Visoka šola za varstvo okolja

DIPLOMSKO DELO

**Vpliv kontroliranih požigov na tla v sestojih primorskega
bora - primer severne Portugalske
Impact of controlled forest fire on soil in Maritime pine
forests - The case of
northern Portugal**

MARKO JOŽE ŠMID

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Varstvo okolja in ekotehnologije

Mentorica: dr. Nataša Kovačić
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SKLEP O DIPLOMSKEM DELU

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Marko Šmid Jože

se dovoljuje izdelati diplomsko delo pri predmetu: <u>Kemija in okolje</u>

Mentor-ica: <u>pred. dr. Nataša Kovačić</u>

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Naslov diplomskega dela v slovenskem jeziku: <u>Vpliv kontroliranih požigov na tla v sestojih primorskega bora – primer Severne Portugalske</u>

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Diplomsko delo je potrebno izdelati skladno z Navodili za izdelavo diplomskega dela.

Pravni pouk: Zoper ta sklep je možna pritožba na Senat v roku 3 delovnih dni.

Dekanica
doc. dr. Natalija Špeh

Diplomsko delo je nastalo pod mentorstvom pred. dr. Nataše Kovačič iz Visoke šole za varstvo okolja.

Delo sem opravljal na terenu območja Severne Portugalske v regiji Vila Pouca de Aguiar, ter v geoloških laboratorijih Instituto Superior de Engenaria do Porto (Portugalska) in laboratorijih Faculdade de Engenharia Universidade do Porto (Portugalska), pod mentorstvom dr. Ane Cristine Meira Castro.

Izjava o avtorstvu

Diplomsko delo je rezultat lastnega dela. Vsi privzeti podatki so citirani skladno z mednarodnimi pravili o varovanju avtorskih pravic.

Marko Jože Šmid

Vpliv kontroliranih požigov na tla v sestojih primorskega bora - primer severne Portugalske

IZVLEČEK:

Tretji letnik študija na Visoki šoli za varstvo okolja sem opravljal kot Erasmus študent na izmenjavi v Portu – Portugalska. Tam sem opravljal praktično usposabljanje v okviru projekta: Vpliv kontroliranih požigov na tla v sestojih primorskega bora - primer severne Portugalske, ki je bil podlaga za izdelavo moje diplomske naloge. Raziskava je bila osredotočena na povezavo med kontroliranim požigom in temperaturo prsti in vplivu ognja na določene fizikalne in kemijske parametre tal: pH, vsebnost vode, temperatura ognja, gostota talnih agregatov, električna prevodnost, delež organske snovi, gline, peska in melja. V raziskavi smo obravnavali podatke pridobljene pred in takoj po kontroliranem požigu.

Kontrolirani požig je bil izveden pod vodstvom državnega organa za gozdarstvo - Autoridade Florestal Nacional (AFN) 25. februarja in 1. marca 2011 v sestojih sredozemskih borovih gozdov območja Vila Pouca de Aguiar. Kontrolirani požig je bil izveden v skladu s strogimi pravili o nizki intenzivnosti in hitrosti 10-12 metrov na uro.

Diplomska naloga je sestavljena iz bibliografske raziskave in opisa postopka kontroliranega požiga in posledic le tega, izhodišč znanstvenih del in člankov povezanih s kontroliranimi in divjimi požari. Sledi opis praktičnega dela na terenu in v laboratoriju. Vzorci tal so bili odvzeti in testirani v laboratoriju. Laboratorijsko delo je bilo opravljeno v laboratorijih Instituto Superior de Engenharia do Porto (Portugalska) in Faculdade de Engenharia Universidade do Porto (Portugalska). V obravnavo rezultatov smo prav tako vključili opis in lastnosti tal. Rezultati laboratorijskih testov, iz katerih so narejeni zaključki, so predstavljeni v programu Microsoft Office Excel 2003.

Iz te študije je mogoče sklepati naslednje:

Kontroliran požig nizke intenzivnosti in hitrosti (10-12 metrov na uro) je povišal temperaturo zemlje na 50 - 80°C. Pri tej temperaturi nismo zaznali nobenega učinka na raziskovane parametre tal. Vpliv ognja je bil zaznan le v zgornjem delu horizonta O, ki je zgorel.

Območje kontroliranega požiga smo obiskali čez dva meseca. Vidno je bilo, da ogenj ni uničil korenin večine rastlinja, saj so trave in grmičevja že poganjali nove poganjke. Razlike v vzorcih pridobljenih pred in po kontroliranem požigu so odraz prostorske variabilnosti tal.

Ključne besede: kontroliran požig, iglasti gozdovi, fizikalne in kemijske lastnosti tal, bibliografska raziskava, praktično delo, laboratorijsko delo.

Impact of controlled forest fire on soil in Maritime pine forests - The case of northern Portugal

ABSTRACT:

As a third year pre-graduate student of Environmental Protection College (Visoka šola za varstvo okolja, Slovenija), I had the opportunity to participate in a scientific study focused on impact of controlled fire on some forest physical and chemical soil parameters in pine land in the North Portugal region of Vila Pouca de Aguiar. This work represents my bachelor degree thesis**.** The research is orientated on relation between fire and soil temperature and impact of fire on soil pH, moisture electrical conductivity, content of organic matter, clay, silt and sand content and bulk density. Study was focused on data of measurements before and immediately after the fire.

This controlled fire was performed by Autoridade Florestal Nacional (AFN) on the 25th of February and 1st of March 2011 in Maritime pine forests of Vila Pouca de Aguiar. The municipality of Vila Pouca de Aguiar has high importance and diversity in terms of geological resources. Standing in a patch of elongated granite biotite, the area is assumed as the "Granite Capital." Nevertheless, the site I studied was a schist area. The fire was carried out under strict rules of low severity and low intensity, and carried out at 10-12 meters per hour.

The thesis is composed by bibliographic research and description of the controlled fire procedure, and consequences of it, following by bibliographic research of scientific works and articles related to prescribed and wild fires effects on soils properties. Further, practical work on field and laboratory is described.

Soil samples were taken and tested in the laboratory. Laboratory work was performed in Laboratories of Instituto Superior de Engenharia do Porto (Portugal) and Faculdade de Engenharia Universidade do Porto (Portugal). The soil description has also been done and considered to the results of the tests. The laboratory work results, from which the conclusions were made, are presented using Microsoft Office Excel 2003.

The following conclusions can be drawn from the present study:

the controlled fire carried out on such slow velocity (12 meters per hour or less) and low fire intensity and severity does not heat the soil significantly (analysing the records it is presumed that the controlled fire reached peak temperatures between 50 and 80°C) and does not show any significant effect on any studied soil parameters. The effect was only directed to litter in upper horizon O (which burned).

Moreover, as the burned area was visited after two months it was clearly visible that the vegetations roots or any other important parts were not affected (grass and herbaceous species have started to grow again). The differences found between the before and after fire samples result from the spatial variability of the soil features.

Keywords: controlled fire, pine tree forest, physical and chemical soil parameters, bibliographic research, practical work, laboratory work.

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List of acronyms

AF	-	After fire
AFN	-	Autoridade Florestal Nacional
ANOVA	-	Analyses of variance
BF	-	Before fire
EC	-	Electrical conductivity
FAO	-	Food and agriculture organization
FEUP	-	Faculdade de Engenaria Universidad do Porto
GIS	-	Geographic Information System
GPS	-	Global Positioning System
horizon A	-	The A horizon is the top layer of mineral soil horizons
horizon O	-	Organic horizon
Horizon Of	-	Organic fermentated horizon
Horizon Oh	-	Organic humic horizon
Horizon Ol	-	Organic litter horizon
IC	-	Inorganic carbon
ISEP	-	Instituto Superior de Engenharia do Porto
ISO	-	International organization for standarts
PC	-	Personal computer
TC	-	Total carbon
TOC	-	Total organic carbon
TOIC machine	-	Total organic and inorganic carbone machine
WT-A	-	Whitney test sample A
WT-B	-	Whitney test sample B

1   Introduction

Forests are one of the economical, social and ecological pillars of development in Portugal. Forest management is exposed to various challenges and uncertainties, which require a sustainable use of resources for the successful future of the economy and climate. Among other activities, measures to preserve and guarantee the self–recovery, geological features, biodiversity and aesthetic appearance are required.

As a third year pre-graduate student of Environmental Protection College (Visoka Šola za varstvo okolja, Slovenija), I had the opportunity to participate in a scientific study of controlled forest fires impact on soil and forest ecosystem in northern Portugal (Vila Pouca de Aguiar).

Study of controlled forest fire impact on soil was carried out in the Instituto Superior de Engenharia do Porto (ISEP) and represents the topic of my bachelor degree thesis. The leader of this project and my co-mentor was dr. Ana C. Meira Castro. Experts from the field of geology, forestry, cartography, geography, statistics, state-controlled units for controlled fires from Autoridade Florestal Nacional (AFN), and representatives of civil protection were also part of the team. The survey itself has been running for several years, but it was for the first time carried out in pineland (previous researches were done in shrub lands). The research was based on bibliographic platform, fieldwork (controlled fire and sampling), laboratory work (sample analysis) and statistical processing of data, which is the key to make, *a posteriory*, the geostatistical model of the effects on specific soil parameters. Sampling was performed prior to controlled fire and immediately after the controlled fire. The purpose was to obtain data of the impact of controlled fire on some parameters of soil, namely electrical conductivity, pH, organic matter, silt, clay and sand content, moisture, porosity and bulk density of soil, and to find out, if the soil had been affected or not. Considering the duration of my internship, my project task was focused on the behaviour of soil pH, soil electrical conductivity, soil organic matter and moisture before and after the controlled fire and at soil layers 0 to 1 cm and 1 to 5 cm.

Mainland Portugal's climate is Mediterranean, hot and dry summers and rainy winters are typical. In summer the temperatures rise above 40 °C and spontaneous combustions in pine tree forests, inside of the country, become frequent phenomenon. Spontaneous combustions are attributed to high summer temperatures, nature of plants in terms of flammability, climate conditions, human interventions and use of forests. In Portugal a controlled fire technic (burning the dry forest biomass - the most flammable material in hot summer days) is used to prevent natural combustions. Thus AFN tries to prevent the spreading of natural fire to other areas, because it (fire) could cause high economical and ecological damage.

Photo 1: Controlled fire in progress (Source: Šmid, 2011)

1.1   Description of controlled fire

Controlled fire is a common technic used by forest management to prevent the spreading of wild fires. The use of controlled fire in Portugal is not a new practical method of pine forest management. Prescribed burning of pine forests for wild fire prevention was described by Frederick Varnhagen, in his Manual of the Practice in 1836. As technical forestry management it was introduced in Portugal in 1982 by the initiative of Eng. Moreira da Silva. Since then researchers have been trying to find out how to use successfully this technique in their environment. But they were mainly studying vegetation and ecology. In order to minimize the area covered by wildfires each year it is essential that the maintenance of forest fuel loads below critical levels is assured. This objective is possible through the use of controlled fires that gradually replace the regime of destructive fires in summer season by a regime of less intense burning in winter season. The intensity of a fire is proportional to the amount of biomass available to fire and to its propagation speed. The controlled fire acts on the factor of limiting considerably the potential energy, but also breaking the horizontal and vertical continuity fuel and increasing the size of the residual fuel and its compression (Fernandes et.al., 2002).

The controlled fire technic is used in period between October and April, when the meteorological conditions (temperature, wind, humidity, pressure, precipitation, biological activity) allow such actions. Controlled fires in Portugal run under legislation (AFN 2006).

Spontaneous combustions were most frequent in forest areas of low economical quality, which did not have dedicated management. North of Portugal has large areas of pine forests, from which the needles and branches were dying, falling and accumulating for several years (Fernandes et.al., 2002).

Controlled fire technic is based on burning of dry forest biomass (fallen branches, leaves and needles) and herbaceous species, such as shrubs, which are highly flammable, when they are dry. Controlled fire allows reducing the quantity of flammable material and decreases the risk of uncontrolled fire spreading to the forest areas near the villages. It also stimulates germination, burns the insects and pathogenic fungus, and prepares the ground for the pioneer plant. In pine tree area controlled fire is usually started in morning hours when the air humidity is higher, the plants are more saturated with water and the air temperature is low. When burning, all vegetation must be removed in a range of ten to fifteen meters per hour. If the burning conditions increase the speed of fire, the fire patrols prevent it with water or soil, to unable the

spreading of the fire to unwanted area. In the shrub areas fire spreads faster. The fire technic that is used on the area depends on meteorological conditions. The best technic, that is being used, is to spread the controlled fire against the wind direction to make it slow and avoid the possibility of uncontrolled spreading. It also provides better burning of the vegetation, and allows making more burning lines in between the sections (Fernandes et.al., 2002).

1.1.1   Fire behaviour

Ignition is the initial process of burning the fuel, and combustion is the self-sustained oxidation process of the fuel to release energy from the ignition. Combustion is the rapid release of energy captured by photosynthesis and stored chemically in the fuel (Fernandes et.al., 2002).

The probability of ignition of the fire is a function of fuel moisture. Factors such as the relative composition and structure of the fuel and wind speed have a secondary importance (Fernandes et.al., 2002).

When a heat source is applied to the fuel, components such as essential oils, water and carbohydrates (mainly cellulose) begin to decompose and produce other flammable gases. This thermal or chemical decomposition of fuel at high temperature is called pyrolysis. The reactions begin to absorb heat, so they are endothermic, but as the fuel temperature increases, the decomposition becomes exothermic and self-sustaining (Fernandes et.al., 2002).

1.1.2   Processes of heat transfer

Heat is transferred by radiation, conduction and convection. The combined effect of all sources of heat transfer is called heat flow (Fernandes et.al., 2002).

1. Radiation is the propagation of energy through space in electromagnetic waves. The radiation intensity varies inversely with square of the distance of the flames and depends on the size of the flames.
2. Conduction is the heat transfer by physical contact and it only affects the fuel immediately adjacent to the front fire.
3. Convection is the heat transfer through the movement of a gas or liquid. In a fire this movement is predominantly vertical, which has a decisive role in the damage the top of the trees. Convection prevails in fires dominated by wind and / or slope.

On flat ground with fuel, even in the absence of wind, fire spread is equal in all directions. In the presence of wind and / or slope the flames tend to approach the fuel, which accelerates heat transfer by radiation and convection, and increases the speed of fire with wind and/or the uphill (Fernandes et.al., 2002).

1.1.3   Basic parameters describing the behaviour of fire

The most important parameters of fire behaviour are the propagation speed, the dimensions of the flame, the intensity of front and the energy emitted per unit area (Fernandes et.al., 2002).

➢ **The propagation speed** is the speed of the linear movement of the front fire spread, measured in m/min or m/h. The estimation of the speed progress of the fire allows calculating the time required to treat a given area according to the technique used for ignition. The speed propagation is determined by wind, slope, fuel moisture, type and structure of the fuel and by width of the front propagation.

➢ **The flame height** is the average distance from the top of the flame to the ground, measured vertically. It depends on the amount and structure of the fuel, on its content of humidity, on wind speed and on slope of the terrain.

➢ **The angle of the flame** is the inclination of the flame to the surface, measured from the axis that defines the length of the flame. It is determined by wind speed and slope of the terrain.

➢ **The flame length** is the distance from the edge of the flame to the midpoint of the combustion zone and is directly related to the intensity of the front fire.

➢ **The depth of the flame** is the width of the combustion zone that possesses a continuous flame, measured perpendicular to the edge of the fire. It depends on the speed of the fire spread and on its residence time (duration of combustion flame) in the fuel.

➢ **The intensity of the fire front** or intensity of Byram (kW/m) is the production of heat per unit time and length of the front. Together with the previous variable (the depth of the flame) has an important meaning in relation to capacity of controlling a fire and in relation to the safety of the persons involved in a controlled fire operation. The intensity of the fire front depends on the propagation speed, on the consumed fuel load and on its caloric content.

➢ **The heat per unit area** (kJ/m^2) is the amount of energy released by the track of the propagation front. It can be quantified by multiplying the quantity of fuel consumed by its calorific power value.

Photo 2: The start of the ignition with small flames (Source: Šmid, 2011)

1.1.4   Content of a controlled fire plan

A controlled fire plan must have: i) a description of the area to burn, including physical and biological characteristics of area, its location, its size, slope, exposure and vegetation type, ii) fuel characteristics, including also the litter characterization and height, iii) a map of area that will be burnt, including representation of the limits of the are that will be burnt, existing barriers, existing defence lines, the ignition pattern, areas of special concern and internal and external

roads (state roads without output and those in difficult traffic), iv) identification of the aims of controlled fire, v) organization of the team involved in the prescribed fire, vi) estimation of the costs of the operation (equipment and team), vii) description of acceptable ranges of fire behaviour, of the meteorological variables and of fuel moisture, viii) technique and pattern of the ignition that will be used and also the protection facilities available ix) Identification of people (inhabitants of the local and local authorities) that should be notified about the occurrence of the prescribed fire action, x) identification about the monitoring procedures for meteorological variables, fire behaviour, operational assessment of the general satisfaction related to the objectives of controlled fire and its costs (Fernandes et.al., 2002).

1.1.5   Implementation of controlled fire

Fire convection should be drawn from a point of ignition or drawn along a perimeter.

The fire should never be started out of the prescribed area and never when the weather conditions, air temperature, pressure and wind velocity, are above limitations.

The time of day when the controlled fire is started has an important impact on fire behaviour. An ignition during the first hours of the day, when the fuels begin to get dry, implies that the fire will intensify as the fuel loses moisture and wind speed increase according to their daily cycles. Failure to recognize these patterns can lead to security problems. Starting a fire around noon, means that the pattern of fire behaviour will tend to decline throughout the day, allowing to make the burning in a safer way. Starting a fire in the late afternoon or early evening can also be appropriate in conditions of greater dryness of the fuel. It is normal that the relative humidity during the season of prescribed fire approaches or reaches 100% overnight. These situations usually inhibit the spread of fire during the early hours of the day, except in topographies and vegetation stands that are more exposed to solar radiation (Fernandes et.al., 2002).

Photo 3: During the afternoon the flames got bigger and faster with help of wind (Source: Šmid, 2011)

Photo 4: Controlled fire lines under perfect conditions (Source: Šmid, 2011)

1.1.6   Fire impact on land and soil

Fire effects on soil and vegetation, which can be seen in result of fires with similar behaviours (occurrence under similar conditions of temperature, relative humidity and wind speed) can be quite different from soil to soil and different vegetation types. Some effects of fire, namely in trees, may be clearly related with the fire behaviour. However, the fire causes many other important effects but they are not possible to be predicted. It is diverse how a particular plant community burn and therefore the resulting impacts are quite variable.

The direct effects that result from fire are related with i) eventual tree mortality ii) reduction of fuel litter iii) reduction of leaves. But the fire also causes changes in the subsequent period, like i) removal of understory vegetation ii) increasing the amount of available nitrogen in soil and iii) improving vegetation forage quality. The consumption of vegetation, litter and humus are associated with the duration of the combustion, the moisture content in the fuel mass (litter does not burn or transmits heat) and weather conditions.

The increase in soil temperature varies with the surface temperature during the fire and depends on the duration of the fire, moisture content of litter and soil, and soil texture. Most of the heat generated by the aerial fuel is dissipated and does not contribute to heat the soil.

The humidity of both litter and soil influences the magnitude of soil warming. The heating of the soil is higher if the litter and soil are dry nevertheless the wet litter conducts better the heat than the dry litter. If both litter and soil are wet, the soil heating caused by fire is very limited, even if the fuel load is high. Soil texture also affects the transmission of heat in soil. Coarse textured soils transfer the heat from the fire more easily and also contain less water and are more porous. Changes in soil nutrients, by adding the nutrients that become available from the rapid decay (by fire) of plant biomass, can improve nutrient conditions in soils with lack of available nutrients. Controlled fire with high intensity can increase soil pH by addition of ash and change the structure of clay aggregates. Acid soils can be greatly favoured by fire, due to increased nutrient availability and increased biological activity and in more alkaline soils the impact is usually negligible. Soil texture in coarse soils (sandy) is more prone than in soils with more clay. Organic compounds that repel water can also be volatilized during the fire. These compounds migrate and condense in the mineral soil, resulting non-hydrate horizons, which can prevent the

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infiltration, causing leaching and erosion. Amount of organic material remaining in the mineral soil can decrease if the soil is subjected to a sufficient temperature (temperature above 175˚C). With temperatures above 500 ˚C some soils acquire a reddish tone due to the oxidation of iron (Fernandes et.al., 2002).

1.2   Consequences of controlled fire

According to the literature consulted, there are many consequences related to controlled fires: impact on air, on vegetation, on soil, on water retention and on the entire ecosystem of the area.

The smoke that fire provides impacts mostly the local area by evaporating water, carbon mono and dioxide and heat to atmosphere. Although, if the wind is strong it can consequently affect ecosystems around the burned area, which can be disturbing for the birds and other animals living near.

Controlled fires have the biggest effect on the burned ground vegetation. However, not all of the vegetation is destroyed by fire, since the mortality directly caused by controlled fire usually does not reach all the plants, so some plant communities, that are resistant enough to survive the fire, start growing again after the prescribed fire. Some of the plants have built a resistant capability to high temperatures, so during the fire they temporary or permanently stop the photosynthesis. It is also normal that older and drier trees suffered more, than younger, that have higher recovering capacity.

Fire effect on soil is proportionally related with burned vegetation, which provides organic material in horizon O. The burned vegetation causes the soil to become temporarily enriched with ash, that contains some mineral nutrients which can be used by plants (the propose of traditional burning agriculture). On the other hand, with rain occurrence short time after the fire, the nutrients can rapidly be drifted to the lower layers of soil and can exceed the plant capability nutrient uptake, which has a negative effect on growing vegetation. In this case we can also expect lower nutrient exchange capacity, since most of the nutrients for vegetation are dissolved in water.

Controlled fire affects water content and water retention in soil so after the fire is burnt out some soil loss and erosion is expected. Water content at the horizon O is mostly evaporated and also reduced in upper part of horizon A. Water retention in horizon O also suffers alterations due to burned organic material. In upper part of horizon A, the water retention is also reduced due to the burned organic material and the evaporated water, which causes a reduction in the aggregates in smaller pieces that are more porous. This phenomenon can also provide higher possibility of soil erosion.

When considering the entire forest ecosystem, the controlled fire has the biggest impact on vegetation made of wooden material, but on the other hand it increases the biodiversity, by transforming the death plants into mineral nutrients and giving more space and nutrients to new generations of plants. There are studies that showed the decreased amount of Na, K, Ca and Mg minerals after the fire, but they returned to previous values after one year (Farres et.al., 2008).

1.3   Objectives and research questions

The main objective in my thesis is to identify if there is an impact of controlled fire on some forest soil physical and chemical parameters in Maritime pineland. This thesis is focused on

relation between fire and soil temperature and also on the relation between fire and soil pH, electrical conductivity, content of organic matter and moisture.

The study was conducted in pine tree area, in the North Portugal region of Vila Pouca de Aguiar, where data for measurements before and immediately after the fire were collected. As this study was focused on results before and immediately after the controlled fire, the meteorological factors were not taken in consideration.

The main research questions are:

- ➢ How much and how long does the controlled fire heat the soil?
- ➢ How does the controlled fire affect soil pH, electric conductivity, organic matter and moisture?
- ➢ How does the controlled fire impact on soil porosity, bulk density and particle size distribution?
- ➢ Does controlled fire affect these parameters in the same way at 0-1cm and 1-5cm depths?

2   State of the art

The objective of most researches on controlled fires was to identify the impact of controlled fire on ecosystem recovery.

In the past there have been done several researches focused on wild fires impact in many soil parameters (micro and macro nutrients, water repellence, water porosity, thermal conductivity, cationic exchange capacity, texture, hydrophobic properties, soil erosion…), which contributed many useful data for further researches. Considering the wild fire impact on soil, the scientific manuscripts, that I have consulted, pointed out that the temperatures of the soil and the burned vegetation can produce changes in soil chemical and physical properties. The magnitude of those changes mostly depended on fire and soil characteristics, on the type of the vegetation cover, on the climate and on the weather conditions (Farres et.al., 2008).

So, we decided to investigate, how much and how long will the prescribed fire heat the soil, since we expected low temperature peaks of our controlled fire(50 - 100 ^{o}C). That way we tried to correlate this data with data obtained from soil sampling parameters.

Fire mainly causes changes in soil and vegetation characteristics, which values depend on intensity of the fire (peak temperatures reached on the soil surface and their duration). In fires of medium (200-400°C) and high intensity (more than 400°C), the disappearance of vegetal cover and partial combustion of organic matter could impact on the soil structure. Losses of organic carbon are generally related to fire temperatures between 200 and 460°C, which causes complete destruction of organic carbon and the soil recovers only when the new vegetation is seeded (Certini 2005).

Our fire assumed to have low temperature peaks (50 - 100 ^{o}C). Therefore we did not expect any changes in soil organic matter content after the prescribed fire.

Research of fire impact on changes in organic matter and some other properties showed that the controlled fires of slash piles, that took place in semiarid Mediterranean climate on Rendzic leptosol with limestone, reached average temperatures up to 222.5^{o}C, did not cause a decrease of soil organic matter. Average carbon values after a wild fire, could increase up to 8% in 10 years, by incorporation of unburned residues, transformation of fresh organic matter into more recalcitrant forms, that can cause the enhancing of the soil carbon sequestration (Gimeno– Garcia et.al., 2000).

Article review of fire effect on properties of forest soils revealed that fire in pine tree forests, with peak temperature of 220°C, can cause up to 37% of organic matter loss, depending on duration of fire and vegetation (Certini 2005). Also, fires with temperatures up to 400°C and more can destroy all the organic matter in soil at depth up to 2cm, which can cause difference in soil bulk density, if the amount of soil organic matter is significant (Massman et.al., 2008).

Previous studies showed that soil temperatures during the fire are highly reduced by high soil moisture content. High soil moisture content reduces maximum soil temperatures and also the depth and duration of sustained high temperatures. High litter moisture content additionally prevents the soil form heating. While the big amount of litter can cause strong and high temperature fire, the lower part of that litter, usually having high moisture, acts as a heat sink rather than a source (Certini 2005).

Our controlled fire tended to reach up to 100°C, which is the boiling point of water. We presumed that this could reduce soil moisture(by evaporating the water) in upper part of horizon A. Therefore we decided to investigate, if there was any effect on soil moisture content.

Research of controlled fire impact on soil pH in pine tree forest of Sacramento Country in Brazil, showed no or insignificant impact on soil pH (Neto et.al., 1993). However in another scenario soil pH increased a little bit after the fire when temperatures exceed 450 °C during the fire. Even more, fire induced increase of pH was insignificant in soils buffered by carbonates (Certini 2005). Other research refers, that because the ash generally has a very high pH, increased burning, with high temperatures, can reflect on increased values of pH, when temperatures exceed $250^{o}C$. On the other hand in researches of heating the soil up to $250^{o}C$ there was noted a slight decrease of pH (Stoof 2011).

From this aknowledgements, we did not expect any difference in soil pH values after the controlled fire.

Electrical conductivity in soil can ephemerally increase after fire as a result of released inorganic ions from the combusted organic matter (Certini 2005). If the electrical conductivity has raised right after the fire, it returned to previous values in period of one year (Farres et.al., 2008).

We presumed that controlled fire could affect soil electrical conductivity, if the fire would reach the mineral part of soil directly.

Soil bulk density changes, after fire, are usually related to the loss of soil organic matter. Soils with high percentage of organic matter could experience slight decrease of bulk density as a result of burned organic matter (Massman et.al., 2008).

As our controlled fire was not to exceed $100^{o}C$, we did not expect any differences in soil bulk density after the controlled fire.

One of the latest scientific researches of wildfires in Portugal was made in North - central Portugal on schist soil with 16% of soil organic matter and covered with shrubs and pine trees (Stoof 2011). According to this research:

> ➢ Heating soils up to $200^{o}C$ did not alter any changes in soil parameters.
> ➢ With increasing temperatures, soil bulk density increased and achieved the highest value (1.1g/cm3) at 300 and $400^{o}C$.
> ➢ Organic matter content showed more consistent response up to $300^{o}C$, when it decreased to 11.3%, and later decreased even more at temperatures of 400 and $500^{o}C$ (9.7 and 7.9%).
> ➢ Ashes generally have a very high pH. When temperatures exceed $250^{o}C$ an increase in the values of pH was registered. However, when heating the soil up to $250^{o}C$, a small decrease of pH was noted.
> ➢ Soil moisture content did not decrease at temperatures up to $100^{o}C$, but heating at 200, 300, 400 and $500^{o}C$ highly decreased soil moisture content.
> ➢ Clay and silt content had increased upon burning and heating, while sand content decreased.
> ➢ The incorporation of rock fragments inside and above the soil surface. Rock cover decreased the depth at which the temperature of $60^{o}C$ was exceeded, but because it prevented the soil from cooling, it also increased the duration of heating above $60^{o}C$ at the soil surface.

We expected our controlled fire to reach temperature peaks up to $100^{o}C$. It was expected to burn all the fuel material and shrubs of the investigated area, which did not include the pine trees that only felt affected on crust, which was burned up to 1m height.

Therefore we decided to focus on investigating temperature, pH, electrical conductivity, soil moisture, organic matter values and correlate the data in order to understand the controlled fire impact on soil.

3 Description of work

3.1 Equipment used on field and in laboratory work

Fieldwork equipment

➢ Steel spatula - pedological spatula with engraved centimetre scale, to measure the depth of a hole dug in the soil
➢ Brush - we used a small brush to help us collecting the ashes after the fire
➢ Square angled wire (25cmx25cm) - considered size of the length and width of the sample spot that was taken from field
➢ Plastic basket for samples - because of the large amount of samples we used a big basket to store them through the day
➢ Plastic sample bags - sample bags of 2L size, to put in the soil sample
➢ Paper cuts and markers - we used paper-cuts and markers to mark the field sample name and characterization of the sample
➢ Porosity and bulk density cylinders with bottom and top cover - we used round steel cylinders, with diameter of 5.5 cm and 5.5 cm height, with the top and bottom rubber covers
➢ Hammer - to hammer the cylinders into the soil, we used a hammer with a head made of plastic material (to make an input of cylinder without bigger disturbance of the aggregates)
➢ Linear measuring device - we helped ourselves with the ordinary linear measuring device of 1mm accuracy, to measure the depth of soil samples and to measure the length between the sample spots
➢ Compass azimuth device - we used calibrated azimuth device to orientate the earth direction and place of sampling spots
➢ GPS device (Trimble geo XH/2008) - after we got prepared GIS map of the sampling area, we orientated on the field with the GPS device, that is 30cm precise
➢ Soil moisture device (Delta-T HH2 Moisture meter) - to measure the percentage of water content in soil we used electronic moisture device that was pre-calibrated and ready to use on field.
➢ Thermocouples (Lascar data logger) - Device containing computer-programed hardware (pre-programed for a period of 72 hours) with temperature detectors, that measured the temperature of soil before and after controlled fire.

Laboratory equipment

➢ Containers to air dry the soil
➢ Divider – for preparing samples for analysis
➢ Sieves and bottom tray - we used sieves to sieve the field samples on required aggregate size
➢ Vibrating sieve machine - we helped ourselves with the vibrating sieving machine, so we did not have to sieve all the material manually
➢ Plastic cups - after sieving the samples, we stored the laboratory samples into the plastic cups with plastic covers in a dry place
➢ Paper-cuts and markers - we used paper-cuts and markers to mark the laboratory sample name and characterization of the sample

➢ Air compression supply - to clean the sieve after each sieving we used an air compression supply installed in the laboratory

➢ 100ml glass bottles - for the pH and electrical conductivity measurement we used 100ml glass cups

➢ Graduated plastic cylinder - graduated plastic cylinder with the scale of 10ml was used to measure the amount of sample required for pH and electrical conductivity test

➢ Analytic weighing instrument - to weigh the required amount of sample we used analytical weighing instrument with 10^{-6}g accuracy

➢ Ventilated furnace - to dry the bulk density cylinders saturated with water we used laboratory ventilated oven

➢ Electromagnetic mixer with dipole mixing sticks - to save our time we used electromagnetic shaker with shaking sticks inside of the sample bottles, that replaced the process of manual mixing

➢ Spatula - we used some plastic and steel spatulas to transfer the soil sample from plastic cups to sample bottles; we also used them to mix the final test solution

➢ Ceramic boats - for the TC (total carbon) and IC (inorganic carbon) test we used specially made high temperature resistant ceramic boats

➢ Steel tweezers - we used laboratory steel tweezers to place and remove the ceramic boats in and out of the organic carbon analyser

➢ Ceramic cup - we used ceramic cups to store the ceramic boats after the test (they were exposed to 900°C)

➢ Total organic carbon analyser (TOC-VcsnShimadzu) - For the determination of total carbon (TC) and inorganic carbon (IC) we used TOC-VcsnShimadzu device. The device consist two main connected parts. One part is used as software and screening console and the other part as sample processing console, where the samples are exposed to high temperatures and chemical reactions. This machine is connected with an oxygen bomb and phosphorus acid bottle pump.

➢ Electrical conductivity and pH meters - to determine the electrical conductivity and pH value of the samples we used electronic device that had two exchangeable electrode extensions. One to measure pH, and the other for electrical conductivity.

➢ Steel laboratory stand - to stable the pH probe and the electrical conductivity probe, we used steel laboratory stand with an up and down moving slide.

3.2   Reagents and solutions

All the reagents and solutions we used during our laboratory work were used as they were originally bought or prepared in chemical laboratory.

➢ Deionized water - we used deionized water with conductivity below 0.1µScm^{-1}, obtained from water distribution to the general laboratory. We used it to prepare solutions and clean the laboratory equipment.

➢ Glucose ($C_6H_{12}O_6$) - we used laboratory glucose that was commercially bought, for the calibration of the total carbon matter equipment.

➢ Sodium hydrogen carbonate ($NaHCO_3$) - we used commercial used sodium hydrogen carbonate, for the calibration of the inorganic carbon matter device.

➢ Phosphoric acid (H_3PO_4) - we used the commercially prepared phosphoric acid in calibration of inorganic carbon matter (IC) device and for measuring IC matter of soil samples.

> ➢ Sulphur acid (H_2SO_4) - we used commercially prepared sulphur acid to clean the ceramic boats after the IC test.
> ➢ Potassium chloride (KCl) - we used laboratory prepared calcium chloride to store the pH electrode.

3.3   Description of sampling area

Our study took place in Northern Portugal, exactly in the pine forest area of Vila Pouca de Aguiar (Figure 1).
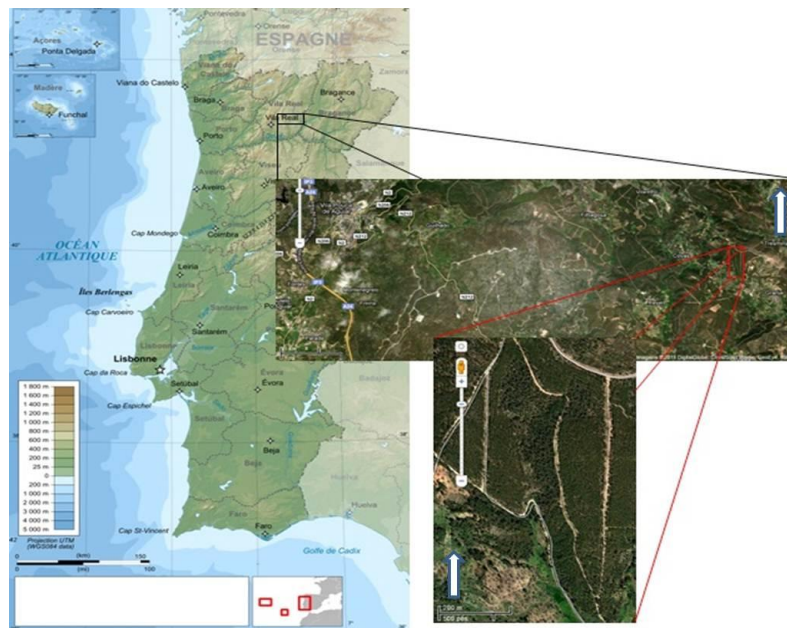
Figure 1: Geographic location of Vila Pouca de Aguiar (Source: Instituto Superior de Engenaria do Porto)

Climate

According to the Koppen-Geiger classification the climate of mainland Portugal is divided into two regions: one characterized by a temperate climate with wet winter and a dry and hot summer (Csa) and another region with rainy winter and a not so hot but dry summer (Csb) (Figure 2).

Climate of Portugal-Koppen classification
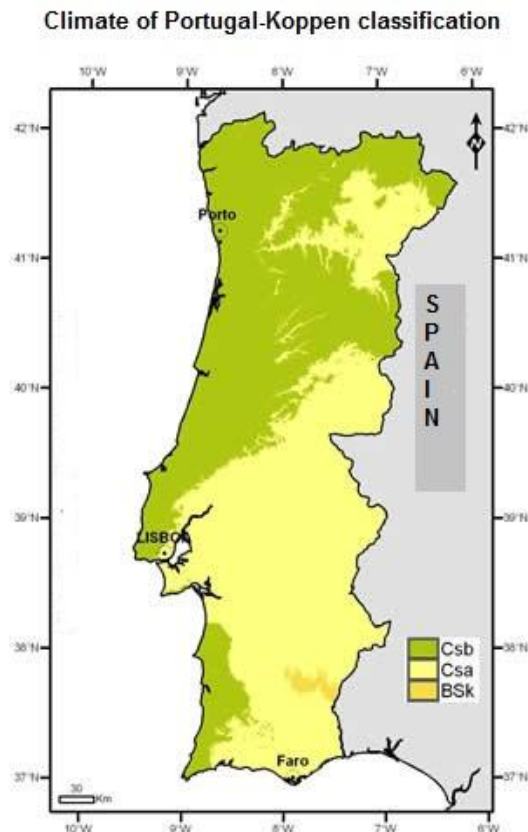
Figure 2: Climate of Portugal, according to the Koppen-Geiger classification (Source: http://www.meteo.pt/)

Spatial analysis shows the annual average temperature varying between about 7°C in the highlands of northern and central interior and about 18°C in the south coast. Based on the same data it is possible to show that the average annual rainfall has the highest values at Minho and Douro Litoral and lower values in the interior of Alentejo (Figure 3).
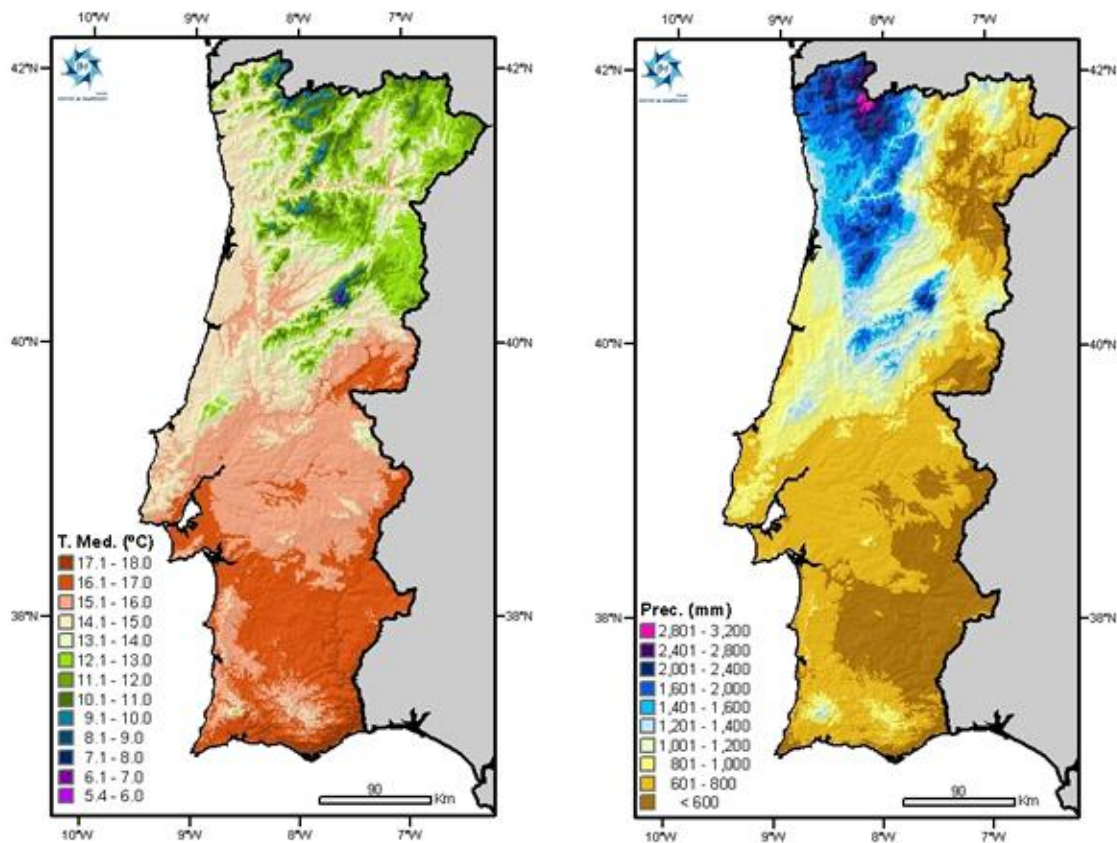
Figure 3: Temperature maps (mean annual temperature in °C (left) and precipitation mean annual in mm (right))(Source: http://www.meteo.pt/)

The climate in the municipality of Vila Pouca de Aguiar is highly variable: while the Alvão area is characterized by its sub-atlantic climate, the Padrela area corresponds in almost all situations to the cold land plateau. In the Tâmega region there is climate area of land transition although the most peripheral edge meets the cold land plateau, while the Tâmega Valley is characterized as hot land.

The weather in Vila Pouca is cold and wet in winter, with occasional snow, particularly above 900 meters altitude, and hot in summer, with high temperatures. "*Nine months of winter and three of hell*", as referred by a local saying.

The climatological characterization presented below shows the average values registered by the Meteorological Institute of Portugal, between 1961 and 1999 (Figure 4).
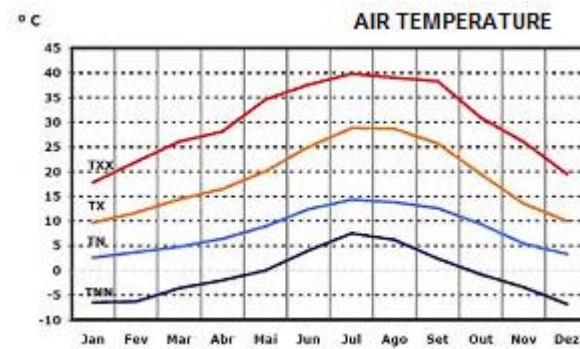
Figure 4: Medium air temperature in Vila Real (Source: http://www.meteo.pt/)

In the warmer months of the year, July and August, the maximum temperatures reach values of around 30 to 40°C, while in the coldest months, December and January, minimum temperatures are between - 5 and 5°C(Figure 4).

The chart below shows the rainfall in the district of Vila Real.
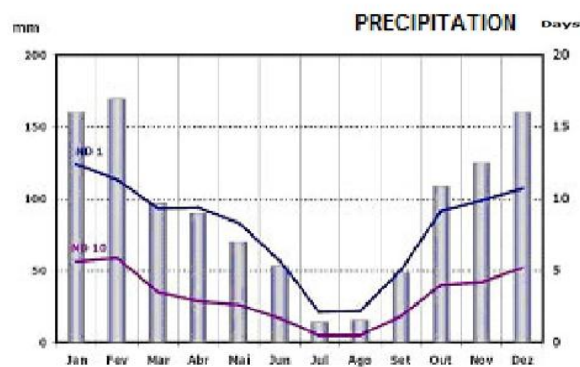
Figure 5: Precipitation in Vila Real (Source: http://www.meteo.pt/)

On average, the wettest month is February, followed by December and January, when levels greater than 150 mm are reached. The minimum amounts of precipitation occur in the months of July and August, corresponding to the warmest months (Figure 5).

The graph on Figure 5 shows the sunlight in the district of Vila Real.
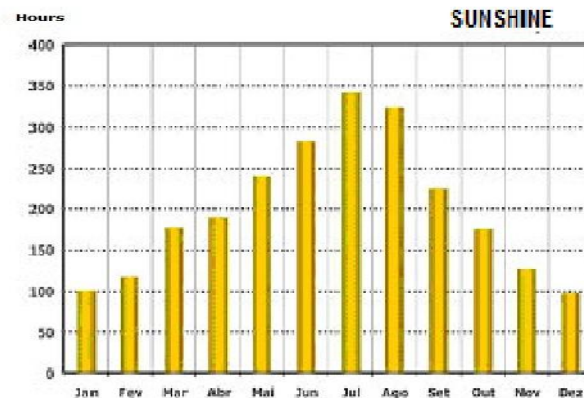
Figure 6: Insolation in district of Vila Real (Source: http://www.meteo.pt/)

The values of sunshine range from about 100 hours of sun (in December and January) and to about 330 hours of sunshine (In July and August), are being directly related to the increase of temperature (Figure 6).

Soil formation factors

Land and topography

The major land formation of the studied area is a medium- gradient hill (gradient of 10-30%). The landscape is positioned on straight concave upper slope on the shoulder orientated to SE.

Land use and vegetation

Studied area is covered by evergreen pine tree forest more than 20 years old, with herbaceous short grasslands and semi deciduous shrubs. The area had a history of human influence of ploughing and man-made ridges, to reduce the erosion and prevent the water drainage.

Soil description

The process of the region's geologic formation and the composition of the rocks determine the soils of the region. In the figure below we can see the main soil types that occur in the watershed of the River Douro in northern Portugal.
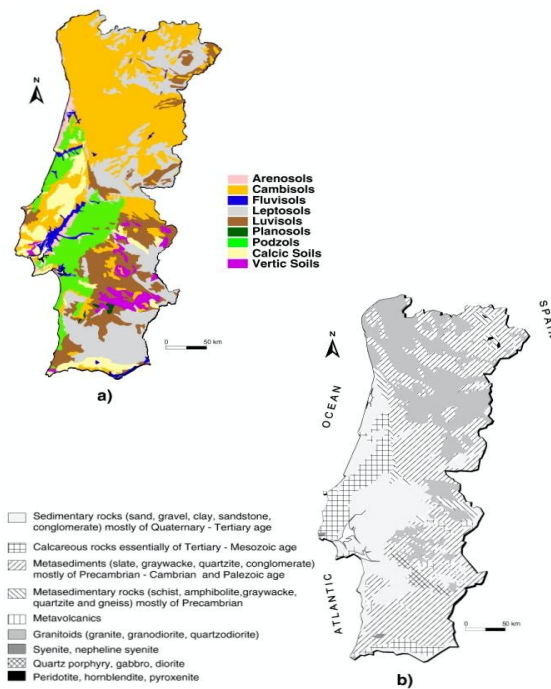
Figure 7: Soil types of Portugal (Source:
http://www.sciencedirect.com/science/article/pii/S037567420700115X)

The soils from Trás-os-Montes region are generally thin and poor often subject to strong erosive phenomena. In the region there is a predominance of lower Paleozoic metasedimentary terrains.

The geologic origin of the region as well as the rock types determine the soils features.

These soils are usually thin and poor, often subject to strong erosion, as a result of geology and geomorphology. The dominant geological units are Paleozoic metasedimentary rocks and granites. In mountain areas, the soil is often eroded by rainfall and bedrock outcrops. These soils are of low agricultural potential and usually abundant, known as umbric chromic Cambisol and Leptosol soil types (Figure 7).

These soils result from the in situ weathering rock substrates or from the sedimentation of materials originated by the erosion of similar rocks. The sediment transport may be by solifluction or by colluviation.

3.4   Sampling

The sampling procedure was done according to the normative ISO 10381, part 1 and ISO 10381, part 2 and also the FAO recommendations. The grid sampling is shown on the Figure 8:

Figure 8: Controlled fire area and grid sampling proposal (Source: Instituto Superior de Engenaria do Porto)

Before fire sampling

Our fieldwork before controlled fire was done in three days, spread through February and March 2011, because of the variable meteorological conditions (3/2/2011, 8/2/2011, 9/2/2011, 24/2/2011, 25/2/2011 and 1/3/2011).

We located the first sample spot on the left corner of the area (looking downside the area) and continued with following sample points on a manual basis of square net (30mx30m), using a GPS map to locate the spots correctly, faster and easier.

The sampling protocol on each sampling point

First, we located the position of the spot, and choose a proper place that looked useful to take all samples needed.

  i.   We placed the square angled wire (25x25) on a proper place and we started collecting the litter in horizon O (Ol, Of,Oh). The amount of litter varied in spots from 2cm to more than 10cm.

  ii. Then we continued in the same 25x25cm square collecting the material from the mineral soil in Horizon A from depth of 0-1cm, then 1-5 cm. We also took the 1kg sample (approximately) of soil material from 0-5cm as sample for the determination of texture and particle size.

  iii. We searched for a proper place in the spot, right near by, to place the bulk density cylinders (carbonated soil has many stones in the surface and inside horizon A), and carefully hammered them perpendicularly downwards, and dug under them with the shovel to take the sample without disturbing the shape of soil aggregates.

iv.   Then, we prepared the soil moisture device and measured percentage of water content in the spot.

These procedures were repeated for all the sampling points marked on the grid map, that is, at each sample point we took soil samples, in a 25cm x 25cm square, and ran the tests according to this order:

- ➢   sample of horizon O (litter)
- ➢   sample of horizon A(0-1cm) for organic matter, pH, electric conductivity
- ➢   sample of horizon A (1-5cm) for organic matter, pH, electric conductivity
- ➢   sample of horizon A (0-5cm) for particle size test ≥ 1kg
- ➢   cylinders for bulk density(1st 0-5cm and 2nd for 5-10cm); we took cylinder samples on every second sample spot
- ➢   ran the soil moisture test

In addition, in 4 randomly chosen spots, we also placed devices that measured the temperature of soil before and after controlled fire – thermocouples (we placed the detectors on the top of horizon O and in horizon A in 0-1cm and in 5 cm depth, and buried the electronic part of the device nearby under the soil).

Photo 5: Taking the soil samples before fire (Source: Šmid, 2011)

The sampling protocol for determination of soil water status (moisture condition)

Soil-water status is the term used for the moisture condition of a horizon at the time the profile is described. The moisture status can be estimated in the field as very dry, dry, slightly moist, moist wet or very wet (FAO 2006)**.**

For soil moisture determination we used HH2 Moisture meter. Before doing the test we had to be sure that the detectors are placed smooth into the soil and are not disturbed by any rock fragment or root. So we:

i.   Removed the litter of horizon O

ii.   Placed the prototype with apertures that are identical positioned as the detectors on the device.

iii. Hammered the nails through the holes previously made with the prototype (if the nails were hammered smooth into the soil till the end we could proceed with the test measurement)

iv. Placed the device sensor detectors into pre-made holes

v. Pressed the read button on the device and waited so that we could read the result

Photo 6: Measuring the soil moisture (Source: Šmid, 2011)

The sampling protocol for collecting the cylinders on the field (for soil porosity and soil bulk density):

i. First we searched for a proper place to hammer the cylinder into the soil (place without stone fragments).

ii. Then we removed the litter from horizon O and hammered the cylinder vertically into the horizon A until the steel cover on the top of the cylinder was at the same level as the top of horizon A.

iii. Afterwards we dug with the shovel deep under the cylinder and took it out without disturbance inside of the cylinder.

iv. We covered the top and the bottom with rubber covers and saved them for laboratory analyses.

Photo 7: Taking the cylinders samples for determination of soil bulk density (Source: Šmid, 2011)

AFTER FIRE SAMPLING

The area where the controlled fire was done (Vila Pouca de Aguiar) was to big to burn it in one day because AFN coordinator imposed that the prescribed fire in that pine area should the taken extremely slowly in not to have have high temperature which could damage trees. Therefore, we burned the prescribed fire area on 25/2/2011 and 1/3/2011. We collected the samples on the same spots as before the fire only 30min after the fire passed the spot (that way we tried to avoid the most of the smog).

Protocol on the sample point

We followed the same protocol as in collecting samples before fire, so the comparison would be authentic. We located the position of the spot with map on GPS device and placed the square angled wire (25x25) on a place that looked proper to take all samples needed.

    i.   We started with collecting of the ashes, which had to be done very precise, since the wind blew it away very fast (we used pedological spatula and small brush).

    ii.   Then we continued collecting the material from the mineral soil in Horizon A from depth of 0-1cm, 1-5 cm.

    iii.   We also took 1kg sample of material from 0-5cm as sample for the determination of particle size.

    iv.   We also took few samples with bulk density cylinders (not as much as before fire, since there was a lot of smog in the area and the daylight was gone too fast).

    v.   We prepared the soil moisture device and measured percentage of water content in the spot.

    vi.   We also dug the thermocouples that had been placed in four spots, so that the data was stored before, during and after the fire.

3.5   Data from thermocouples

Unfortunately, the data that we were looking for was not possible to achieve because some of the thermocouples cables were very damaged and batteries ran off, that is, it was not possible to know the temperature profiles on the top of the litter (horizon O), in boundary of the top of horizon O and in horizon A and at 1 cm depth. However, analysing each record *per se*, it is presumed that the controlled fire in our research reached peaks temperatures between 50 and 80°C. In fact, as the controlled fire was done in an area that had not been burned for two decades, there was a layer of litter that prevented the high temperatures of fire to progress into the soil deep. Soil moisture measurements in situ are in agreement to this supposition.

3.6   Laboratory work and procedures

We stored our field samples in geotechnical laboratories of Instituto Superior de Engenharia do Porto (ISEP) and Faculdade de Engenharia da Universidade do Porto (FEUP), where afterwards the laboratory work took place. Because of a large number of samples and the time when the lab was avaliable to use, each of us had to plan his working schedule for at least 9 days ahead.

We decided to follow the sampling and analysis test procedures from the international standard methodologies, namely ISO 11464:2006, ISO 11465:1993 and ISO 10694:1995 and also the instructions referred on Carter (Carter 1993) and Jones (Jones 2001).

The resolution of the balance followed the criteria that should be less or equal to 0.0001 times the mass of the sample in accordance to the following table:

Table 1: Criteria for choosing the resolution of the analytical balance in laboratory

Mass of sample g	Balance resolution mg
> 1	less than 0.1
1 to 0.1	less than 0.01
< 0.1	less than 0.001

Sieving

Determination of soil pH, electrical conductivity and organic matter required laboratory samples with soil aggregates passing 2mm aperture sized sieve. First we sieved the before fire samples and then the after fire samples.

i.   We started by combining the manual and vibrating sieving, to make as much laboratory samples as we could in short time.

ii. After each field sample was sieved, we stored the laboratory sample into plastic cups with top plastic covers and marked them.

Photo 8: Preparation of laboratory samples with sieving vibrator device (Source: Šmid, 2011)

Cylinders preparation

Bulk density is defined as the mass of a unit volume of dry soil (105°C). This volume includes both solids and pores and, thus, bulk density reflects the total soil porosity.

Low bulk density values (generally below 1.3 kg.dm^{-3}) generally indicate a porous soil condition. Bulk density is an important parameter for the description of soil quality and ecosystem function. High bulk density values indicate a poorer environment for root growth, reduced aeration, and undesirable changes in hydrologic function, such as reduced water infiltration. Bulk density maybe highly dependent on soil conditions at the time of sampling. Changes in soil volume due

to changes in water content will alter bulk density. Soil mass remains fixed, but the volume of soil may change as water content changes (FAO 2006).

There are several methods of determining soil bulk density. One method is related with the obtaining of a known volume of soil, dry it to remove the water, and weigh the dry mass. Another uses a special coring instrument (cylindrical metal device) to obtain a sample of known volume without disturbing the natural soil structure, and then to determine the dry mass (FAO 2006)**.** For our research we determined soil bulk density by metal cylindrical devices.

Protocol in the laboratory:

  i.   We carefully opened the bottom covers of the cylinders (so we did not loose any material) and put on the bottom of the cylinder a water permeable, but not absorbable, tissue fix with rubber rings.

  ii. Then we slowly put the cylinders in the steel tray, with the bottom on the tray, and remove the top cover of the cylinders.

 iii. After, we introduce the cylinders to the water (at half height) for 24 hours. After 24 hours we refill the water a bit more and wait more 24 hours. After we refill until the total height of the cylinder (but taking in attention that water don't go on the soil) and wait more 24 hours. The process stopped when cylinders are completely saturated.

 iv.   Then, we weight them on balance scale, record the value and put them in the ventilated oven for 48h exposed to heat of 105ºC.

  v.   After 48h in the oven, we weight their value again and calculate the porosity and the bulk density of each cylinder sample (the resolution of the balance has a resolution of 0.01).

Photo 9: Drying the water saturated samples in the ventilated oven at 105ºC (Source: Šmid, 2011)

Determination of soil pH

Soil pH is one of the most common and important measurements in standard soil analyses. Many soil chemical and biological reactions are controlled by the pH of the soil solution in the equilibrium with the soil particle surfaces (Carter 1993).

Soil pH expresses the activity of the hydrogen ions in the soil solution. It affects the availability of mineral nutrients to plants as well as many soil processes. When the pH is measured on field,

the method used should be indicated on the field data sheet. However, the field soil pH should not be a substitute for a laboratory determination (FAO 2006)**.**

Soil pH measured in water is the pH closest to the pH of soil solution in the field (low electrical conductivity and not fertilized soils). When measuring pH in the water, it is important to keep the ratio between soil and deionized water constant and as low as possible. The solution must be sufficient to immerse the electrode properly without causing too much stress when inserting the tip of the electrode into the soil and to allow the porous pin on the electrode to remain in the solution above in the soil (Carter 1993).

To determine the soil pH we used the sieved samples that passed through 2mm sieve and were taken from the depth of 0-1 cm and 1-5 cm.

Preparation of the samples:

i.   To prepare the mixture of the soil and demineralized water, we used 100mL glass bottles previously cleaned with deionized water;

ii.   We measured 2g of soil and carefully put it into the bottle;

iii.   Then we measured 20mL of demineralized water in a graduated plastic cylinder and put it in the bottle where the soil sample already was;

iv.   We were stirring the solution of water and soil with the glass stirring rod for 30 minutes;

v.   After 30 min of stirring, we left the solution to settle for 60min;

vi.   After 60min the samples were ready to do the pH test;

The pH test procedure:

i.   First, we calibrated the device for pH test with 4.01pH and 7.01pH buffering solution.

ii.   Then, we turned on the pH device and dipped the detector carefully into the bottle with our sample solution so it did not touch the un-dissolved part of soil on the bottom;

iii.   We pressed the button for reading and waited until the device stabilize the result of pH in the solution (when stabilized it signals with a beep and shows the exact result on the screen);

iv.   We cleaned the detector with demineralized water and continued with the same procedure with other samples.

Determination of electrical conductivity

The level of soluble salts in the soil solution can be classified by determining the electrical conductivity of the solution. As the level of the salts increases, the usual effect is a decreased plant growth. Therefore the soluble salt determination has considerable significance. Soils affected by high soluble salt levels are also difficult to manage particularly when Na is the major cation contributing to the high salt level. Salinity affects about 25% of the croplands in the world and is becoming an increasing problem in most irrigated croplands. The cations Na^+, K^+, Ca^{2+}, Mg^{2+} and NH_4^+, and anions Cl^-, $(NO_3)^-$, $(HCO_3)^-$, $(SO_4)^{2-}$, and $(CO_3)^{2-}$ contribute to the conductivity of the soil solution or irrigation water.

The specific conductance or soluble salt level of a soil can be determined from a water saturation extract or a 1:2 (v/v) soil/water extraction. In International Units it has been found convenient to express specific conductance as milliohms per centimetre, which is equivalent to dS/m (Jones 2001).

Specific conductance is determined using an electrical resistance bridge, referred as conductivity meter. Specific conductivity is measured at 25ºC between electrodes 1cm^3 in a surface area and placed 1cm apart (Jones 2001).

For determination of the soil electrical conductivity we used the sieved samples that passed through 2mm sieve and were taken from the depth 0-1cm and 1-5cm. We followed the norms previously referred to.

Preparation of samples:

i.   First, we calibrated the floating sensors of the electrical conductivity device.

ii. We prepared the clean 100ml glass bottles cleaned with the deionized water;

iii. We measured 10ml (cm3) of soil sample from laboratory sieved sample (material passing 2mm sieve) in a graduated plastic cylinder and put it into the cup;

iv. We added 20 ml of demineralized water and we were stirring the solution with steel spatula for 30 min;

v.   After 30 min of stirring, we left the samples to settle down for 60min ;

vi. After 60min period, the measurement of electrical conductivity had to be done in the next 2 hours;

Electrical conductivity test procedure:

i.   First we turned on the electrical conductivity device;

ii. We dipped the detector carefully into the bottle with our sample solution, so it did not touch the un-dissolved part of soil on the bottom;

iii. The detector of conductivity had a flow detection, so there should not be any physical disturbance in direction to detector, sample bottle or table;

iv. The electrical conductivity detector had to be placed exactly above the solid parts on the bottom, and under the solid parts floating on the top of the solution;

v.   After the result on the screen settled, we recorded the data and removed the detector;

vi. We cleaned the detector with demineralized water and continued with the same procedure on other samples;

Photo 10: Sample preparation for determination of soil pH and soil electric conductivity (Source: Šmid, 2011)

Determination of organic matter

Soil organic matter refers to all decomposed, partly decomposed and un-decomposed organic materials of plant and animal origin. It is generally synonymous with humus although the latter is more commonly used when referring to the well decomposed organic matter called humic substances (FAO 2006).

Humidification is a process followed by mineralization and decomposing of organic part of the soil, which transforms the dead organic matters into CO_2, H_2O, NH_3, H_2S etc. Humidification and mineralization of organic matter is a slow process that mostly depends on microbiological activity and relation of C/N in dead organic matter.

Sorrow humus is usually the upper part of horizon A in pine forests and contains badly decomposed vegetation lefts. It appears usually in acid soil environment with lack of Ca^{2+} and Mg^{2+} cations.

Quantity of soil organic matter can also be calculated by determining the value of Carbon (C%), that appears in organic matter (average 45-60%). That's why we multiply the percentage of carbon with factor f= 1.78 – 2 (Stritar 1991).

The content of organic matter of mineral horizons can be estimated from the Munsell colour of a dry and/or moist soil, taking the textural class into account. This estimation is based on the assumption that the soil colour (value) is due to a mixture of dark coloured organic substances and light coloured minerals. This estimation methodology does not work very well in strongly coloured subsoils. It tends to overestimate organic matter content in soils of dry regions, and to underestimate the organic matter content in some tropical soils. Therefore, the organic matter values should always be locally checked as they only provide a rough estimate (FAO 2006).

For the organic matter determination we used electronic device TOC-VcsnShimadzu, which was placed in FEUP's (Faculdade de Engenharia Universidade do Porto, Portugal) laboratory. We calibrated the machine few days before we ran the test on soil samples. The sample aggregate size was required as in the tests before, so we used already sieved and prepared laboratory samples (aggregate size 2mm and less). The resolution of the analytical balance used in measurements has a resolution of 0.0001.

Calibration of the TOC-IC machine:

i.   We opened the oxygen bottle that was adjusted to 3.4 bar on the scale of the exhaust of the machine and 180 bar on the scale of the exhaust of the oxygen bomb. To start with the test the temperature of the TC part of machine had to reach 900ºC and for the IC 200ºC.

ii. For the calibration of Total Carbon (TC) we used 4 samples of glucose ($C_6H_{12}O_6$), which gave us at the end the linear curve that represented proper calibration.

iii. For the calibration of and Inorganic Carbon (IC) we used 5 samples of sodium bicarbonate (reaction with 4-5ml of H_3PO_4.), which at the end also gave us the linear curve that represented proper calibration.

This way we saved the calibration curve in the software of device. The machine had specific software required chemistry and computer skills. During the test the samples were exposed to 900ºC (for TC) or 200ºC (for the IC). The results were delivered straight through the output on PC, or printed straight out of the machine on the paper.

Photo 11: TOC-VcsnShimadzu (Source: Šmid, 2011)

Preparation of samples for total organic carbon and inorganic carbon determinations (first we ran the tests, with samples collected before fire, and then with the after fire samples):

i.   First we tried the TC test and the IC test with 2 samples weighting 50mg (one for each test), to see if the amount of soil used to detect the organic matter fits to the calibration curves. The tests were positive, so we could start to run the tests with soil samples.

ii. Then we continued by weighing 50mg of each soil sample in a ceramic boat using an analytic weighing instrument. The amount was small, so we used the laboratory steel spatula to transfer the soil from plastic cup to ceramic boat.

Photo 12: Measuring the amount of soil sample (Source: Šmid, 2011)

Total carbon test procedure:

i.   We opened the oxygen bottle that was adjusted to 3.4bar on the scale of the exhaust of the machine and 180bar on the scale of the exhaust of oxygen bomb. To start with the test the temperature of the TC part of machine had to reach 900ºC.

ii.   We transferred the prepared sample in the ceramic boat from the analytical weighing instrument to TOC-VcsnShimadzu machine with the help of tweezers and placed it carefully into TC test part of the machine. We slide the sample into the machine and pressed the start button to run the test. After 6-8 minutes the screen signalled us to remove the sample and take the ceramic boat out.

iii. The sample in ceramic boat was exposed to 900ºC, so we had to cool it in the ceramic cup.

iv.   We went on in the same way for all the samples we had.

v.   The results of tests were, as we adjusted, automatically stored in the software of the machine and printed out when we finished with work.

Photo 13: Placing the ceramic boat into the TOC-VcsnShimadzu (Source: Šmid, 2011)

Inorganic carbon test procedure:

i.   We opened the oxygen bottle that was adjusted to 3.4bar on the scale of the exhaust of the machine and 180bar on the scale of the exhaust of the oxygen bomb. To start with the test the temperature of the TC part of machine had to reach 200ºC.

ii.   We predicted that there should not be any inorganic material in the samples, so we randomly chose 10 samples and made the test.

iii. We transferred the prepared sample in the ceramic boat from weighing instrument to TOC-VcsnShimadzu machine with tweezers and placed it carefully into the IC test part of the machine.

iv.   We slid the sample into the machine, pumped 4ml of phosphoric acid (H_3PO_4) that was connected with a tube to the machine and pressed the start button to run the test. The phosphoric acid was first injected into the sample and then slid into machine and heated to 200ºC (at this temperature the chemical reaction takes place).

v.   We repeated the same procedure with the rest of the samples.

vi.   The results of the tests were, as we adjusted, automatically stored in the software of the machine and printed out when we finished with work. As all the test samples we had tested showed 0% results, we decided to conclude this test.

4 Results and discussions

All data from laboratory analysis were organized and are presented in a concise and clear table (Table 2). The statistical analysis and data treatment were done using numerical calculus from Microsoft Office Excel 2003.

First a basic statistical description of the data was done according to the typical statistics measures. This exploratory data analysis is summarized in Appendix A.

After that a linear correlation between variables was investigated. Appendix B summarizes the obtained results. According to this table it is possible to identify in the matrix which variables are correlated or not correlated and the strength or the weakness of the relationship. It is also possible to identify the orientation of the relationship between variables, that is, if they are positively related or negatively related. We optionally did not explore nonlinear relations between variables.

With the Wilcoxon-Mann-Whitney test we found a strong linear correlation among the variables. This test was used as a substitute for the nonparametric t-test for equality of means of two samples. It is intended to verify whether two independent samples expressed on ordinary scale came from the same population. Then, we investigated if it was possible to achieve a regression model for those variables.

Descriptions of results, analysis and interpretations are presented separately.

Table 2: Data (averages over 5 replicates)

Sample collected Before the Controlled Fire event

Sample collected After the Controlled Fire event

Outputs show that:

Soil pH

i.   Soil pH mean values in depth do not vary abruptly. The same can be said of the pH mean values in relation to time (before and after the fire). No difference of pH value at any depth was also reported in previous researches (Farres et.al., 2008)

ii. Considering the 1-5cm depth, the data distribution presents a positively asymmetric distribution in relation to time, which means that the mean values of the data collected at 1-5cm before and after the fire are higher than their median values, respectively.

iii. Considering the 0-1cm depth, the data before the fire presents a positively asymmetric distribution, but the distribution of the data after the fire presents a negatively asymmetric distribution, which means that the mean values of these data are lower than the median values.

iv. The standard deviation in depth is low, like standard deviation at 0-1cm after fire (0.4 to 0.3, at 0-1cm), so we could conclude that pH in 0-1cm was evenly distributed after the fire. Looking at the variation coefficient we can conclude the same.

Soil electric conductivity (EC)

i.   In average the electrical conductivity of these soil samples is low. The soil is non-saline according to the Benton Jones classification (Jones 2001). The mean values of soil electric conductivity in depth do not vary abruptly, except the BF samples 0-1cm, where the values deceased after fire.

ii. Considering the 1-5cm depth, the data distribution of the data presents a positively asymmetric distribution in time, which means that the mean values of the data collected at 1-5cm before and after the fire are higher than their median values.

iii. Considering the 0-1cm depth, the data before the fire presents a positively asymmetric distribution in time, that is, the mean values of these data are higher than their median values.

iv. The standard deviation in depth is low, like for example the standard deviation at 0-1cm after the fire (25-5,6, at 0-1cm), so we could conclude that electric conductivity in 0-1cm was evenly distributed after the fire.

Soil organic matter (OM)

i.   There was no inorganic carbon detected in any sample.

ii. Soil organic matter mean values in depth do not vary significantly. The same can be said of the organic matter mean values in relation to time (before and after the fire). This result was expected as we knew that, according to the bibliography, the controlled fire of low temperature peaks (under 222,5°C), as was ours, do not cause a decrease of soil organic matter (Gimeno-Garcia et.al., 2000). On the other hand average organic matter after the wild fires can increase by incorporation of unburned residues (Certini 2005).

iii. Considering the depth 1-5cm, the data distribution of the data presents a positively asymmetric distribution in time, which shows that the mean values of the data collected

at 1-5cm depth before and after the fire are higher than their median values, respectively.

iv. Considering the 0-1cm depth, the data before the fire presents a positively asymmetric distribution in time, which shows, that the mean values of these data are higher than their median values.

v. The standard deviation in depth is low, like for example the standard deviation at 0-1cm after the fire (2,4 - 1,5, at 0-1cm), so we can conclude that organic matter in 0-1cm was evenly distributed after the fire.

Soil moisture in-situ (SM)

i. We can conclude that no variation was observed. The fire did not affect this property, which made us believe that the fire did not heat the soil A horizon (under the litter) as much. Soil moisture mean values do not vary significantly considering the results in time. The similar results were found in another research by simulating the wildfire (Stoof 2011), where soil moisture did not decrease at temperatures up to 100°C, while temperatures over 200°C and more significantly decreased soil moisture.

ii. Considering the time, the data distribution of data presents a negative asymmetric distribution before fire, which shows that the mean values of the data collected before fire are lower than their median values.

iii. Considering the time, the data after the fire presents a positively asymmetric distribution in time, which shows, that the mean values of these data are higher than their median values.

iv. The standard deviation in time is low, even though it rises after the fire from 3.8 to 4.3.

Results that need reflection:

i. At depth 0-1cm the values of electric conductivity deceased after fire.

ii. The organic matter values were in normal levels for this soil types. As we still have some samples left and stored we can still confirm these values later with another device/method.

iii. The soil porosity and bulk density have normal values for this type of soil and did not change significantly. However, it was expected that a soil texture would be more clayey because the original rock is metasedimentary and is rich in phylosilicates. Maybe the MALVEN particle size analyser is not suitable for this type of soil. As we still have some samples left and stored we can confirm these values later with another device/method.

Considering the correlation matrix (Appendix B), it is possible to identify variables that possess a strong correlation. However, as we previously exposed the items that need reflection, we will explore only the correlation of EC-BF:1-5 and EC-AF:1-5 (the one who makes more sense).

For the other variables that possess lower correlation coefficients, a Wilcoxon-Mann-Whitney analysis should be considered in order to confirm that all samples with the same characteristics came from the same population (all samples are representative of the studied site).

Table 3: The Wilcoxon-Mann-Whitney test *(mean=297.5, standard deviation=29.0)*

	WT-A	WT-B	z	Significance level
pH-AF:0-1 and pH-AF:1-5	233	362	-2.2	0.01
EC-BF:1-5 and EC-AF:1-5	288	307	-0.3	0.01
OM-BF:1-5 and OM-AF:1-5	288	307	-0.3	0.01

At a significance level 0.01, the 3 parameters of pH after fire (at depths 0-1 and 1-5), electric conductivity at depth 1-5cm (before and after the fire) and organic matter at depth 1-5cm (before and after the fire) can be considered as independent samples from the same population. We can proceed with this analysis after answering the previous reflexions i) ii) iii).

Table 4: Regression for EC-BF:1-5cm and EC-AF:1-5 (significance level 95%)

Regression Statistics	
Multiple R	0.95
R Square	0.91
Adjusted R Square	0.90
Standard Error	1.13
Observations	17

ANOVA

	df	SS	MS	F	Significance F
Regression	1	183.48	183.48	143.52	4.42342E-09
Residual	15	19.18	1.28		
Total	16	202.66			

	Coefficients	Standard Error	t Stat	P value	Lower 95.0%	Upper 95.0%
Interception	0.339	2.024	0.168	0.869	-3.974	4.653
EC-BF:1-5	0.999	0.083	11.980	4.42342E-09	0.821	1.177

According to the results, it is possible to built a linear regression model with a confidence level of 95% where 91% of the values of the variable $EC\text{-}AF\text{:}1\text{-}5cm$ can be predicted (or explained) by the values of the variable $EC\text{-}BF\text{:}1\text{-}5cm$ according to the equation:

$$EC\text{-}AF\text{:}1\text{-}5cm = 0.339 + 0.999\ EC\text{-}BF\text{:}0\text{-}1cm$$

This regression model is significant (F-value=143.52). The same conclusion can be obtained, as P-values are inferior to 0.05. However, this regression model is redundant, as expected, so it must be understood as an exercise only.

5   Research questions and conclusions

How much and how long does the controlled fire heat the soil? Unfortunately, the data that we were looking for – a profile of temperatures on the top of the litter (horizon O), in boundary of the top of horizon O and in horizon A and at 1 cm depth - was not possible to achieve because some of the thermocouples cables were damaged and batteries went off. However, analysing each record *per se*, it is presumed that the controlled fire in our research reached peak temperatures between 50 and 80°C.

How does the controlled fire affect soil pH, electric conductivity, organic matter and moisture? No significant alterations on these soil parameters were observed. Fire with temperature peaks under 100˚C, does not affect soil moisture significantly, since the water starts to evaporate significantly by reaching the boiling point (100˚C). Our controlled fire did not reach temperature over 80 ˚C, so there was no change detected. However, at depth 0-1cm the values of electric conductivity deceased after fire. We attributed this to spatial variability of soil.

How does the controlled fire impact on soil porosity, bulk density and particle size distribution? The soil porosity and bulk density have normal values for this type of soil and did not change significantly. However, the soil texture was expected to contain more clay, since the original rock is metasedimentary and is rich with phylosilicates.

Does the fire affect these parameters in the same way at 0-1cm and 1-5cm depths? Results pointed out that this particular controlled fire, carried out under strict rules of low severity and low intensity, and carried out at 10-12 meters per hour and soil temperatures under 80ºC, had no mesurable effect on studied soil parameters. The effect was only directed to litter in upper horizon O (which burned).

The layer of litter above the mineral part of soil was very thick and satutared with water on the bottom. This reduced the high temperatures to reach the mineral part of soil. Therefore the highest fire temperatures did not reach mineral part of soil and could not diminishe soil moisture, or affect on soil pH, electrical conductivity and bulk density values.

We visited the burned area after two months and noticed the grass and *herbaceous* species that started to grow again (that indicates that the vegetation was not affected to the roots or other important parts). The differences we found between the before and after fire samples, result from the spatial variability of the soil features.

5A Odgovori na zastavljena razislovalna vprašanja in zaključki

Kako močno in koliko časa kontroliran požig segreva tla? Nekateri merilniki temperature tal v času požiga niso beležili podatkov, ker so bile detektorske žice poškodovane. Analiza podatkov po posamični enoti merilnikov je pokazala, da so najvišje temperature na prehodu iz horizonta O v horizont A, znašale med 50 in 80°C.

Kako kontroliran požig vpliva na pH, električno prevodnost, organsko snov in vsebnost vode v zemlji? Po kontroliranem požigu in testih v laboratorijih ni bilo zaznanih nobenih sprememb v raziskovanih parametrih tal. Ogenj, ki ne presega temperature 100˚C, ne vpliva na vsebnost vode v tleh, saj le ta prične izhlapevati pri temperaturi 100˚C. Naš raziskovani kontroliran požig ni presegel 80˚C. Nekatere vrednosti električne prevodnosti so bile po kontroliranem požigu nižje. Po ponovnih testih smo ugotovili, da je do teh odstopanj prišlo zaradi prostorske raznolikosti tal in vzorcev.

Kako kontrolirani požig vpliva na poroznost, gostoto in porazdelitev velikosti agregatov tal? Vrednosti poroznosti in gostote agregatov tal so v skladu s tipom tal in se po kontroliranem požigu niso spremenile. Glede na meta-sedimentno matično osnovo, ki je polna filosilikatov, smo pričakovali, da bodo tla vsebovala več glinastih delcev.

Ali ima kontroliran požig enak vpliv na raziskovane parametre v globini 0-1cm in 1-5cm? Rezultati so pokazali, da kontrolirani požig nizke intenzitete (najvišje temperature tal pod 80ºC) in hitrosti (10-12metrov na uro) ne vpliva na raziskovane parametre tal. Učinek kontroliranega požiga je bil zaznan le v odpadlem rastlinju zgornjega dela horizonta O, ki je zgorelo.

Horizont O, nad mineralnim delom tal, je bil zelo debel in v spodnjem delu močno vlažen. To je zmanjšalo možnosti vpliva visokih temperatur ognja in prenosa toplote na mineralni del tal. Najvišje temperature ognja niso dosegle mineralnega dela tal in tako niso mogle vplivati na vlažnost, pH, električno prevodnost, vsebnost organske snovi in gostote agregatov tal.

Ko smo po dveh mesecih spet obiskali območje kontroliranega požiga, smo opazili, da so trave, grmičevje in zelnate vrste ponovno pognale poganjke (kontroliran ogenj ni prizadel ključnih funkcionalnih delov rastlin, kot so npr. korenine). Razlike, ki smo jih našli v določenih vrednostih vzorcev, pridobljenih pred in po kontroliranem požigu, so rezultat prostorske raznolikosti tal.

6   Future work

At depth 0-1cm the values of electric conductivity deceased after fire. We need to study this in order to understand why.

The values of soil texture were expected to contain more clay, since the original rock is metasedimentary and is rich with phylosilicates. Maybe the particle size analyser (Malvern - Mastersizer 2000) is not suitable for this type of soil. As we still have some samples left and stored, we can confirm these values later with another device/method.

7   References

[1]   Diário da República. Plano Nacional de Defesa da Floresta Contra Incêndios(AFN), št.102/2006, str. 3511-3559

[2]   Canada Department of Agriculture. 1976. Glossary of Terms in Soil Science Research Branch. Medmrežje: http://sis.agr.gc.ca/cansis/glossary/a/index.html (7.4.2011)

[3]   Carter, M.R., Gregorich, E.G. 2006: Soil sampling and methods of analysis. Medmrežje: http://www.planta.cn/forum/files_planta/methods_of_analysis_212.pdf (5.2.2011)

[4]   Certini, G. 2005. Effects of fire on properties of forest soils: a review. Medmrežje: http://www.fsl.orst.edu/ltep/Biscuit/Biscuit_files/Refs/Certini%20Oa%202005%20fire.pdf (8.1.2011)

[5]   Food and agriculture organization of the United Nations. 2006. Guidelines for Soil Descriptions. Medmrežje: ftp://ftp.fao.org/agl/agll/docs/guidel_soil_descr.pdf (5.2.2011)

[6]   Farres, M., Outeiro, L., Ubeda, X. 2008. Short-term effects on some soil variables after a prescribed fire. The Montrgri Massif case study. Medmrežje: http://meetings.copernicus.org/www.cosis.net/abstracts/EGU2008/01903/EGU2008-A-01903.pdf (5.2.2011)

[7]   Fernandes, P., Botelho, H., Loureiro, C. 2002. Manual de formação para a tecnica do fogo controlado. Medmrežje: http://www.cifap.utad.pt/Fernandes_Manual_Forma%E7%E3o%20T%E9cnica%20Fogo%20Controlado.pdf (5.2.2011)

[8]   Gimeno-Garcia, E., Andreu, V., Rubio, J. L. (2000). Changes in organic matter, nitrogen, phosphorus and cations in soil as a result of fire and water erosion in a Mediterranean landscape. European Journal of Soil Science, Oxford, 7, št. 51, str: 201-210

[9]   ISO 10381-1:2002. Soil quality – Sampling - Guidance on the design of sampling programmes, Geneva

[10]   ISO 10381-2:2002. Soil quality – Sampling – Guidance on sampling techniques, Geneva

[11]   ISO 11464:2006. Soil quality – Pretreatment of samples for physic-chemical analysis, Geneva

[12]   ISO 11465:1993. Soil quality – Determination of dry matter and water content on a mass basis – gravimetric method, Geneva

[13]   ISO 10694:1995. Soil quality – Determination of organic and total carbon after dry combustion (elementary analysis), Geneva

[14]   Jones, B.J. (2001). Laboratory Guide for Conducting Soil Tests and Plant Analysis, London, CRC Press.

[15]   Massman, W.J., Frank, J.M., Reisch, N.B. 2008. Long-term impacts of prescribed burns on soil thermal conductivity and soil heating at a Colorado Rocky mountain site: a data/model fusion study.   Medmrežje: http://www.fs.fed.us/rm/pubs_other/rmrs_2008_massman_w001.pdf (5.2.2011)

[16]   Medmrežje: http://www.meteo.pt/ (5.4.2011)

[17]   Medmrežje: http://www.sciencedirect.com/science/article/pii/S037567420700115X
          (5.4.2011)

[18]   Meira-Castro, A.C., Carvalho, J.P., Ribeiro, S. (2011). Prescribed burning impact on
          forest soil properties – A Fuzzy Boolean Nets approach. Environmental Research,
          Barcelona, 2, št.111, str: 199-204

[19]   Neto, J. G., Soares, R. V. (1995). Influência da queima controlada no pH do solo em
          povoamentos de Pinus sp, na região de Sacramento, MG. Ciência Florestal, Santa
          Maria, 5, št.1, str: 87-101

[20]   Rebecca B. 2004. Soil survey laboratory methods manual. Medmrežje:
          http://www.scribd.com/doc/15751720/Soil-Survey-Lab-Methods-Manual-2004-USDA
          (10.2.2011)

[21]   Stritar, A. (1991). Pedologija. Ljubljana, Ponatis v samozaložbi (I. Stritar).

[22]   Stoof, C.R. (2011). Fire effects on soil and hydrology. PhD thesis. Wageningen,
          Wageningen University.

8   Appendix

Appendix A: Basic descriptive statistics 1

Appendix B: Basic descriptive statistics 2

	pH-BF-0-1	pH-AF-0-1	pH-BF-1-5	pH-AF-1-5	EC-BF-0-1	EC-AF-0-1	EC-BF-1-5	EC-AF-1-5	OM-BF-0-1	OM-AF-0-1	OM-BF-1-5	OM-AF-1-5	SM-BF	SM-AF	litter	ash	P-BF	P-AF	BD-BF	BD-AF	Clay-BF	silt-BF	sand-BF	clay-AF	silt-AF	san-d-AF
pH-BF-0-1	1																									
pH-AF-0-1	0.2	1																								
pH-BF-1-5	0.2	0.7	1																							
pH-AF-1-5	0.1	0.8	0.6	1																						
EC-BF-0-1	-0.3	-0.0	-0.1	0.3	1																					
EC-AF-0-1	0.0	-0.4	-0.4	-0.1	-0.2	1																				
EC-BF-1-5	-0.4	0.2	0.1	0.5	0.2	-0.1	1																			
EC-AF-1-5	-0.4	0.3	0.1	0.4	0.1	-0.2	1.0	1																		
OM-BF-0-1	-0.3	-0.03	-0.1	0.1	0.5	0.1	0.2	-0.1	1																	
OM-AF-0-1	0.0	0.3	0.1	0.3	0.1	0.5	1.0	0.1	0.5	1																
OM-BF-1-5	-0.4	0.2	0.1	0.4	0.2	-0.1	1.0	1.0	0.2	-0.2	1															
OM-AF-1-5	-0.4	0.2	0.0	0.1	0.0	-0.1	0.1	-0.1	0.1	0.3	-0.1	1														
SM-BF	0.5	0.2	0.2	0.5	0.5	0.0	0.0	0.0	0.5	0.5	0.2	0.0	1													
SM-AF	0.3	0.0	0.1	0.3	0.3	0.0	0.0	0.0	0.4	0.4	0.3	-0.1	0.5	1												
litter	0.3	-0.1	-0.2	-0.1	0.3	0.3	0.4	0.3	0.1	0.1	0.1	0.0	0.1	0.1	1											
ash	0.4	0.0	0.0	0.2	0.0	0.5	0.5	0.4	0.5	-0.2	-0.1	0.0	0.3	0.5	-0.7	1										
P-BF	-0.2	-0.2	-0.2	-0.1	-0.0	0.4	0.5	0.5	-0.1	0.3	0.0	0.0	-0.4	-0.2	-0.3	0.1	1									
P-AF	0.0	0.2	0.2	0.3	-0.0	0.4	0.5	0.4	0.0	0.0	-0.2	-0.1	-0.1	0.1	-0.4	0.0	0.1	1								
BD-BF	-0.3	-0.0	-0.4	-0.4	-0.4	0.4	0.5	0.4	-0.1	-0.0	-0.3	-0.2	-0.6	0.3	0.2	-0.1	0.1	-0.1	1							
BD-AF	0.2	0.1	0.3	0.3	0.1	0.4	0.5	0.3	0.3	-0.0	0.3	0.3	-0.1	0.4	0.3	-0.1	0.1	-0.1	0.2	1						
Clay-BF	-0.3	-0.6	0.3	0.3	0.4	0.1	0.1	0.1	0.0	-0.0	0.3	0.5	0.5	-0.1	-0.0	0.0	-0.3	-0.4	-0.5	-0.1	1					
silt-BF	-0.3	0.3	0.3	0.2	0.0	0.1	0.3	0.1	-0.0	-0.0	0.3	0.5	-0.5	-0.2	-0.3	-0.1	0.3	0.0	-0.5	-0.0	-1.0	1				
sand-BF	0.3	0.3	0.3	0.2	-0.0	0.1	0.3	-0.3	0.0	0.1	-0.4	0.4	0.5	0.2	0.3	0.0	0.3	0.0	0.5	0.1	1.0	-1.0	1			
clay-AF	-0.4	-0.1	-0.1	-0.1	0.4	0.1	-0.1	0.3	-0.1	0.2	-0.1	-0.1	0.4	-0.3	-0.6	-0.2	-0.3	0.4	-0.2	-0.3	0.2	0.3	-0.3	1		
silt-AF	-0.4	-0.1	-0.2	-0.1	0.4	0.1	-0.1	0.3	-0.1	0.2	-0.1	-0.1	0.4	-0.3	-0.6	-0.2	0.1	0.4	-0.2	-0.3	0.2	0.3	-0.3	-1.0	1	
sand-AF	0.4	0.1	0.2	0.1	-0.4	-0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.3	0.6	0.0	-0.1	-0.4	0.2	0.3	-0.2	-0.3	0.3	-1.0	-1.0	1