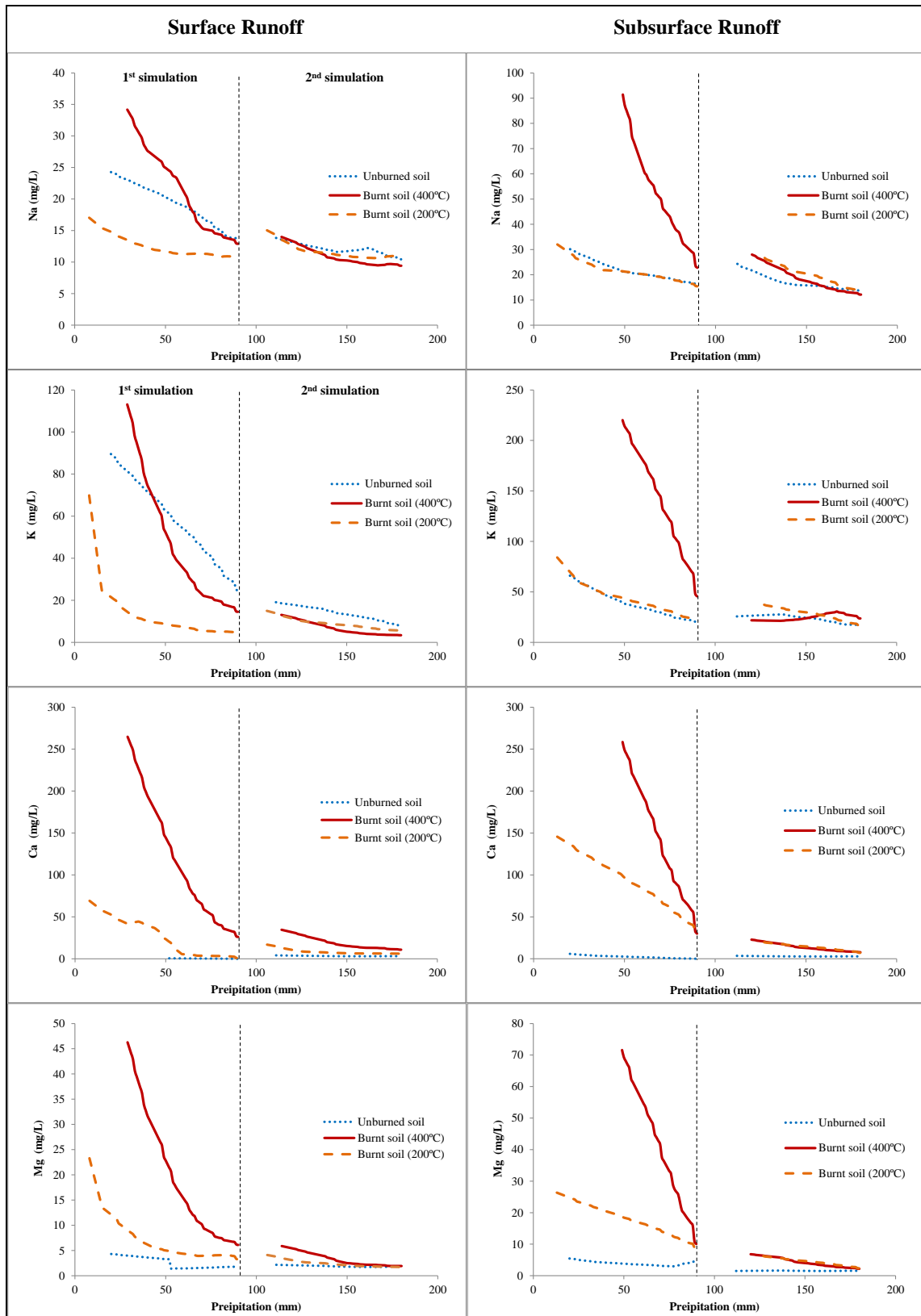


Figure 1. Cation concentrations in water measured during the rainfall simulations



## 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

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**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 (Quenéa 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<sup>-1</sup> 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<sup>-1</sup>, from 100 to 500 °C at 20 °C min<sup>-1</sup> 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 (C<sub>10</sub>-C<sub>29</sub>), 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 indenes) 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 C<sub>10</sub>-C<sub>33</sub>), 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.

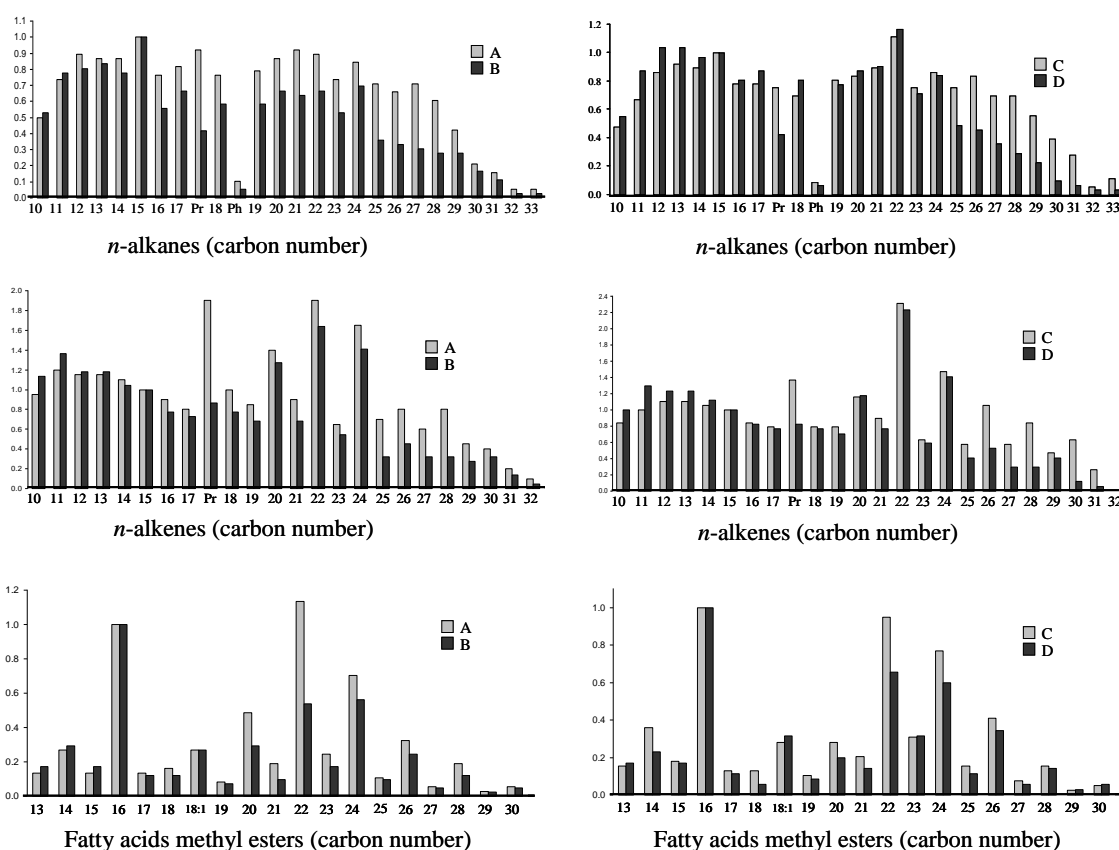
The burnt samples presented a slightly higher relative abundance of highly condensed aromatic structures. They are usually released in incomplete combustion processes as occur commonly in wildfires, and indicate the presence of black carbon or thermally altered refractory OM (Tinoco et al., 2006).

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.  $\beta$ -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 C<sub>10</sub>-C<sub>33</sub>, having a bimodal distribution with maximums at C<sub>13</sub> and C<sub>21</sub>, and C<sub>15</sub> and C<sub>22</sub> 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 C<sub>10</sub>-C<sub>32</sub> with maximum at C<sub>22</sub>.



**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 C<sub>15</sub>. Abundances of fatty acids are normalized to Palmitic acid (C<sub>16</sub>). Axis numeral indicates the carbon number). Pr, pristane; Ph, phytane

*n*-fatty acids were also identified in the range C<sub>13</sub>-C<sub>30</sub>. 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 (C<sub>16</sub>) and behenic acid (C<sub>22</sub>) 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 unburnt 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 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 <sub>10</sub> - C <sub>23</sub> /		ΣC <sub>10</sub> - C <sub>15</sub> /	ΣC <sub>24</sub> - C <sub>33</sub> /	Pr/C <sub>17</sub>	Ph/C <sub>18</sub>	Pr/Ph	AC <sub>L</sub>	ΣC <sub>10</sub> - C <sub>23</sub> /		ΣC <sub>10</sub> - C <sub>15</sub> /	ΣC <sub>24</sub> - C <sub>33</sub> /	Pr/C <sub>17</sub>	ΣC <sub>13</sub> - C <sub>18</sub> /	ΣC <sub>10</sub> - C <sub>18</sub> /	ΣC <sub>19</sub> - C <sub>30</sub> /	
	ΣC <sub>24</sub> - C <sub>33</sub>	ΣC <sub>10</sub> - C <sub>33</sub>	ΣC <sub>10</sub> - C <sub>33</sub>	ΣC <sub>24</sub> - C <sub>33</sub>					ΣC <sub>10</sub> - C <sub>33</sub>	ΣC <sub>10</sub> - C <sub>33</sub>	ΣC <sub>19</sub> - C <sub>30</sub>	ΣC <sub>13</sub> - C <sub>30</sub>		ΣC <sub>13</sub> - C <sub>30</sub>			
short/long	short/total	long/total					short/long	short/total	long/total			short/long	short/total	long/total			
<b>A</b> (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>B</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	
<b>C</b> (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	
<b>D</b> (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

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### 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 (CO<sub>2</sub>) and methane (CH<sub>4</sub>), which are green-house gases contributing to global warming. During wildfires large amounts of CO<sub>2</sub> are released to the atmosphere (Flannigan *et al.*, 2000). After the fire, forest ecosystems become a carbon sink, which atmospheric CO<sub>2</sub> 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).

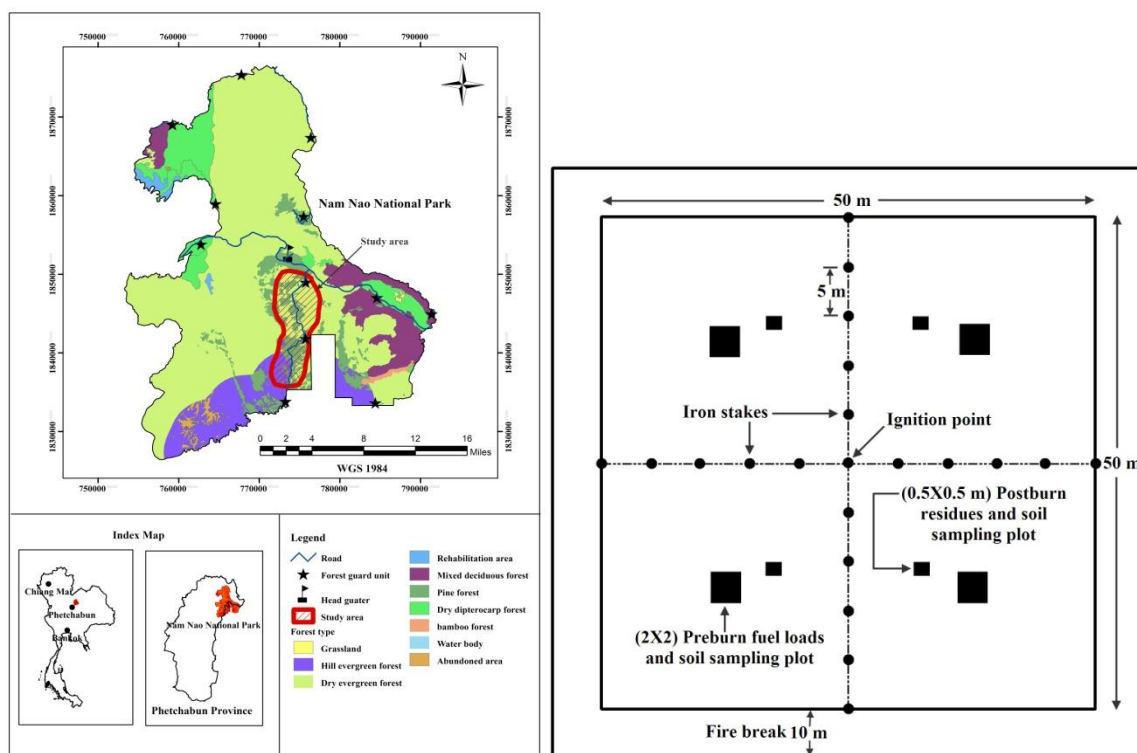
Pine forest in Thailand, consists of three sub-communities, including pine forest, pine-oak forest and pine-dipterocarp forest (Marod and Kutintara, 2009). Although pine forests are a fire-dependent ecosystem, but too frequent fires may lead to forest ecosystem and nutrient depletion, and may affect 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 <sup>a</sup>	0.02 <sup>a</sup>	0.06 <sup>a</sup>	0.35 <sup>a</sup>	2.33 <sup>a</sup>	0.22 <sup>a</sup>	5.63 <sup>a</sup>
O-PF	0.64 <sup>b</sup>	0.14 <sup>a</sup>	0.05 <sup>a</sup>	0.27 <sup>a</sup>	2.19 <sup>a</sup>	0.68 <sup>a</sup>	3.98 <sup>b</sup>

**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 <sup>a</sup>	0.19 <sup>a</sup>	0.25 <sup>a</sup>	0.43 <sup>a</sup>	0.87 <sup>a</sup>	4.76 <sup>a</sup>	85
O-PF	3.98 <sup>b</sup>	0.15 <sup>a</sup>	0.28 <sup>a</sup>	1.42 <sup>b</sup>	1.85 <sup>b</sup>	2.13 <sup>b</sup>	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).

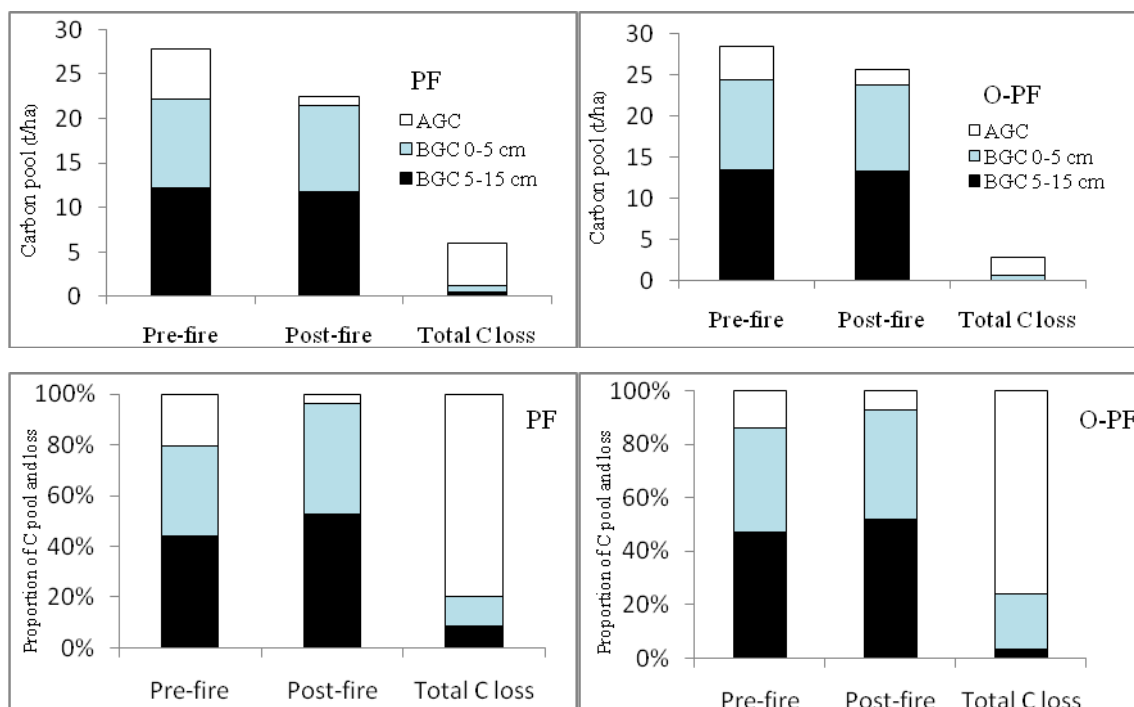
**Table 3.** Pre-and Post-burning belowground carbon in each site

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

**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

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**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 m<sup>2</sup>) 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,  $\beta$ -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

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**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

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**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 m<sup>2</sup> 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

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**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<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O



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).

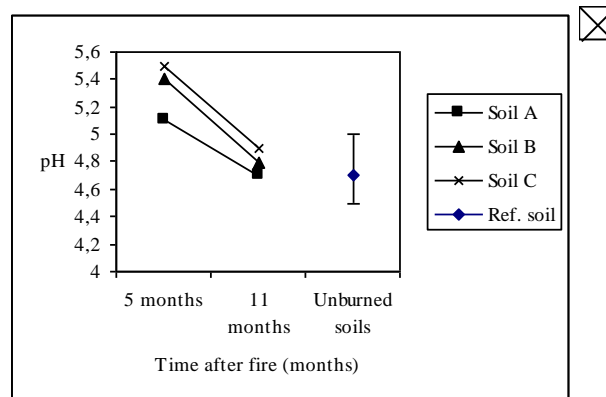
## Results and conclusions

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 (Someshwar, 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.

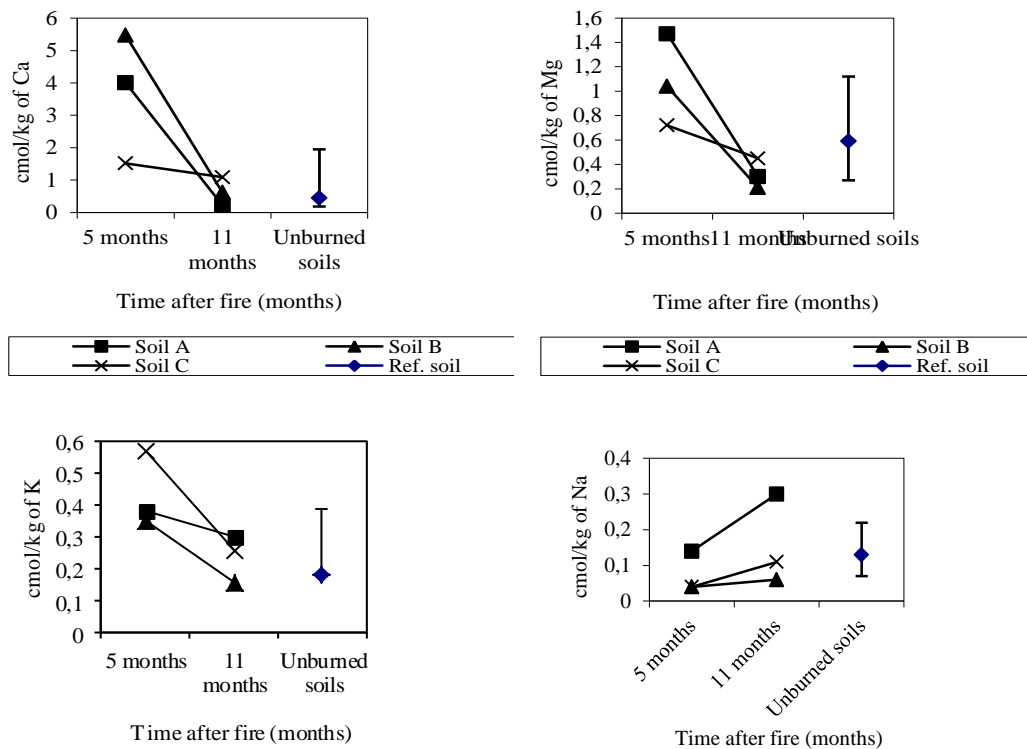
**Table 1.** Chemical analysis of ash and underlying soils, 5 months after the fire.

Sample	pH	C	O.M.	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Ca	Mg	K	Na	Zn	Cu	Mn	Fe	Nitrogen		
	H <sub>2</sub> 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

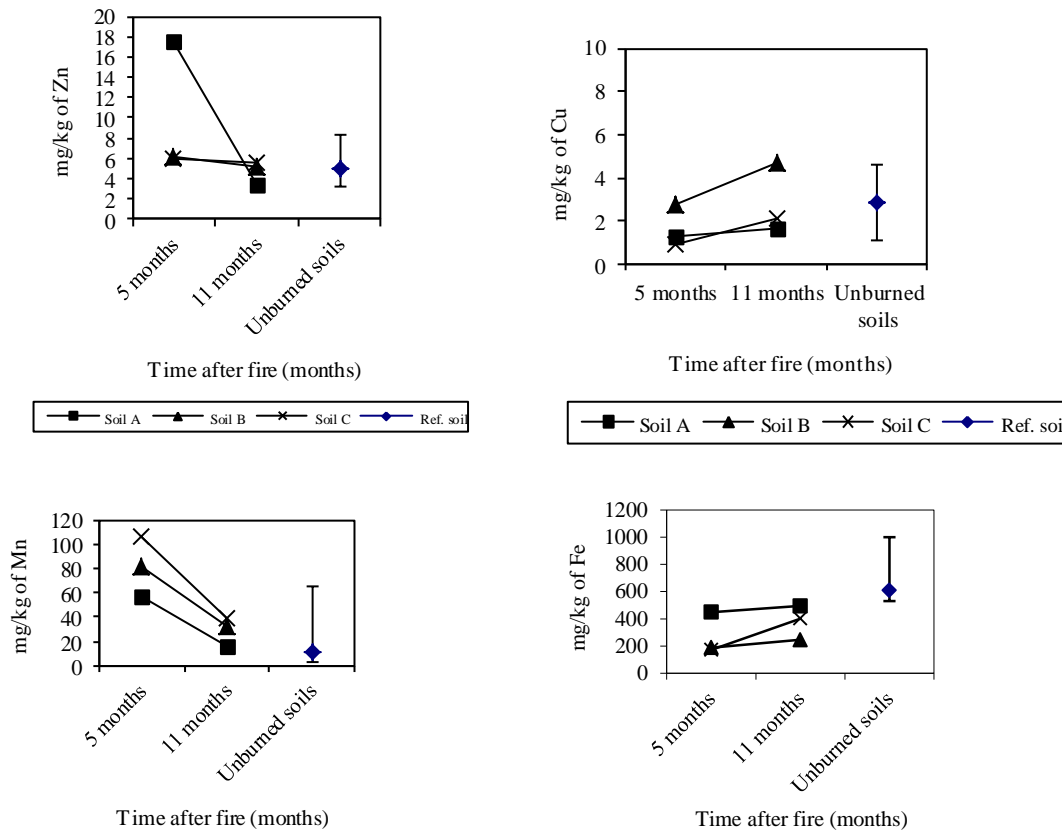
Results of the soils composition about one year after the wildfire show a recovery of pH values (Fig. 1), close to the reference value (obtained from soil samples collected outside the burnt area, which is consistent with the decrease in content of base cations, that approached the reference values (Fig. 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.



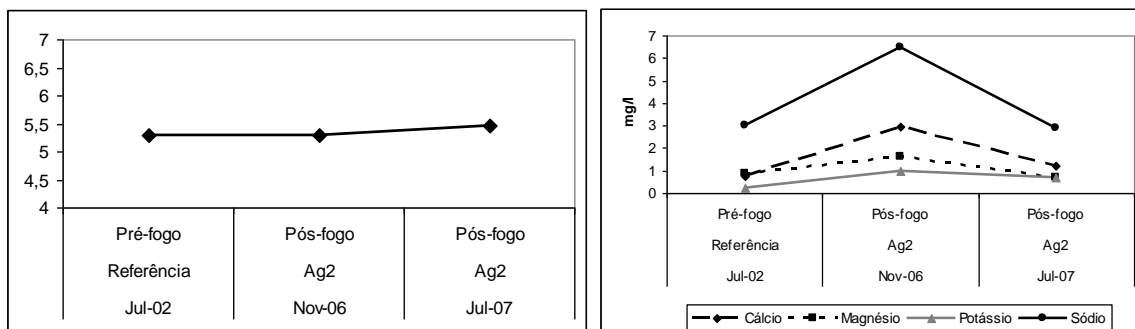
**Figure 2.** Temporal variation of cations (Ca, Mg, K and Na) in soil samples of the burnt area and comparison with values of unburnt soils.



**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.

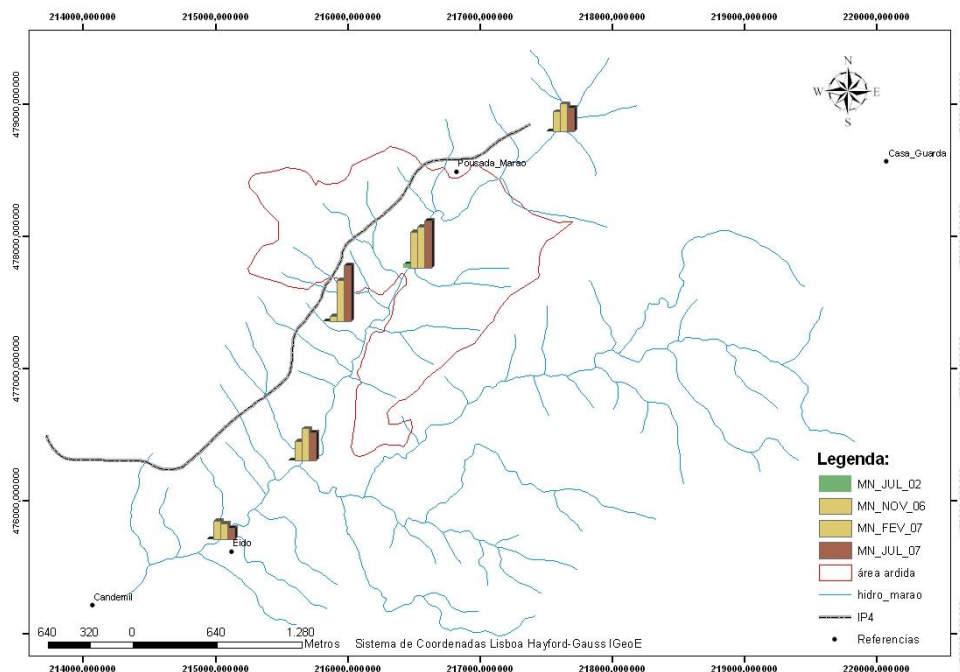


Figure 5. Variation on Mn concentration in the water along the Marão river.

## 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

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**Key-words:** soil chronosequence, prescribed fire, chemical composition, solid-state <sup>13</sup>C 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

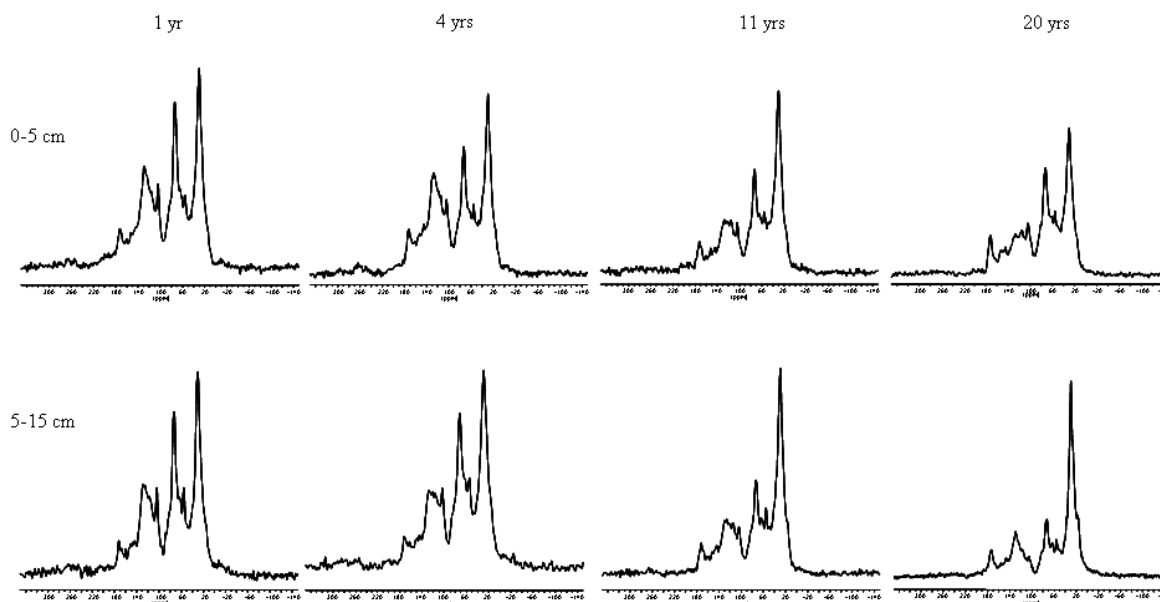
The study site was in Florida, on the *Merritt Island Wildlife Refuge*. Ecosystem is an oak shrub managed by prescribed fires (moderate intensity). We used a chronosequence of soils collected in plots protected from fire for 1, 4, 11 and 20 years. Climate is subtropical and soil highly sandy, potentially 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 <sup>13</sup>C nuclear magnetic resonance (<sup>13</sup>C-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 (K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>/H<sub>2</sub>SO<sub>4</sub>, 80°C) resistant elemental carbon (OREC).

### Results and conclusion

The C stock proved to decrease from 38 to 26 mg OC cm<sup>-3</sup> 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<sup>-3</sup> soil and 7±2 mg OC cm<sup>-3</sup> 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

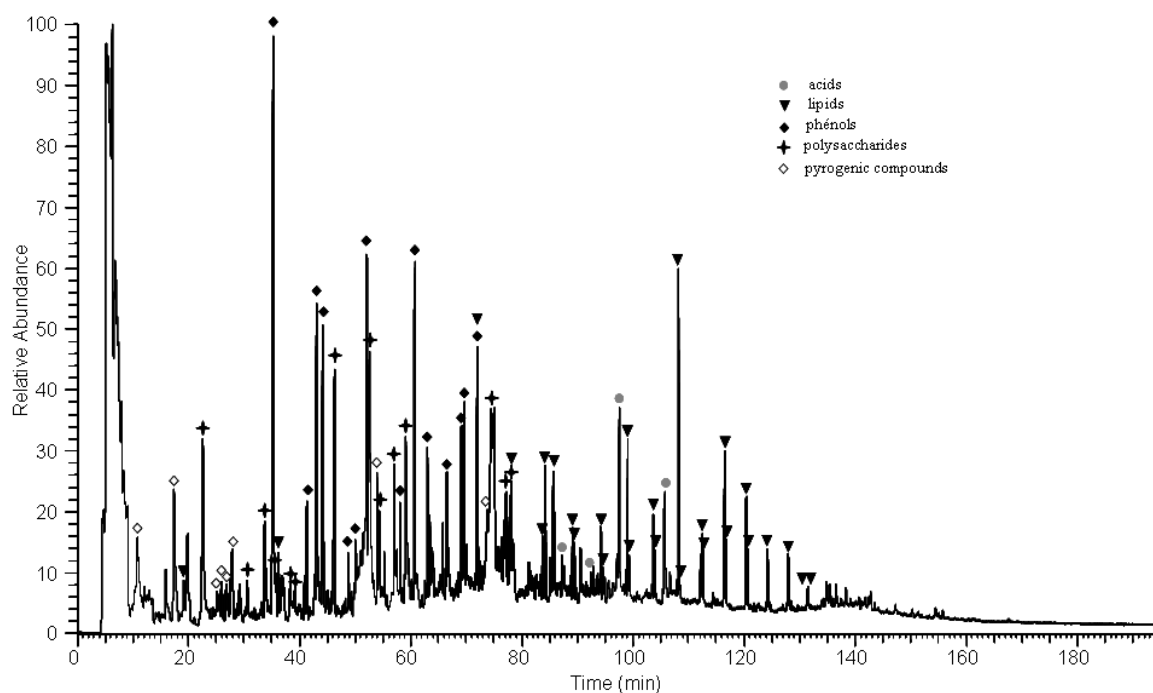
decrease of the O-alkyl C occurred between 1 and 4 years after the fire, followed by the decrease of the aromatic-C contribution between 4 and 11 years after the fire. 20 years after the fire, the alkyl-C contribution became lower. In the 5-15 cm depth, no change occurred between 1 and 4 years, whereas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



**Figure 1.** soil organic matter spectra obtained by <sup>13</sup>C-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 <sup>13</sup>C-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

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**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

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**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 m<sup>2</sup> 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

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**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.

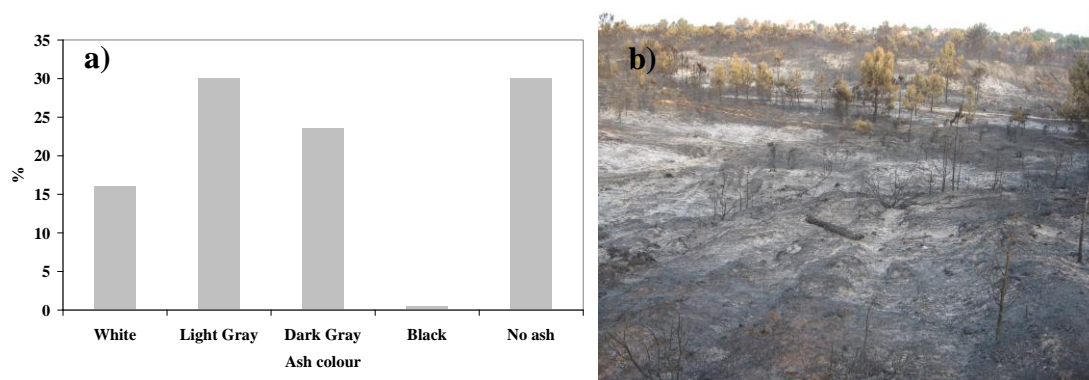
Omnidirectional semi-variogram of ash thickness was performed in order to observe the spatial structure of the variable. Spatial dependence was observed calculating the nugget/sill ratio. If the ratio is greater than 75%, the variable shows weak spatial dependence, between 75% and 25%, the variable shows 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 ( $\pm 6.13$ 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).

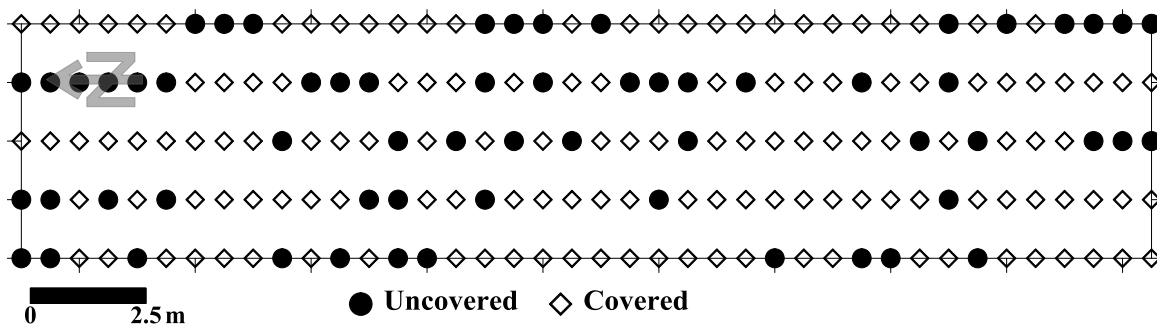


Figure 2. Spatial localization of not covered and non covered soil areas. ( $N=200$ ).

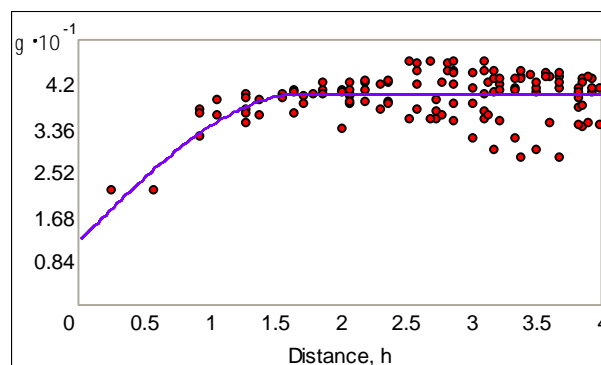


Figure 3. Omnidirectional semi-variogram calculated for ash thickness. Line represents the best fitted model. Range =1.45; sill =4.18 m; nugget effect= 1.22; nugget/Sill ratio = 26.84%. Distance, h in meters.

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	<i>r</i>
OK	-0.485	0.996	0.09282	0.4696	0.45***
<b>SK</b>	<b>-0.567</b>	<b>0.983</b>	<b>0.09292</b>	<b>0.4638</b>	<b>0.49***</b>
UK	-0.403	0.991	0.1365	0.4739	0.46***
IK	-0.400	0.822	-0.305	0.5523	0.04 <sup>n.s</sup>
PK	-0.403	0.802	0.005665	0.5007	0.05 <sup>n.s</sup>
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., Houg, 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 València.
- 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

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**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 20<sup>th</sup> 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

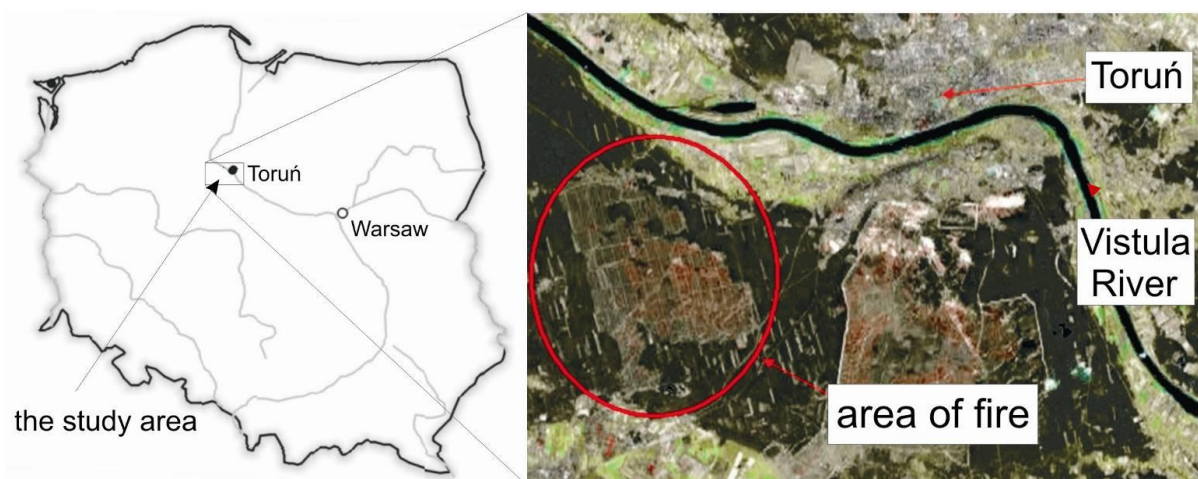
The study was conducted in the Cierpiszewo fire area (52°57’N, 18°27’E; 50 m a.s.l.) in Central Poland (fig. 1), where almost 30 km<sup>2</sup> of pine forest was burnt in 1992. The fire has been one of the biggest of all forest fires in Poland in last hundred years. The mean yearly precipitation in 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 <sup>-2</sup> ]	OC stock [kg·m <sup>-2</sup> ]	Nt stock [g·m <sup>-2</sup> ]
<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 <sub>au</sub>	2,1	69,4	37,7	0,91	41	0,85	0,47	11,4
AE <sub>au</sub>	3,1	3,0	1,4	0,06	23	0,99	0,48	22,2
ABwoBs <sub>au</sub>	13	1,9	0,83	0,04	21	3,20	1,40	67,5
Bwo <sub>au</sub>	24	0,2	0,16	0,01	16	0,58	0,54	33,8
<i>Plot C- interrows</i>								
Oi <sub>au</sub>	0,7	57,6	34,7	0,75	46	0,15	0,12	2,77
AE <sub>al</sub>	5,3	6,0	3,3	0,12	27	3,16	1,75	62,2
Obu <sub>al + au</sub>	3,5	20,2	11,4	0,42	27	3,00	1,68	63,6
AE <sub>au</sub>	3,9	3,7	2,4	0,09	27	1,24	0,74	29,4
ABwoBs <sub>au</sub>	4	1,8	0,79	0,04	20	0,94	0,41	21,0
Bwo <sub>au</sub>	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 Cierpiszewo 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., Pokojaska 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

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**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  $\text{Cl}_2\text{Ca}$  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  $\text{Cl}_2\text{Ba}$ , 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  $\text{NH}_4^+$ ,  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  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  $\text{Cl}_2\text{Ca}$ , 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.

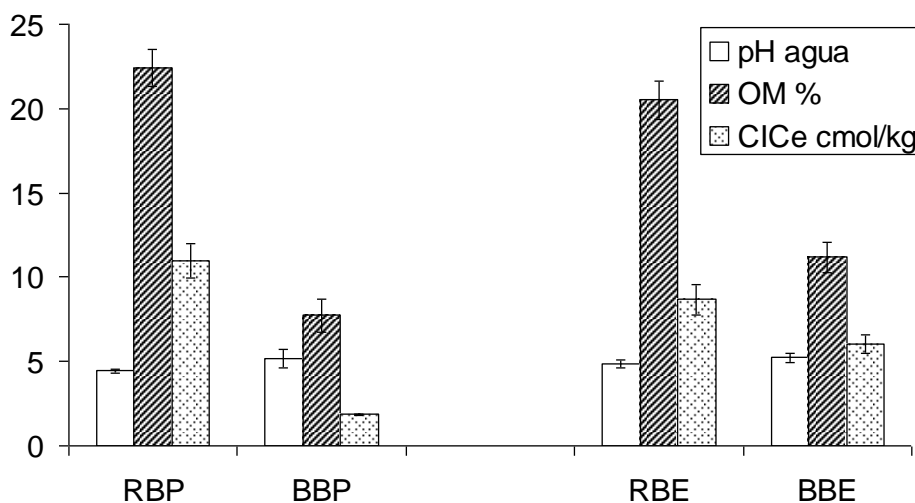
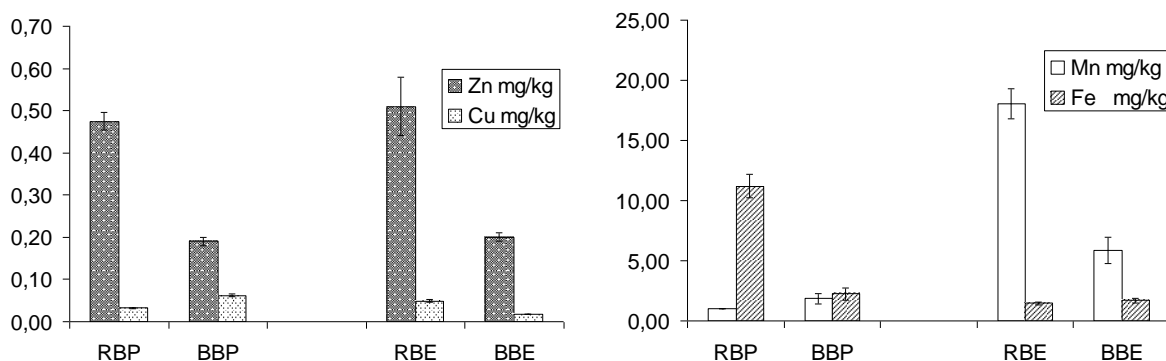


Figure 1. Chemical properties (pH, OM and CEC) of the bulk and rhizospheric soil.



**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 Bodenk.* 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

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**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 m<sup>3</sup>/h, of which around 60 m<sup>3</sup>/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 analyzer for pH, OM, macronutrients, micronutrients, heavy metals, pathogens, and



electrical conductivity. Outside composting experiments were conducted at Pontearreas (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 1m<sup>3</sup> 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<sup>-1</sup>. 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 NH<sub>4</sub><sup>+</sup>, NO<sub>3</sub><sup>-</sup> and PO<sub>4</sub><sup>-3</sup> 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

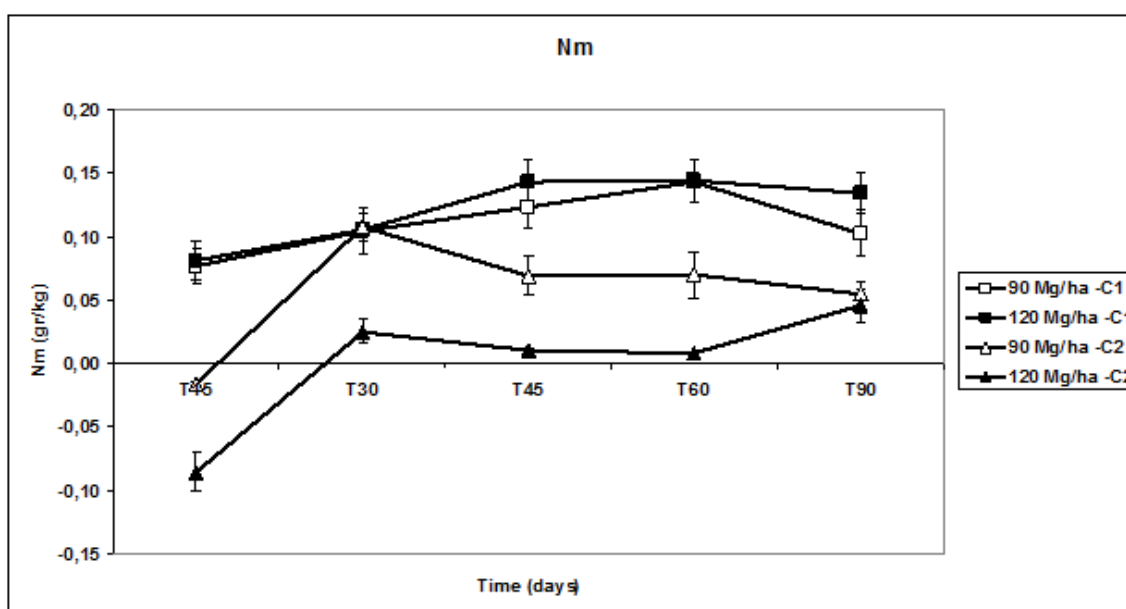
Sludge from turbot farm was analyzer for pH, OM, macronutrients, micronutrients, heavy metals, pathogens, and electrical conductivity. Results showed a very high water content in fresh fish manure (86%), an organic matter content around 33.8 %, and a neutral pH (7.5), total N content with values around 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  $\text{NO}_3^-$  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  $\text{NH}_4^+$  content, in the final vermicompost and compost, was around 101 and 186  $\text{mg.kg}^{-1}$  VC1, VC2, respectively.

In the laboratory incubation assay with similar rates of vermicompost, values of Nm were  $>100 \text{ mg.kg}^{-1}$  in the case of VC1 (pine sawdust + fish manure). For VC2 (pine sawdust + fruit waste + fish manure) with  $120 \text{ Mg.ha}^{-1}$  rate, the Nm values were very low ( $<45 \text{ mg.kg}^{-1}$ ), and low ( $<53 \text{ mg.kg}^{-1}$ ) with  $90 \text{ Mg.ha}^{-1}$  rate (Figure 1), probably this low values were due to the fruit waste is a source of C that immobilise N.



**Figure 1.** Net mineralized N ( $\text{g.kg}^{-1}$ ). (C1-vermicompost 1- pine sawdust + fish manure; C2-vermicompost 2- pine sawdust + fruit waste + fish manure).

$\text{NH}_4^+$ -N was the predominant form of inorganic N at the incubation start (T0). Nitrification increased gradually and at the end of the incubation (T90),  $\text{NO}_3^-$ -N represented the predominant form. Samples with 90 and  $120 \text{ Mg.ha}^{-1}$  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 dates 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  $>$  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 12<sup>th</sup> 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. 2<sup>nd</sup> 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)

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**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

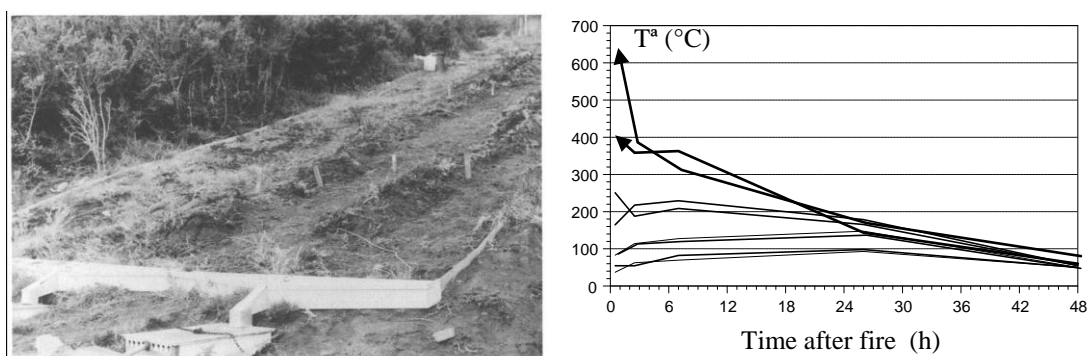
The soil was an Umbric Leptosol (FAO, 1988) developed over granite. Mean slope was 30% and altitude 350m. The scrubland vegetation consisted of mainly *Ulex europaeus* and Ericaceae. Surface runoff was collected in two tanks located at the down-slope end of the burned plots as well as the undisturbed 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 <sup>2</sup> )	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):

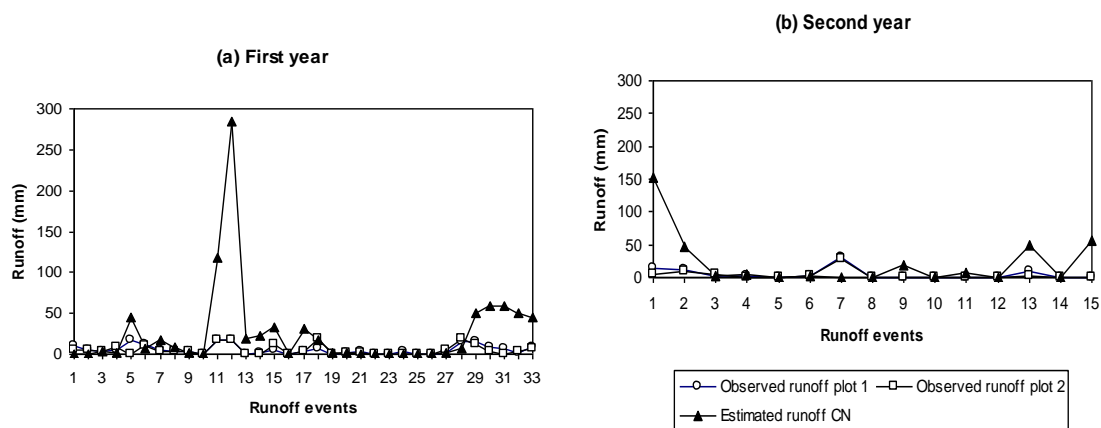
$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

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  $P_0 = 0.2S$ . 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  $P_0 = 0.2S$  (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:  $y = -0.129 + 0.813x$  ( $r = 0.79$ ;  $p < 0.001$ ).



**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			
			+	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 legend. 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. *Hydrological 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**

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**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**

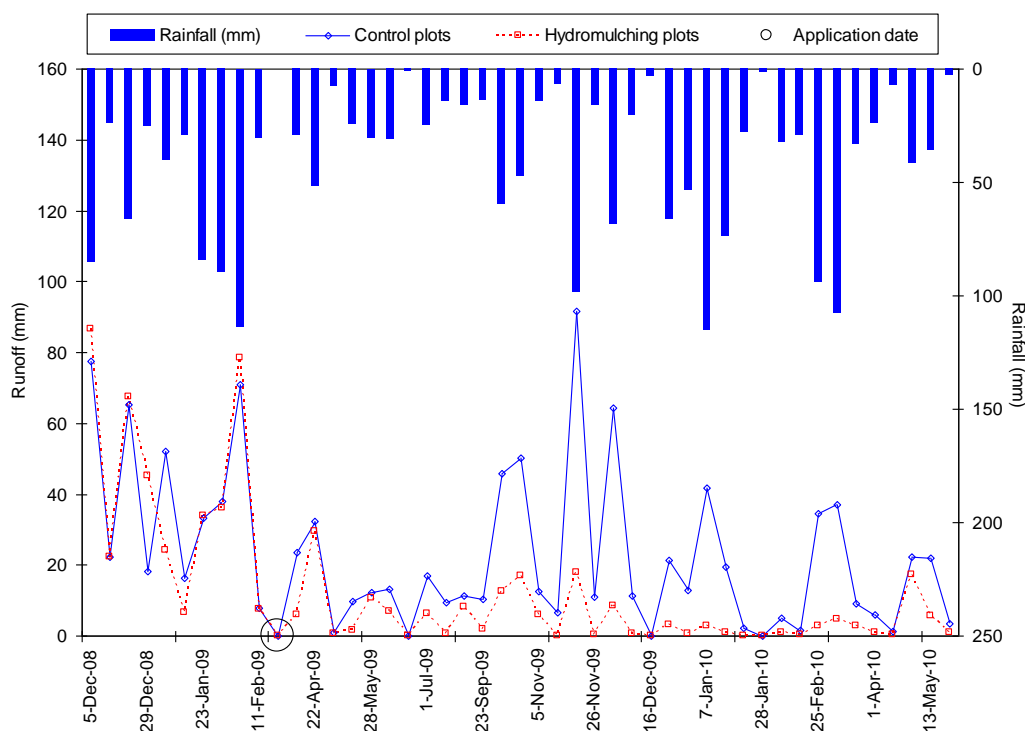
This study was carried out in the municipality of Arganil in a Maritime Pine stand on common grounds (“baldio”) that burnt during August 2008 and that was logged during the winter of 2008/2009 (mainly because of the nematode plague risk). The experimental set up involved 6 bounded plots of roughly 10 m<sup>2</sup> and 8 bounded plots of 0.25-0.50 m<sup>2</sup>. 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 m<sup>2</sup> 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 m<sup>2</sup> 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

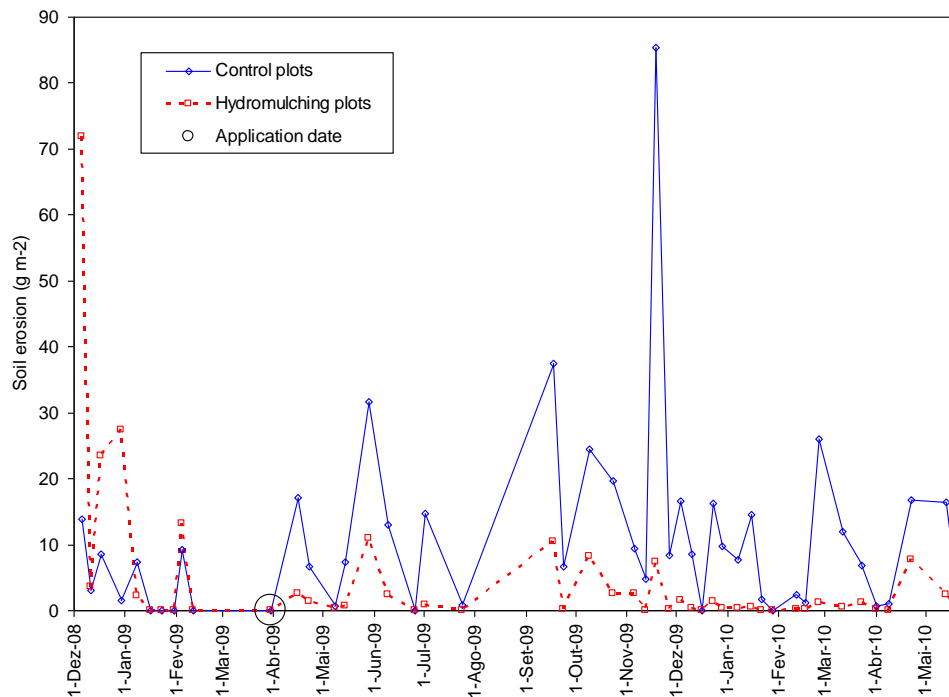
Total rainfall from 31 March 2009 to 20 May 2010 was 1327 mm. The untreated bounded plots showed an overall runoff coefficient of 47% while the treated plots produced 14%, which means a reduction of 70% (Figure 1). This is possibly linked to the effect that the green cover of organic fibers of the hydromulching 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<sup>-2</sup> for the control plots, and 99 g m<sup>-2</sup> 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<sup>-2</sup>). 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<sup>-2</sup> versus 65 indiv. m<sup>-2</sup>).



**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

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**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  $\Delta Z$  and  $\Delta Z_a$  (*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 (Roşca *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 (Ţicleanu 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  $\Delta Z_a$  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 (Roşca *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 Jilț-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 coaly clays, and the highest values ( $> 50$ ) in porcelanites; in the latter, FeO is sometimes totally oxidized to  $\text{Fe}_2\text{O}_3$ . Thus, regarding the chemical constituents (Table 1), the porcelanites show higher  $\text{Fe}_2\text{O}_3$  contents as compared with the "original"/"fresh" clays, while the FeO,  $\text{CO}_2$ ,  $S_{\text{tot}}$  and  $\text{H}_2\text{O}^+$  contents are higher in the latter.

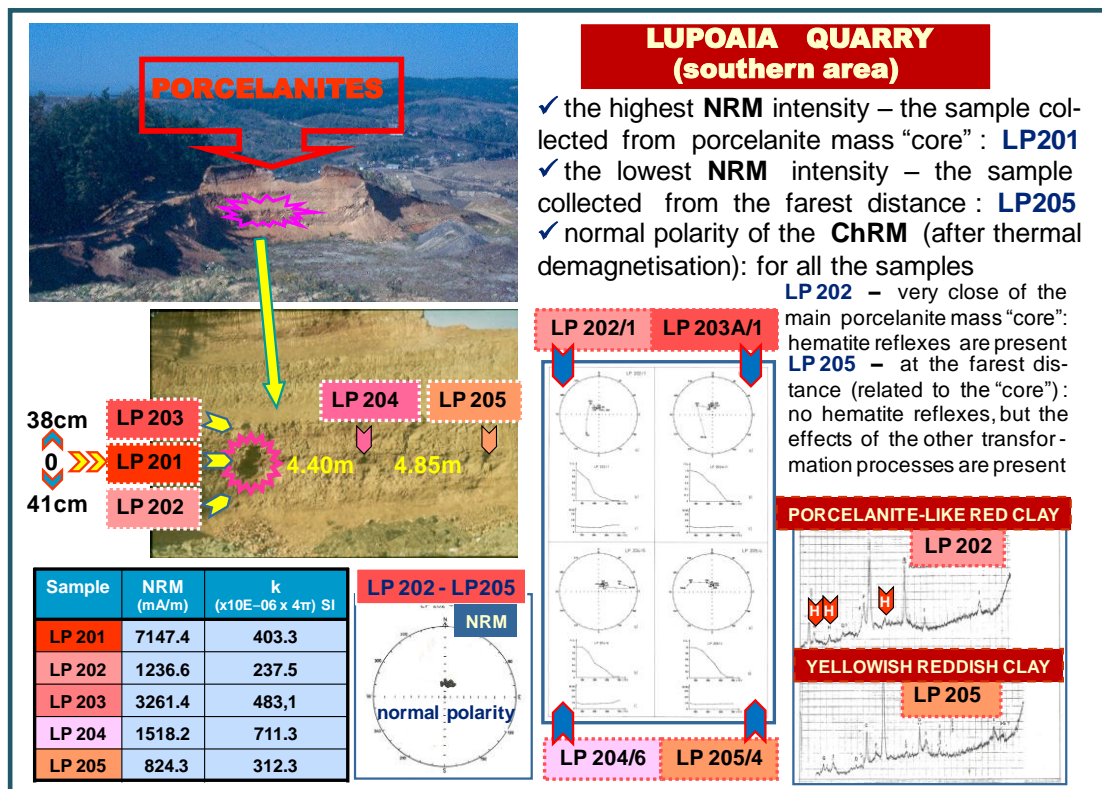
**Table 1.** Chemical composition of the clays and porcelanites sampled in the Lupoia lignite quarry (western Dacic Basin, Romania).

Legend: red – higher contents; blue – lower contents.

Chemical constituents (%)														
SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	Fe <sub>2</sub> O <sub>3</sub> total	MnO	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	CO <sub>2</sub>	S <sub>total</sub>	H <sub>2</sub> O
<b>Clays</b>														
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
<b>Porcelanites</b>														
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).

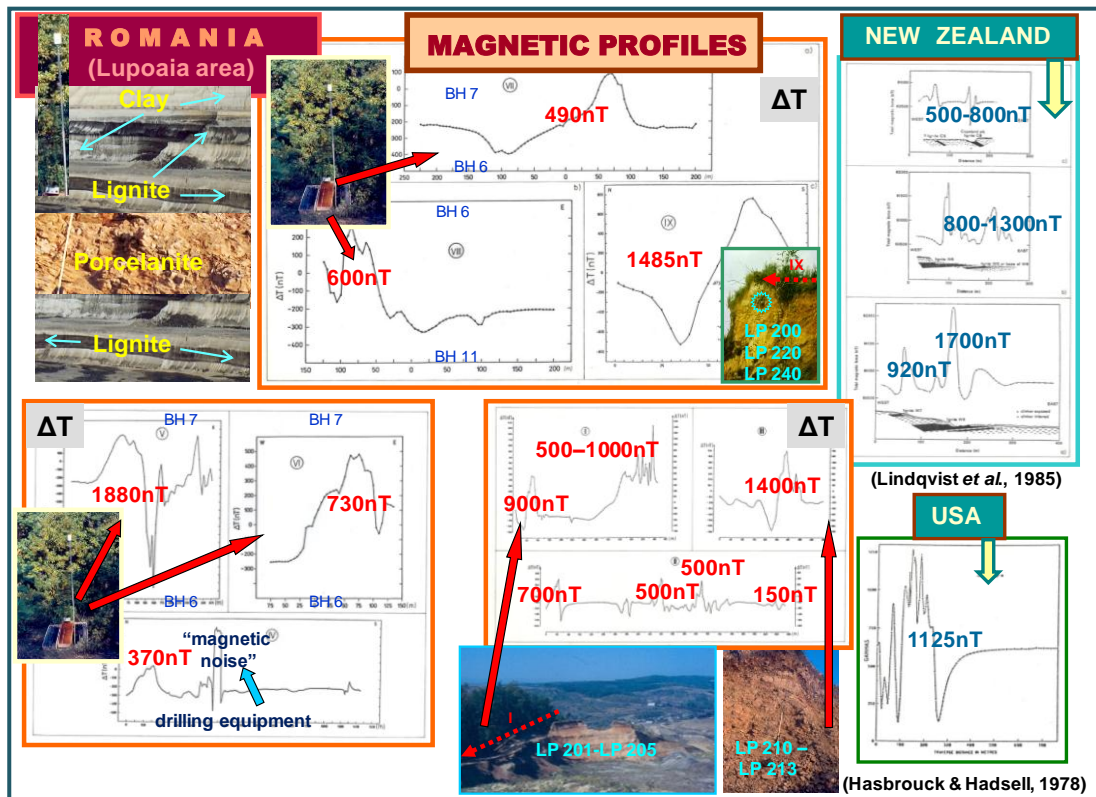
To present some geophysical and mineralogical features determined for porcelanite deposits, an example from the southern area of the Lupoia lignite quarry is given in Fig. 1.



**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 Lupoia – 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 auto-combustion of certain coal seams with petrographic-mineralogical availability for auto-ignition. 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 Lupoia 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 Hrad, 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

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**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 m<sup>2</sup>). 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

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**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

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**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 m<sup>2</sup>), 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.



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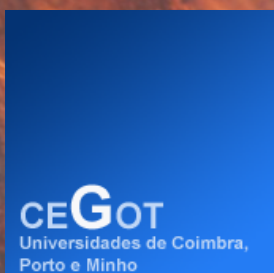
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