Space-time monitoring of prescribed burnt soils performance – an effective tool for forest management

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Abstract
Among the most important measures to prevent wild forest fires is the use of prescribed and controlled burning actions in order to reduce the availability of fuel mass. However, the impact of these activities on soil physical and chemical properties varies according to the type of both soil and vegetation and is not fully understood. Therefore, soil monitoring campaigns are often used to measure these impacts. In this paper we have successfully used three statistical data treatments - the Kolmogorov-Smirnov test followed by the ANOVA and the Kruskall-Wallis tests – to investigate the variability among the soil pH, soil moisture, soil organic matter and soil iron variables for different monitoring times and sampling procedures.

Key Words
Forest soil, prescribed fire, soil properties, forest management.

Introduction

In Portugal, prescribed fires are often used by forest managers in order to reduce the likelihood of wildfires or to minimize their impact if they occur (Botelho *et al.* 1999; Fernandes *et al.* 2004). This forest management strategy of fire prevention has legal support under Portuguese law and is generally implemented between October and April (PNDFCI 2008). Although several studies have shown a direct relation between these controlled actions and the decrease of wildfire occurrences, the overall impact of these preventive actions on Portuguese forestry soil and geosystems is complex and not completely characterized (Rau *et al.* 2008). In this work we intend to present information about space and time modifications of some forest soil properties, namely pH, soil moisture, organic matter and iron, previously submitted to prescribe burning. The Kolmogorov-Smirnov, ANOVA and Kruskal- Wallis statistical analysis tests were used to examine the variance and relationship among these forest soil properties. The data used for this work focused on monitoring records of a forest soil self-recovery capabilities once subjected to a prescribed fire by AFN (The Portuguese Authority for Forests) in March 2008. The forest soil properties considered were pH, soil moisture, organic matter content and iron content. A sub-layer sampling procedure was considered during a one year span (Castro 2009; Ribeiro 2009).

Material and methods

Gramelas is located in NW Portugal and is referred in the Portuguese cartographic unit as Ru 1,1. It has as pedological dominant units the thin umbric regosol in shale (RGul.x) and the umbric leptosol in shale (LPu.x). As subdominant pedological units, it has the chromic cambisol humic/umbric in deposits of quartzite and/or shales (CMux.vq), and the dystrict leptosol in shale (LPd.x) (DRAEDM 1995; Serviços Geológicos de Portugal 1961).

According to the information available in the Portuguese Soil Map (DRAEDM 1995; Serviços Geológicos de Portugal 1961) this soil has the following characteristics: low capacity of cationic exchange, low degree of base saturation and low capacity of water and nutrient retention. It also possesses the following characteristics: i) very reduced thermal amplitude; ii) available conditions for the radicular development in the soil layer between 30 the 50 cm; iii) low soil fertility; iv) no occurrence of water in the soil throughout most of the year except in very short periods and during intense rainfalls; v) occasional occurrence of a high deficit of water in the soil during July through September; vi) high risk of erosion without aptitude for agriculture and with low aptitude for the forest exploration and/or silviculture-shepherd concerns; vii) soil with less than 50% of coarse elements (rock and gravel) in horizons superficial and subsurface up to 50 cm of depth; viii) without terraces or with wide terraces; ix) dominant slopes varying between 25-30% to 40-45%. The studied area (approximately 1ha) had not been burned for approximately 7 years and was subjected to prescribed fire by the AFN in March 2008.

(a) (b) (c)

Figure 1. Appearance of the area in study: (a) before, (b) during and (c) after the forest fire.

The soil samples were taken during six different phases (before prescribed forest fire, right after the prescribed fire, and 45, 90, 270 and 360 days after the prescribed forest fire) and used to determine soil pH, soil moisture, organic matter and iron. Five distinct points for sampling collection were considered: Point number 1 was located on a level land with low vegetation, close to a water line; Point number 2 was located in level land with lots of vegetation; Point number 3 was located on a strong slope with low vegetation, Point number 4 was located on a strong slope with lots of vegetation; Point number 5 was located on level land with low vegetation. The sub-layers sampling collection procedure consisted of collecting16 sub-samplings on a previously traced circumference with 2 meters of diameter in three different depths (3cm, 6cm and 18cm) using a clean manual auger. The soil samples were transported to the laboratory in air-tight bags which clearly identified the point of the sampling collection and the depth and the date of the collection procedure.

The statistical analysis - results and discussion

The Kolmogorov-Smirnov test was used as the first statistical analysis approach. This allowed us to draws conclusions about the normality of the variable's distribution. Considering

$$\max_{K\text{-}S} = \max |Fo(xi) - Ft(xi)| \quad (1)$$

where, $\max_{K\text{-}S}$ = maximum different between theoretical and observation values, the following results were obtained:

Table 1. Kolmogorov-Smirnov test output.

Null hypothesis – *H0:* "*normality assumptions about the distribution of variables*" N = 90; α = 0,05 ; $K\text{-}S_{crit.}$ = 0,143		
Variables	K-S Test	
pH	(max K-S = 0,139)	Accept *H0*
Sm - (soil moisture)	(max K-S = 0,104)	Accept *H0*
Om - (orgânic matter)	(max K-S = 0,084)	Accept *H0*
Fe - (iron content)	(max K-S = 0,148)	Rejected *H0*

According to these results, the normality of the data could not be verified for all variables and therefore two different statistical data treatments were considered – the ANOVA and Kruskall-Wallis tests. The ANOVA test was used to analyze homogeneity of the samples in space and on soil properties values in time where

$$V_A = \frac{k\sum_j \left(\bar{x}_j - \bar{x}\right)^2}{n-1} \quad ; \quad V_R = \frac{\sum_i \sum_j \left(x_{ij} - \bar{x}_j\right)^2}{kn-k} \quad ; \quad F = \frac{V_A}{V_R} \quad (2)$$

where, V_A = samples variance and V_R = group variance, the following results were obtained:

According to these ANOVA results, and although the homogeneity on all soil properties during the monitoring time was not verified (that is H0: µpH = µpH1 = … =µpH365 is rejected), the soil parameters pH, organic matter and iron show homogeneity in space and/or in depth. That is, the local of sampling collection clearly influences the soil properties values but no significant difference were found at the same sampling local at different depths (0-3cm, 3-6cm and 6-18cm). Attempts were made to draw conclusions about the median behavior of soil properties (variables) with the Kruskall-Wallis test It is a one-way analysis of variance by ranks nonparametric test. As a distribution free test, there is no need to use normality assumptions about the distribution of variables, so it is assumed that the samples drawn from the population are random and the cases of each group are independent. The value of Kruskal- Wallis test given by

$$K = \left[\frac{12}{N(N+1)} \sum_{j=1}^{k} n_j \overline{R}_j^2 \right] - 3(N+1) \quad (3)$$

where, K = Kruskal- Wallis test value, , the following results were obtained:

Table 2. ANOVA test output.

Null hypothesis – H0: " *there are no differences between means of different groups (times)"* α = 0,05 ; $F_{crit.}$ = 2,32		
Variables	ANOVA	
pH	(F = 132,08) Rejected *H0*	
Sm - (soil moisture)	(F = 4,674) Rejected *H0*	
Om - (orgânic matter)	(F = 20,152) Rejected *H0*	
Fe - (iron content)	(F = 10,643) Rejected *H0*	

Null hypothesis – H0: " *there are no differences between means of different samples (locals)"* α = 0,05 ; $F_{crit.}$ = 1,826		
Variables	ANOVA	
pH	(F = 0,093)	Accept *H0*
Sm - (soil moisture)	(F = 1,860)	Rejected *H0*
Om - (orgânic matter)	(F = 0,728)	Accept *H0*
Fe - (iron content)	(F = 0,628)	Accept *H0*

Table 3. Kruskall-Wallis test output.

Null hypothesis – H0: " *samples are from identical populations - equality of population medians* " α = 0,05 ; $\chi^2_{\alpha;g-1}$ =11,07		
Variables	Kruskall-Wallis Test	
pH	(K = 80,60)	Rejected H0
Sm - (soil moisture)	(K = 25,24)	Rejected H0
Om - (orgânic matter)	(K = 57,11)	Rejected H0
Fe - (iron content)	(K = 38,62)	Rejected H0

According to the Kruskall-Wallis test, the ANOVA results have been confirmed, that is, all groups of variables exhibit different median behaviors (e.g. pH, pH_1, pH_{30}, pH_{90}, pH_{270}, pH_{365}) and cannot be considered as belonging to the same population.

Conclusions

There is a great variability among the variables when considering the records at different monitoring times according to the statistical procedures that were used in this study. Thus, it may be said that the time between each sampling campaign is crucial for the values obtained in different variables. On the other hand, each sampling site showed a relative homogeneity. This will allow us to consider the possible replacement of three samples at different depths for a single sample at a single depth (we propose an average depth).

References

Anderson MZ, Diniz D (2006) Effects of Prescribed Burning on Humidity, Physical and Chemical Properties, Organic Matter and Soil Temperature on Grazing Pasture – Efeito da queima sob o teor de umidade, características fisicas e quimicas, materia organica e temperatura no solo sob pastagem. *Revista Electrónica de Veterinaria* **VII**, 04.

Botelho H, Rigolot E, Rego F, Guarneri F, Binggelli F, Vega J, Fernandes P, Prodon R, Molina D, Gouma V, Leone V (1999) FIRE TORCH, Prescribed burning as a tool for the mediterranean region: a management approach. Contrat N° ENV4-CT98-0715. Periodic Tecnical Report; UTMAD Portugal; PIF.

Carter MC, Foster CD (2004) Prescribed burning and productivity in southern pine forests: a review. *Forest Ecology and Management* **191**, 93–109.

Certini G (2005) Effects of fire on properties of forest soils: a review. *Oecologia* **143**, 1–10.

DeBano LF (1991) 'The effect of fire on soil properties. Proceedings of Management and Productivity of Western-Montana Forest Soils'. General Technical Report INT-280. (USDA Forest Service: Ogden).

DRAEDM-Agroconsultores and Geometral (1995) Soil and possible land use on Entre Douro and Minho region - Carta de solos e carta de aptidão da terra do Entre Douro e Minho. Escala 1: 100 000.

EUFIRELAB (2006) Methods to study fire impacts on plants (forest stands, shrubs, herbaceous taxa), soil and fauna.

Fernandes P, Botelho H (2004) Analysis of the prescribed burning practice in the pine forest of northwestern Portugal. *Journal of Environmental Management* **70**, 15–26.

Gonzalez-Perez J, Gonzalez-Vila F, Almendros G, Knicker H (2004) The effect of fire on soil organic matter - a review. *Environment International* **30**, 855– 870.

Neff JC, Harden JW, Gleixner G (2005) Fire effects on soil organic matter content, composition, and nutrients in boreal interior Alaska. *Canadian Journal of Forest Reseach*, **35**, 2178–2187.

PNDFCI (2008) 'Plano Nacional de Defesa da Floresta contra Incêndios'.

Rau BM, Chambers JC, Blank RR, Johnson DW (2008) Prescribed Fire, Soil, and Plants: Burn Effects and Interactions in the Central Great Basin. *Rangeland Ecology and Management* **61**, 169–181.

Rego FC (1986) Effects of prescribed fire on vegetation and soil properties in Pinus pinaster forests of Northern Portugal. PhD thesis, University of Idaho, Moscow.

Serviços Geológicos de Portugal (1961) 'Carta Geológica de Portugal, Notícia explicativa de Caminha. Lisboa'.

Siegel, Castellan (1988) 'Nonparametric Statistics for the Behavioral Sciences'. 2nd edition. (New York: McGraw–Hill).