

Effect of Selected Extinguishing Agents on Organic Carbon and Nutrients Leaching from Burned Soil

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Abstract: The aim of this work is to determine the effect of selected extinguishing agents - water and Pyrocool B on the organic carbon and nutrients leaching from burned soil in laboratory conditions. The simulation of fire was performed in a laboratory oven by exposing the samples of soil to the temperatures from 100 °C to 600 °C and constant time of 60 minutes. After that, hot or cold burned soil was extinguished by extinguishing agents. Subsequently the suppression of thermally influenced soil was carried out, as well as the chemical analysis of total organic carbon and chosen soil nutrients in the extract of soil. To determine the carbon, nitrogen and phosphorus substances are used with conventional chemical laboratory methods.

Keywords: wildfire; soil; leaching; total organic carbon; nutrients; Pyrocool B

1. Introduction

With the expansion of biofuel, the feedstock cultivation is closely linked with the issue of intentional or unintentional burning of biomass. Wildfire is an unplanned, unwanted wildland fire including unauthorized human-caused fire that are mostly created by carelessness while manipulating with fire. It may be also defined as a “forest fire”, an uncontrolled fire on lands covered wholly or in part by timber, brush, grass, grain, or other flammable vegetation. Fire intensity describes the rate at which a fire produces thermal energy and it can be defined as the maximum temperature recorded at a certain point and the time that the temperature remains at a certain point, expressed in °C s⁻¹. Burn severity, often used interchangeably with the term fire severity, describes the response of ecosystems to the fire. It can be used to describe the effects of fire on the soil, water system, ecosystem flora and fauna, atmosphere, and also society. Burn severity is a product of fire intensity and residence time. It can be generally divided into three main groups [1]:

1) low burn severity – less than 2 % of the area is severely burned, less than 15 % is moderately burned and the remainder of the area is burned at a low severity or unburned,

2) moderate burn severity – less than 10 % of the area is severely burned, but more than 15 % is moderately burned and the remainder is burned at a low severity or unburned,

3) high burn severity – more than 10 % of the area has spots that are burned at a high severity, more than 80 % is severely or moderately burned and the remainder is burned at a low severity.

The magnitude of the heat pulse into the soil depends on fuel loading, content of fuel moisture, its distribution, rate of combustion, soil texture, soil moisture content and other factors. The movement of heat into the soil does not only depend upon the reached peak temperature, but even more upon the length of time that the heat source present. Generally, “lightly burned” forest fire will come near the soil surface temperatures between 100 and 250 °C and the 2 cm below the surface will not exceed 100 °C. In “moderately burned” areas, surface temperatures are typically in the 300 to 400 °C range and may be between 200 and 300 °C at the 1 cm depth. A “severely burned” area may result in surface temperatures approaching up to 760 °C. Nevertheless, the temperatures at the soil surface during the wildfire can even approach 900 °C. These highest soil temperatures are associated with the areas that have the longest duration of burning and areas of the greatest fuel consumption. Dry soil is a poor conductor of heat; therefore at 5 cm below the surface, the temperature does not likely exceed 150 °C. High-temperature fires may completely consume the surface organic layers where the organic material mineralized or volatilized nutrients during the oxidation [2]. In low intensity fires, combustion of litter and soil organic matter that is the major storehouse of carbon and many other elements in soils, including nitrogen, phosphorus, sulphur, calcium and magnesium; it may increase plant available nutrients. That results in a rapid growth of herbaceous plants or other successional species and a significant increase in plant storage of nutrients. Whereas high intensity fires can result into a complete loss of soil organic matter that consists of carbon, volatilization of N, P, S, K and death of microbes [3, 4].

Soil is the largest terrestrial pool of carbon on the Earth's surface. It stores nearly twice more carbon than atmosphere [5]. "Organic carbon" is a term used for the carbon that is in organic matter, while "inorganic carbon" is carbon in other compounds, mostly CO₂, carbonate and bicarbonate compounds, carbonaceous materials or graphite. Organic carbon makes about 70 % of carbon pool and the remaining consists of carbonates [6]. It is important for the function of ecosystems having a major influence on the physical structure of the soil, the soil's ability to store water, form complexes with metal ions and supply nutrients. Loss of organic carbon may, therefore, lead to a reduction in soil fertility, land degradation or the worst case to desertification. Soil in natural forests tend to have higher soil organic carbon content than the agricultural soil [7]. Wildfire has the potential to change the amount of carbon that is stored in soil. As soil is burned, the chemical structure of soil organic matter can be altered through the partial combustion or alteration of soil organic matter and through the production of highly recalcitrant black carbon [8]. During the fires at higher temperatures can be most of the organic matter mass transformed into CO₂ and water vapour with nutrients loss as gases [2]. There is a large potential for carbon loss due to an ignition of soil organic matter horizons during combustion in relatively dry soil, however, wet soil are also predisposed for combustion [8]. Organic and humic materials start usually decomposing at 100 °C. That means the distillation of volatiles and loss of organic carbon in soil starts at this temperature. Above the temperature 200 °C the charring process starts. Between the temperatures of 130 and 190 °C lignin and hemicelluloses begin to degrade and almost all organic carbon is destroyed at 500 °C. These temperatures are easily reached during brushland and forest fires. Small organic matter rich particles may reach the temperature even higher than 1000 °C when burning on the topsoil. Therefore, the total destruction of carbon during the fire may occur [9].

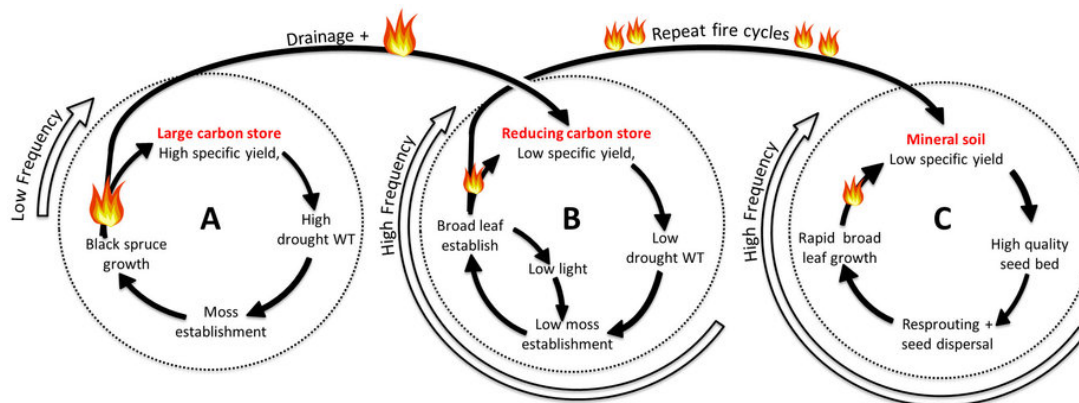


Figure 1: Conceptual carbon cycle in peat soil affected by fire [10]

Nitrogen is a unique component in soil because almost all nitrogen found in vegetation, water and soil of wildland systems has to be added to the system from the atmosphere, as it is the richest atmosphere component (78 %). It is a part of all amino acids and proteins and also an essential compound for nearly every physiological process in plants [9]. Nitrogen is one of the most important nutrients affected by fire and often the growth limiting factor on many sites, and therefore is the major of interest. In soil, this element exists in many different forms and constantly changes from one form to another. Nitrogen that is presented in soil organic matter converts to the inorganic form by the process of mineralization. The transformation of organic nitrogen to the ammonia (NH₃) and ammonium (NH₄⁺) forms is referred to "ammonification". The consequent ammonium can then be transformed to the nitrate form (NO₃⁻) by a process called "nitrification". The decomposition process is carried out by living organisms and they may need additional nitrogen to decompose the residues. If the nitrogen supply is limited, soil microbes compete with plants for fertilizer nitrogen in a process called immobilization. When these microbes die, nitrogen tied up in the decomposition process becomes available for the crop use again [7]. During wildfires, nitrogen is easily volatilized and lost from the aboveground fuels, litter, duff and upper soil layers at relatively low temperatures, 200 – 500 °C [2, 9]. The differences between percentage of nitrogen and total amount of nitrogen started at 100 °C and became greater until about 500 °C [2]. That means there is a gentle increase in the nitrogen loss by volatilization as temperature increases. However, nitrogen cations like nitrates and ammonium are not easily volatilized and usually remain on the site in a highly available form and are more prone to off-site movement in surface runoff and leaching. An abundance of cations can be found in the thick ash layers (or ash-bed) remaining on the soil surface following high-severity fires [9, 11]. The ammonium and nitrate form is directly usable by plants. This is due to the fact that NH₄⁺ is released from organic matter with heating and nitrification is often stimulated [8]. Ammonium represents the most important inorganic fraction in soil after nitrogen. Being part of the crystalline structure and consequently fixed in the compound over crystalline powers, it occurs less solid as salt or adsorptive fixed in other materials. Nitrogen in

the nitrate form is highly soluble salt in water and very mobile. Rainfall or fire extinguishing by water moving through the root zone may wash nitrate downward, reaching tiles or drainage channels and potentially reach groundwater or surface water. Leaching can be a more serious problem in highly permeable sandy soil than in clayey soil and the magnitude of nitrate loss depends on the intensity of the rainfall or extinguishing water and the amount of nitrate present in the soil [12]. Loss of nitrate by leaching is of concern for some reasons. Firstly, nitrate below the root zone is no longer available for the crop use. Secondly, water quality problems caused by the excess amount of nitrogen may result in the quality deterioration of drinking water sources and wildlife habitat [7]. For this reason, the amounts of nitrate and ammonium are particularly important to determine after fire [12].

Phosphorus is probably the second most limited nutrient found in soil that limits production processes in the ecosystem. The main reservoirs of phosphorus in nature are rocks and sediments created in the ancient history of the lithosphere. It occurs in soil as both organic and inorganic forms. The organic form is found in humus and other organic materials, especially the soil organic matter [7]. Organic phosphorus is held very tightly and generally is not available for plant uptake until the organic materials are decomposed. The phosphorus is then released via the mineralization process. Mineralization is realized by microbes, and as with nitrogen, the rate of phosphorus release is affected by factors such as soil moisture, structure of the organic material, oxygen concentration and pH. Microbes may compete with plants for phosphorus, if the decomposing organic materials are high in carbon and low in nitrogen and phosphorus (i.e. wheat straw). Immobilization, the reverse process, refers to the tie-up of plant-available phosphorus by soil minerals and microbes that use phosphorus for their own nutritional needs [7]. The inorganic part occurs in various combinations with minerals like iron, aluminium, calcium and other elements, most of which are not very soluble in water [13]. Mineralization and immobilization occur simultaneously in soil. However, mineralization will be the dominant process if the phosphorus content of the organic material is high enough to meet the requirements of the microbial population [7]. Both organic and inorganic forms of phosphorus are important sources for the plant growth, but their availability is controlled, as mentioned, by soil characteristics and environmental conditions. Phosphorus occurs in acid soils as negatively charged phosphate ion H_2PO_4^- , or in alkaline soils as HPO_4^- . Such ions react with iron, aluminium, and manganese compounds in acid soil and with calcium compounds in neutral and alkaline soils. They become strongly attached to the surface of these compounds or forms of insoluble phosphate precipitates. These reactions remove immediately available phosphate ions from the soil solution. Phosphate ions do not leach to underground water, as do nitrate ions, not even in sandy soils [13]. The relative amount of each form of phosphorus varies greatly among the types of soil. The total amount of phosphorus in a clayey-textured soil is being up to ten times greater than in a sandy soil [7]. Of all plant nutrients, phosphorus is usually the most closely associated with accelerated production of weeds and algae which results in the well-known appearance of eutrophication [12, 13]. During the fire, phosphorus is lost at a higher temperature than nitrogen. It can be volatilized at high burn temperatures, approximately 750°C , whereas other mineral cations such as calcium, magnesium, and potassium are typically converted to oxides that are relatively more soluble [2]. Only about 60% of the total phosphorus is lost by a nonparticulate transfer when an organic matter is totally combusted. The combustion of organic matter leaves a relatively large amount of highly available phosphorus in the surface ash found on the soil surface immediately after fire. This highly available phosphorus immobilizes very easily, if calcareous substances are presented in the ash. Thus, it becomes unavailable for a plant growth [9].

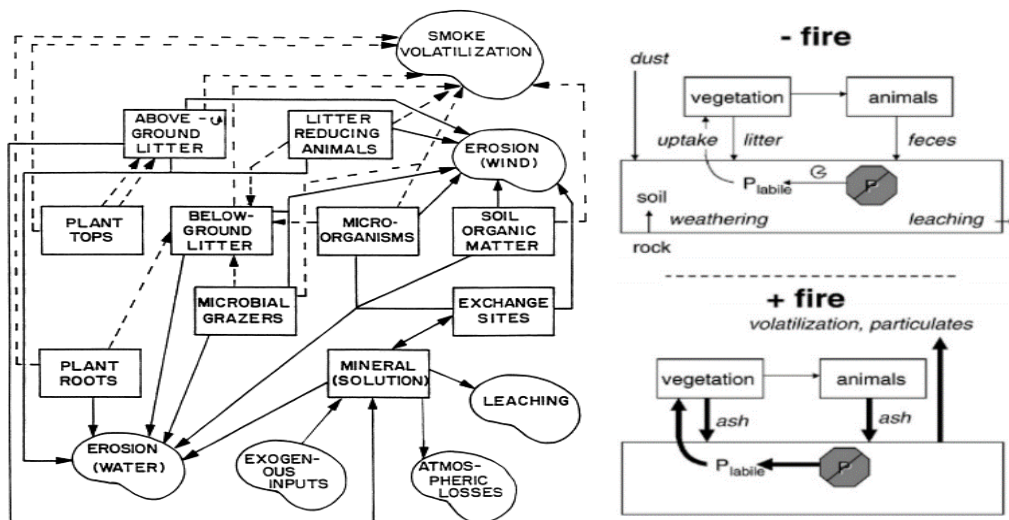


Figure 2: Conceptual nitrogen and phosphorus cycle in soil affected by fire [11, 14]

2. Material and methods

2.1. Sample collection and characterization

The field collection of soil samples was carried out at one point of delivery from the upper A genetic horizon to a depth of 30 cm in September 2009 in the former Botanical garden in Trnava. The collected soil sample was placed in polythene bags. After transported to the laboratory, soil was treated in a standard way, namely free drying in a dark and dry place, crushing in a porcelain mortar, homogenization, sieving to the size below 2 mm. After that, all samples were detailed characterised by methods reported in [15].

2.2. Extinguishing Agents

Extinguishing agents are various substances and materials used to stop or slow down the combustion process. In our experiments we used:

- 1) Distilled water – water is the most widely used and common extinguishing agent because it is inexpensive, readily available and effective in the fire suppression.
- 2) Pyrocool B – is commercial product – straw yellow viscously liquid used as a wetting agent and mixed with water in 0.4 % concentration. Its main compound is non-ionized surfactant based on ethoxylated alcohol.

2.3. Laboratory heating experiments

The simulation of fire was carried out in a laboratory oven/muffle furnace by exposing the samples of soil to the heat. The used temperatures were from 100 °C to 600 °C and constant 60 minutes duration. Samples were located in porcelain boats. They were filled up to approximately 0.5 cm with the exact weight of 10 grams (this is the standard procedure used in all our experiments, and is in compliance with [16] or [17]). After 60 minutes hot/cold burned soil was extinguished by 100 mL of distilled water wetting agent Pyrocool B mixed with distilled water in 0.4 % concentration. Extracts of burned soil were filtrated and quantitatively transferred to 250 mL volumetric flask with distilled water adjusted volume. Subsequently, the chemical analyses of chosen soil nutrients in extracts were carried out.

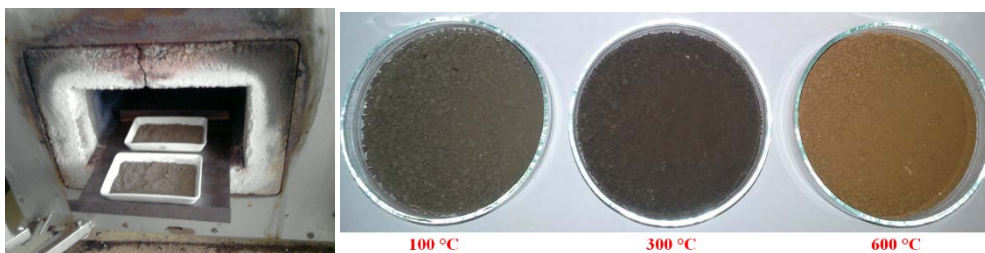


Figure 3: The simulation of fire in muffle furnace by exposing the samples of soil to the heat

2.4. Spectrophotometric analysis of nutrients in soil extract

All chemical analyses were carried out with solutions prepared from pure chemicals (LaChema, Brno; Mikrochem, Pezinok; MERCK, Bratislava) using a spectrophotometric method with spectrophotometer TermoSpectronic GENESIS™ in a 5 cm quartz cuvette. Detailed description of the used methods is reported in [18] and [15].

- 1) The analysis of organic carbon content is based on the oxidation of solutions by chromosulfuric mixture by increased temperature of reaction.
- 2) The analysis of ammonium cations is based on the reaction of ammonium ions with Nessler reagent, which forms a yellow-brown compound.
- 3) Nitrates – phenol-sulphuric acid is readily nitrated and alkaline solutions of nitrated derivatives are intensely yellow coloured. With increasing concentration of nitrates, the intensity of the yellow colour increases as well.
- 4) The analysis of phosphate ions is based on the reaction of ammonium molybdenate with orthophosphate ions to phosphomolybdenic acid. This is reduced to molybdenum blue.

3. Results and discussion

3.1. Characterisation of the initial soil sample

The exchange pH value of the soil sample assumes a value of 7.3 (slightly alkaline) what, is typical for feature of brown carbonate soil type occurring around the Trnava region. Total organic carbon is very high (3.14 mg g⁻¹), from which the calculation of humus content (5.52 %) shows very strong humus content. Level of humification is very weak, takes the value of 9.23 %. In the humic horizon are dominated fulvic acids over

humic acids ($C_{HA/FA} = 0.29 : 1$). Colour ratio ($Q_{4/6}$) was also low, only 3.86. Soil particle size analysis classified samples as sandy – loam soils.

Table 1: Qualitative and quantitative parameters of the input soil sample

pH _{KCl}	[–]	7.3
Sand	[%]	26.5
Silt	[%]	53.3
Clay	[%]	20.2
Total organic carbon (TOC)	[mg g ⁻¹]	3.141
Content of organic carbon in water-soluble matter	[mg g ⁻¹]	1.02
Content of organic carbon in water-insoluble matter	[mg g ⁻¹]	2.12
Humus content	[%]	5.42
Carbon in humus matter	[mg g ⁻¹]	1.28
Carbon in non-humus matter	[mg g ⁻¹]	1.86
Ratio of carbon in humus matter and TOC	[mg g ⁻¹]	40.80
Content of carbon in humic acids	[mg g ⁻¹]	0.29
Content of carbon in fulvic acids	[mg g ⁻¹]	1.00
Ratio of carbon in humic acids and fulvic acids	[–]	0.29
Degree of humification	[%]	9.23
Colour factor of humic substances $Q_{4/6}$	[–]	3.86

3.2. Organic carbon

In general, extinguishing of burned soil by distilled water established lower leaching ability than extinguishing by 0.4 % Pyrocool B. Significant peak occurred at the temperature 100 °C in extract of burned soil extinguished by distilled water in the hot condition, where the analysed concentration of organic carbon was 83.87 % higher when compared to the unburned soil sample. Soil organic carbon is the major component of soil organic matter and fire which could occur at temperature about 100 °C caused the rapid loss of labile soil organic matter because of decomposition [12]. Therefore, the measured concentration of leached organic carbon at this temperature was so high. Consequent increasing of temperatures used to burn soil down caused a slight decreasing of TOC in extracts of burned soil extinguished by distilled water. Notable lowering started to occur at the temperature 500 °C when concentration decreased by 96.78 % in comparison with reached peak concentration at the temperature 100 °C. At the temperatures above 500 °C concentrations occurred in extract are very low. There was no concentration of organic carbon in extracts measured at the temperature 550 °C in both cases (hot and cold condition).

When demonstrating results of measuring organic carbon concentrations in extracts of burned soil extinguished by 0.4 % Pyrocool B, the peak was reached at the temperature 200 °C in the cold condition. In comparison with unburned soil sample the leached peak concentration raised by 83.82 %.

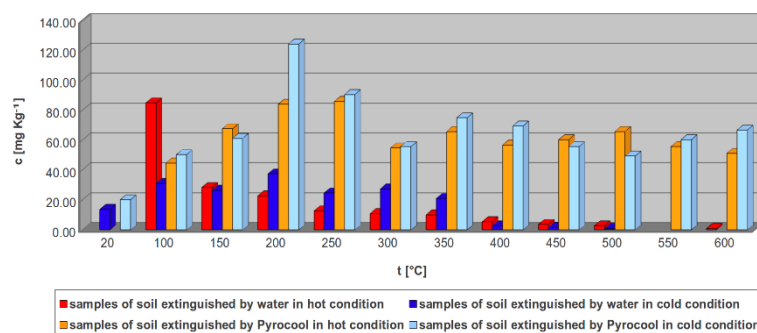


Figure 4: Organic carbon concentration changes in burned soil samples extracts

However, wetting agent Pyrocool B is a mixture of etoxylated alcohols which contained carbon groups and influenced the results of analysis. Figure illustrates concentrations of burned soil samples extinguished by Pyrocool B lowered by 0.4 % Pyrocool B organic carbon concentration. The results of this Figure 5 were obtained by the same technique as in case of soil extracts. The only difference is that soil was substituted by sand and extinguished by 0.4 % Pyrocool B. After lowering the content of organic carbon in every sample extinguished by Pyrocool B, there was no concentrations of leached organic carbon obtained at the temperature:

20 °C in unburned soil, 100 °C in hot and cold condition, 300 °C in hot condition and 600 °C in hot condition. Concentration started to fall from the temperature 400 °C and remained almost at the same level until the temperature 600 °C.

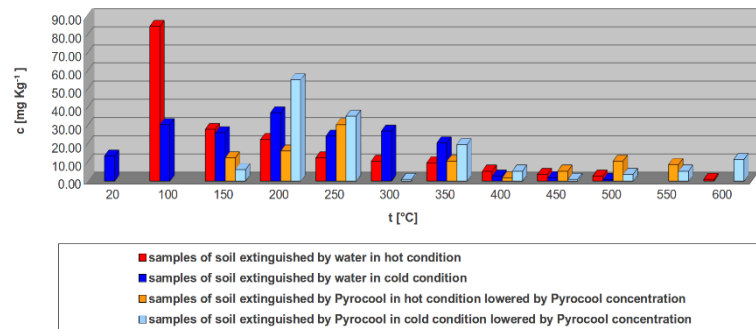


Figure 5: Organic carbon (without Pyrocool B carbon) concentration changes in burned soil samples extracts

3.3. Ammonium cations

The content of ammonium cations in extracts of burned soil extinguished by distilled water alternates the increase with the decrease as represented in Figure 6. The increasing character is established until the temperature 200 °C where the highest concentrations are reached. The concentration of ammonium cations leached at this temperature and extinguished in cold condition grew by 83.59 %, in hot condition by 79.62 % when compared with unburned soil sample. Mroz at al. [19] reported a 77 % increase of ammonium content in burned soil of a red pine forest in their research. In general, it can be said that results of this research correspond to already accomplished experiments, even when nutrient concentration was measured in extracts of burned soil. However, the degradation of ammonium cations starts to be indicated at the temperature 250 °C. In comparison with samples burned at the temperature 200 °C, the content of leached nutrient decreased by 51.54 % when extinguished in hot condition and by 30.34 % when extinguished in cold condition. The concentration of ammonium cations in extracts is significantly lower at the temperatures 450 – 600 °C. A decline was from 97.62 % to 99.38 % when compared with reached peaks at the temperature 200 °C. Soil temperature, pH and availability of cations increase during the fire of soil and the main source of NH_4^+ content in extracts was the decomposition and mineralization of labile soil organic matter where especially nitrogen from amino acids and proteins changed to ammonium cations [20]. DeBano et al. [21] reported that enormous amounts of ammonium could be found in the ash and underlying soil after low severity fires.

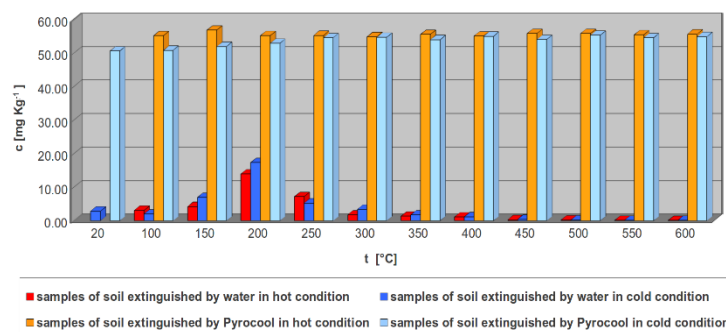


Figure 6: Ammonium cations concentration changes in burned soil extracts

The content of ammonium cations extinguished by wetting agent Pyrocool B at 0.4 % concentration remained at the same level while burning samples of soil at temperature 100 °C to 600 °C. Each sample extinguished by Pyrocool B in hot condition proves a slightly higher leaching ability. Compared with an unburned soil sample, the concentration of leached ammonium cations was insignificantly higher. However, compared with samples extinguished by distilled water, the difference was much more visible, e.g. extract from unburned soil extinguished by 0.4 % Pyrocool B contained 94.38 % higher concentration of leached ammonium cations than unburned soil extinguished by distilled water. According to Couto-Vazquez et al. research [22], where burned soil was extinguished by the mixture of water and foaming agent Auxquimica RFC-88 at 1 %, the

concentration of N-NH_4^+ was also higher when compared with unburned soil samples, as well as burned soil samples extinguished by water. It might be inferred that ingredients in water mixed with foaming or wetting agent have a significant impact on nutrients leaching. The reaction of NH_4^+ cations presented in samples of burned soil extinguished by Pyrocool B (etoxyated alcohols C12-C15, branched and linear) forms well water-soluble amines. Higher aliphatic amines are liquids themselves. Boiling point and hence the volatility of amines is much lower than the boiling point of alcohol. If excessive amounts of alcohol was used, the mixture of primary, secondary and tertiary amines which has different volatility level should be created.

3.4. Nitrates

Concentration of nitrates in extracts extinguished by distilled water in hot condition changed by temperature used to burn samples of soil and it had rising tendency until the temperature 200 °C. On the other hand, falling tendency could be visible from the temperature 300 °C when extinguished in hot and also in cold condition. The highest concentration was measured at the temperature 200 °C in the both cold and hot condition. In comparison with unburned soil sample, the leached concentration increased by 21.28 % when extinguished in the hot condition and by 57.95 % when extinguished in the cold condition. The fall of nitrates content was notably lower at the temperatures from 450 °C until 600 °C. A drop in concentration of nitrates in soil extracts extinguished in hot condition was from 61.7 % to 76.52 % when compared with a reached peak concentration. A drop in concentration of nitrates in soil extracts extinguished in the cold condition was from 85.22 % to 94.32 % in comparison with a reached peak concentration.

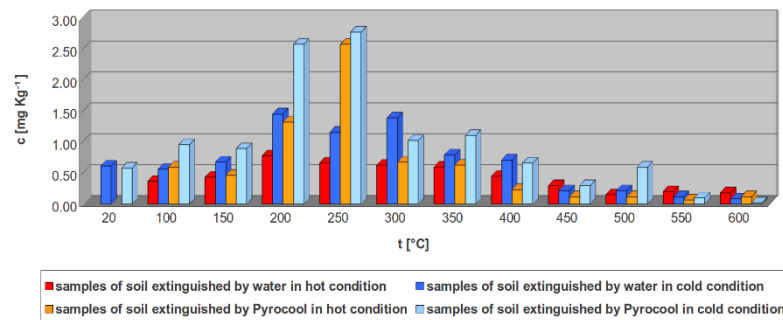


Figure 7: Nitrates concentration changes in burned soil samples extracts

The nitrates in extracts extinguished by Pyrocool B showed higher leaching ability in almost all samples and had the same tendency of increasing and decreasing as in case of soil samples extinguished by distilled water. The highest leached concentration was reached at the temperature 250 °C. In comparison with unburned sample the concentration of leached nitrates increased by 78.34 % in case of sample extinguished in hot condition and by 79.89 % in case of sample extinguished in cold condition. At the temperatures from 450 °C until 600 °C, a significant fall of NO_3^- concentration occurred. The content of leached nitrates in the sample extinguished in hot condition at the temperature 600 °C decreased by 95.51 % and in the sample extinguished in cold condition at the same temperature by 99.41 % when compared with reached peak concentrations.

3.5. Phosphate ions

Phosphate ions leached from samples extinguished in hot condition by distilled water demonstrate lower concentrations in comparison with samples extinguished in the hot condition by 0.4 % Pyrocool B. The most significant difference in concentrations can be seen at the temperature 350 °C and 600 °C. At the temperature 350 °C the difference between concentrations is 45.38 % and difference at the temperature 600 °C increased to 75.07 %. In comparison with unburned soil samples extinguished by water and 0.4 % Pyrocool B, the concentration of leached phosphate ions in extracts of each sample are higher. Therefore, heating the soil up to different temperatures supports leaching of this nutrient. In case of samples extinguished in cold condition by distilled water, the concentrations of realized phosphate ions reached two peaks at the temperature 300 °C and 450 °C followed by growing tendency. Nevertheless, extinguishing of burned soil by wetting agent Pyrocool B, that is a mix of different surfactant, proved the highest impact to phosphate ions leaching. From Figure 8 it can be seen that the highest concentration in soil extract occurred when suppressed by Pyrocool B at the temperature 400 °C in the hot condition. In comparison with unburned soil sample the concentration of leached P-PO_4^{3-} at this temperature increased by 46.27 %. No significant peaks occurred while burning soil samples were extinguished by Pyrocool B at different temperatures, as it was carried out while extinguishing burned soil samples with distilled water.

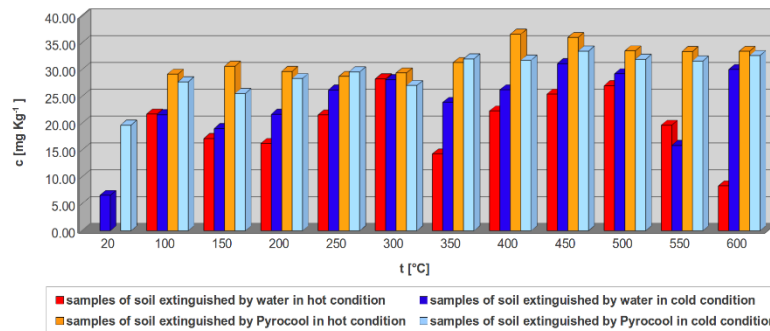


Figure 8: Phosphate ions concentration changes in burned soil samples extracts

4. Conclusions

In this paper, the main problems associated with wildfire, their effect on essential soil nutrients are summarized. Soil is fundamental to a healthy and functioning ecosystem and generally, fire changes soil's chemical properties and affects its function. After suppression, the nutrients from soil may leach into surface water and groundwater. From the obtained results it demonstrates that:

1) The analysis of an organic carbon concentration in extracts of burned soil extinguished by water proved the highest leaching ability at the temperature 100 °C when an organic matter starts to decompose. Almost all organic carbon is destroyed at the temperature 500 °C and higher, which is easily reached during wildfires. Suppression carried out by Pyrocool B in burned soil samples present similar leaching ability of organic carbon.

2) The organic carbon concentration decrease in our measurements started to visible from temperature 450 °C and no concentration in extracts of burned soil extinguished by distilled water occurred at the temperature 500 °C. These temperatures are easily reached during forest fires and the total destruction of carbon during the fire may occur. Soil organic matter consists mostly of carbon, hydrogen and oxygen. According to DeBano at al. [21] during the fire at the temperatures between 250 °C and 400 °C phenolic (-OH) and carboxyl (-COOH) groups lost are. According to Gonzalez-Perez et al. [5] the decomposition of soil organic carbon starts at the temperature 100 °C, as mentioned and charring process starts above the temperature 200 °C. Almost all organic carbon is destroyed at the temperature 500 °C which was also proved in our measurements.

3) Measured concentration of ammonium cations in soil extinguished by distilled water alternates increase with a decrease with the highest leached amount reached at the temperature 200 °C. The availability of NH_4^+ content in extracts rises because of the decomposition and mineralization of soil organic matter. Extinguishing by Pyrocool B has a significant impact on ammonium cations leaching; however, it did not prove why the leaching ability is so high. This issue needs further research.

4) The content of nitrates in extracts suppressed by water demonstrates growing tendency until the temperature 200 °C and therefore, causes the increase of inorganic nitrogen content in extracts of burned soil samples, respectively in burned soil. The degradation of nitrogen begins to be visible at the temperature 300 °C and this loss occurs due to the volatilization of nitrogen. Extinguishing by Pyrocool B shows a higher leaching ability of nitrates.

5) From the results of analysis it demonstrates that the influence of lower temperatures (to 250 °C) causes rising of inorganic nitrogen content in extracts of burned soil samples or in burned soil. The degradation of nitrogen begins to be visible at the temperature 300 °C. It showed that the nitrogen loss via volatilization occurs at temperatures from 200 °C and at the temperature above 500 °C the half on nitrogen content is lost in the atmosphere [23] which was also proved in our measurements. The content of inorganic nitrogen in our samples were sharply lower from the temperature 300 °C. It assumed that the loss of nitrogen content at relatively lower temperatures could be caused by different soil types and the composition of overlying soil horizon. The surplus content of nitrates in soil and water belongs to the risk factors. It has the influence on the environment, and which can impair its quality and damage the human health. For excessive nitrate content in heavy humus soils (humus content in soil is more than 4 %) considered NO_3^- concentration is higher than 230 mg kg^{-1} [7]. Measured results follow that the content of NO_3^- in extracts depends on the temperature used to burn the soil. However, our results from the analysis of burned soil samples extinguished by water and wetting agent Pyrocool B do not exceed the trigger value of NO_3^- concentration in water and therefore, do not present a significant danger to the environment and human health.

6) The leached concentration of phosphate ions from burned soil after extinguishing with distilled water has a growing tendency to the temperature 450 °C. Organic phosphorus is slowly mineralized to phosphate form during the decomposition of organic matter and therefore becoming more available to organisms. The phosphate ions content in extracts decreased significantly from the temperature 500 °C due to a gradual volatilization of

phosphorus from burned soil to the atmosphere. Extinguishing of burned soil by wetting agent Pyrocool B was proved to have a higher impact on phosphate ions leaching.

7) In general, the increase of leached $P-PO_4^{3-}$ at the temperatures 200 – 300 °C may have been caused by the decomposition of organic material from “unprocessed” soil organic matter. The increase of leached $P-PO_4^{3-}$ from temperature 400 °C to 500 °C could be attributed to changes in the way of binding different phosphorus forms, such as binding to iron, aluminium or calcium. The phosphate ions content in extracts dropped significantly from the temperature 500 °C or higher. This decrease can be attributed to the gradual volatilization of phosphorus from burned soil to the atmosphere. However, [21] described the volatilization of phosphorus at the temperature up to 900 °C. According to [21], as well as according to our other research, pre-fire phosphorus is contained in organic matter or inorganic minerals. Organic phosphorus is slowly mineralized to phosphate form during the decomposition of organic matter and therefore becoming more available for organisms. Quite enormous amounts of highly available phosphorus can be found in the ash and on the soil surface immediately after some fires.

The results of chemical analyses demonstrate that fire of soil has impact on the nutrient leaching after extinguished by different agents. After suppression, the nutrients from soil may leach into surface water and groundwater. Therefore, nutrients cycle in ecosystems, the quality of soil and water are affected.

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References

- [1] BENTO-GONCALVES, A., et al. *Fire and soils: Key concepts and recent advances*. In: *Geoderma*. 2012. Vol. 191. pp. 3 – 13.
- [2] ICE, G. G., NEARY, D. G., ADAMS, P. W. *Effects of Wildfire on Soils and Watershed Processes*. In: *Journal of Forestry*. 2004. Vol. 102. pp. 16 – 20.
- [3] VERMA, S., JAYAKUMAR, S. *Impact of forest fire on physical, chemical and biological properties of soil: A review*. In: *Proceedings of the International Academy of Ecology and Environmental Sciences*. 2012. Vol. 2. pp. 168 – 176.
- [4] YILDIZ, O., et al. *Effects of forest fire on soil nutrients in Turkish pine (Pinus brutia, Ten) Ecosystems*. In: *Journal of Environmental Biology*. 2010. Vol. 31. pp. 11 – 13.
- [5] GONZALEZ-PEREZ, J. A., et al. *The effect of fire on soil organic mater - a review*. In: *Environment International*. 2004. Vol. 30. pp. 855 – 870.
- [6] BATJES, N. H. *Total carbon and nitrogen in the soils of the world*. In: *Soil Science*. 1996. Vol. 47. pp. 151 – 163.
- [7] BEDRNA, Z. *Environmental Soil Science*. Bratislava: Slovak Academy of Sciences, VEDA. 2002. pp. 352. ISBN 80-224-0660-0
- [8] ERICKSON, H. E., WHITE, R. *Soils Under Fire: Soils Research and the Joint Fire Science Program*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. May 2008. pp. 17. General Technical Report PNW-GTR-759
- [9] NEARY, D. G., RYAN, K. C., DeBANO, L. F. *Wildland fire in ecosystems: effects of fire on soils and water*. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. September 2005. pp. 250. General Technical Report RMRS-GTR-42-vol.4
- [10] KETRIDGE, N., TURETSKY, M. R., SHERWOOD, J. H., THOMPSON, D. K., MILLER, C. A., BENSCHOTER, B. W., FLANNIGAN, M. D., WOTTON, B. M., WADDINGTON, J. M. *Moderate drop in water table increases peatland vulnerability to post-fire regime shift*. In: *Scientific Reports*. 2015. Vol.5.
- [11] NEARY, D.G., et al. *Fire effects on belowground sustainability: a review and synthesis*. In: *Forest Ecology and Management*. 1999. Vol. 122. pp. 51 – 71.
- [12] JANBEN, Enno. *Determination of total Phosphorus, total Nitrogen and Nitrogen Fractions*. [online]. [accessed 2016-10-13, 19:33 CET]. Linked from: <http://www.ecn.nl/docs/society/horizontal/hor16_nutrient.pdf>
- [13] SCHULTE, E. E., KELLING, K. A. *Soil and Applied Phosphorus*. [online]. [accessed 2013-02-15, 14:27 CET]. Linked from: <www.soils.wisc.edu/extension/pubs/A2520.pdf>
- [14] HARTSHORN, A.S., COETSEE, C., CHADWICK, O.A. *Pyromineralization of soil phosphorus in a South African savanna*, In: *Chemical Geology*. 2009. Vol. 267, pp. 24 – 31.

- [15] FIALA, Karel. *Mandatory methods of soils analysis*. VÚPOP Bratislava. 1999. p. 142. ISBN 80-85361-55-8.
- [16] BADIA, D. AND MARTI, C. (2003). *Plant ash and heat intensity effects on chemical and physical properties of two contrasting soils*. In: *Arid Land Research and Management*, Vol. 17 (1). p. 23 – 41.
- [17] GLASS, D.W., JOHNSON, D.W., BLANK, R.R. AND MILLER, W.W. (2008). Factors affecting mineral nitrogen transformation by soil heating: a laboratory – simulated fire study. *Soil Science*. Vol. 173. p. 387 – 400.
- [18] BARTOSOVA, A., MICHALIKOVA, A., SIROTIK, M., SOLDAN, M. *Comparison of Two Spectrophotometric Techniques for Nutrients Analyses in Water Samples*. In: *Research Papers of Faculty of Materials Science and Technology, Slovak University of Technology*. January 2013. Vol. 20. Issue 32. pp. 8 – 19. ISSN 1338-0532.
- [19] MROZ, G.D., JURGENSEN, M.F., HARVEY, A.E., LARSEN, M.J. *Effects of fire on nitrogen in forest floor horizons*. In *Soil Science Society of America Journal*. 1980. Vol. 44. pp. 395 – 400.
- [20] DRISCOLL, K. G., AROCENA, H. B., MASSICOTTE, H. B. *Post-fire soil nitrogen content and vegetation composition in sub-boreal spruce forests of British Columbia's central interior, Canada*. In *Forest Ecology and Management*. 1999. Vol. 121. pp. 227 – 237.
- [21] DeBANO, L. F., NEARY, D. G., FFOLLIOTT, P. F. *Fire's effects on ecosystems*. 1998. New York: John Wiley & Sons, Inc. pp.333. ISBN 0-471-16356-2.
- [22] COUTO-VAZQUEZ, A., GONZALEZ-PRIETO, S. J. *Short- and medium-term effects of three fire fighting chemicals on the properties of a burnt soil*. In: *Science of the Total Environment*. 2006. Vol. 371. pp. 353 – 361.
- [23] KNICKER, H. *How does fire affect the nature and stability of soil organic nitrogen and carbon? A review*. In *Biochemistry*. 2007. Vol. 85. pp. 91 – 118.