Short term spatio-temporal variability of soil water extractable Al and Zn after a low severity grassland fire in Lithuania

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Introduction

Combustion causes the mineralization of soil organic matter and litter, increasing the availability of nutrients for plant uptake and leaching (Neary et al., 1999; Certini, 2003; Pereira et al., 2011). Depending on fire severity, fire intensity, ecosystem and vegetation affected, soil type, slope, aspect and post-fire rainfall, fire can cause changes in soil properties in space and time (Certini, 2005; Úbeda and Outeiro, 2006). Due the increase of pH, the solubility of major cations is favored immediately after fire, especially due the redistribution of ash and charred material on the soil surface and into the soil profile (Lewis, 1974; Ludwig et al., 1998; Murphy et al., 2006). Generally, the increase of pH favours the immobilization of micro-nutrients, which are also present in important quantities in ash and charred material (Pereira & Úbeda, 2010; Pereira et al., 2010a; Marañón-Jiménez et al., 2013). Due to different conditions of burning (e.g.: type and density of vegetation, moisture, slope and aspect) fire severity is very heterogeneous and the impacts on soil can be highly variable (Keeley, 2009; Knapp & Keeley, 2006). Redistribution processes are also very important in grassland fires, where tree cover is virtually zero (Pereira et al., 2013b). This temporal redistribution can have implications on soil properties, soil erosion and different uptake rates of nutrients by plants (Doerr et al., 2006; Lasanta & Cerdà, 2005; Pereira et al., 2010a; Pereira et al., 2010b). Consequently, studying the spatial and temporal distribution of soil nutrients in the post-fire period is necessary for the evaluation of fire-affected soils. Distribution of nutrients after fire can be assessed with data interpolation techniques. The aim of this work is to study the spatio-temporal impact of a low-severity grassland fire on soil water extractable Al and Zn.

Methodology

Study area, sampling, statistical analysis , laboratory analysis and statistical and spatial distributiona analysis

The study area it is located near Vilnius city (54° 42' N, 25° 08 E, 158 masl). This area was affected by a wildfire by 15th April 2011 due human negligence in an abandoned agricultural area, converted to grassland. Fire severity was low, as observed by the presence of unburned patches and high cover of black ash on the soil surface. Three days after burning, a flat area of 400 m2 (20 × 20 m) in the burned and in a adjacent control area were selected for this study (Pereira et al., 2012; Figure 1a). Soil samples were collected immediately after the fire, 2, 5, 7 and 9 months after the fire in 25 points regularly distributed, selected according to the grid shown in Figure 1b.

Descriptive statistics (mean, standard deviation - SD - and coefficient of variation - CV%) were analysed. Prior to statistical and spatial analysis, data normality and homogeneity of variances were tested with the Shapiro-wilk and Levene's test respectively. Data were transformed with the Neperian-logarithm (ln) function to fit the requirements of the normal distribution. In order to identify spatial and temporal differences between plots a Repeated Measures ANOVA was carried out (significant differences were considered at *$p<0.05$). When significant differences were found, pos-hoc comparisons were carried out (Tukey HSD post hoc test).* In order to identify the best spatial predictor several well-known interpolation methods were tested previously to data interpolation: ordinary kriging and other deterministic methods as inverse distance weighted (IDW) raisen to 1, 2, 3 and 4, radial basis functions (inverse multiquadratic, multilog, muitiquadratic, natural cubic spline and thin plate spline) and first and second order local polynomials. Further information about the described interpolation methods can be found in Pereira & Úbeda (2010) and Pereira et al. (2010a). The best interpolation method was identified using the cross-validation procedure. Cross validation was obtained by comparing the value from each sampling point with the estimated one. The errors produced allowed us to calculate the mean error (ME) and the root mean square error (RMSE). The most accurate interpolation method was the one with lower RMSE (Pereira et al., 2013a). Finally, data were calculated using the best interpolation method. Comparisons of data were calculated using Statistica 7.0 (Statsoft Inc., 2007) and interpolations were carried out using Surfer 9.0 (Golden Software).

Results

Table 1. Descriptive statistics of soil water-extractable Al and Zn in control and burned plots. Different letters following mean values denote significant differences among periods (upper case) and between treatments (lower case) at a *$p<0.05$. $N=25$*.

Period	Treatment	Soil water-extractable Al			Soil water-extractable Zn		
		Mean	SD	CV%	Mean	SD	CV%
After the fire	Control	1.93 Ba	1.59	82.38	0.23 Aa	0.19	82.60
	Burned	1.40 Ba	1.26	90.00	0.22 Aa	0.15	68.18
2 Months	Control	4.81 Aa	1.95	40.54	0.25 Aa	0.14	56
	Burned	4.04 Aa	2.84	70.29	0.16 Aa	0.09	56.25
5 Months	Control	0.68 Ca	0.35	51.47	0.05 Ba	0.02	40
	Burned	0.73 Ca	0.28	38.35	0.03 Bb	0.02	66.66
7 Months	Control	1.08 Ba	0.45	41.66	0.02 Ca	0.01	50
	Burned	1.15 Ba	0.48	41.73	0.02 Ca	0.01	50
9 Months	Control	3.12 Aa	1.40	44.72	0.21 Aa	0.06	28.57
	Burned	3.10 Aa	1.35	43.54	0.13 Ab	0.05	38.46

Table 2. Assessment of interpolation methods for calculation of the distribution of soil water-extractable Al in the control area. RMSE values immediately after fire, 2, 5, 7 and 9 months after fire. The most accurate method is marked with an asterisk (*).

Method	Type	Immediately after fire	2 months	5 months	7 months	9 months
KRG	Ordinary (Point)	0.489	0.560	0.550	0.355	0.433
IDW	Power (1)	0.54	0.491*	0.456	0.456	0.420
	Power (2)	0.517	0.497	0.455*	0.415	0.403
	Power (3)	0.505	0.509	0.474	0.391	0.399*
	Power (4)	0.500	0.519	0.495	0.378	0.400
RBF	Inverse multiquadratic	0.527	0.536	0.458	0.420	0.412
	Multilog	0.469	0.580	0.522	0.349	0.418
	Multiquadratic	0.505	0.580	0.593	0.349	0.443
	Natural cubic spline	0.639	0.759	0.896	0.360	0.538
	Thin plate spline	0.545	0.664	0.719	0.343*	0.481
LP	1	0.468	0.604	0.591	0.372	0.439
	2	0.463*	0.657	0.631	0.370	0.461

Table 3. Assessment of interpolation methods for calculation of the distribution of soil water-extractable Al in the burnt area. RMSE values immediately after fire, 2, 5, 7 and 9 months after fire. The most accurate method is marked with an asterisk (*).

Method	Type	Immediately after fire	2 months	5 months	7 months	9 months
KRG	Ordinary (Point)	0.644	0.516	0.450	0.404	0.452
IDW	Power (1)	0.588*	0.571	0.424	0.404	0.389*
	Power (2)	0.594	0.541	0.422*	0.378	0.401
	Power (3)	0.598	0.524	0.425	0.374*	0.412
	Power (4)	0.599	0.519	0.429	0.379	0.421
RBF	Inverse multiquadratic	0.593	0.536	0.423	0.383	0.400
	Multilog	0.654	0.515*	0.438	0.399	0.430
	Multiquadratic	0.641	0.524	0.623	0.425	0.466
	Natural cubic spline	0.645	0.627	0.526	0.568	0.557
	Thin plate spline	0.640	0.563	0.518	0.483	0.504
LP	1	0.650	0.596	0.470	0.388	0.456
	2	0.641	0.593	0.501	0.400	0.464

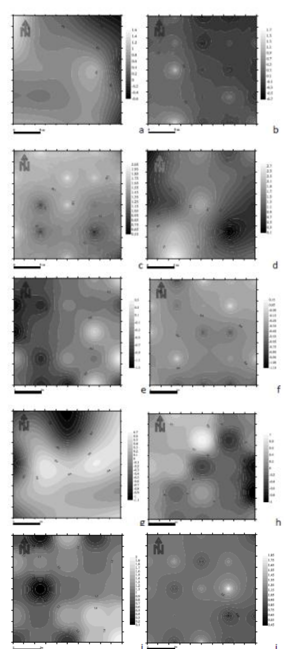


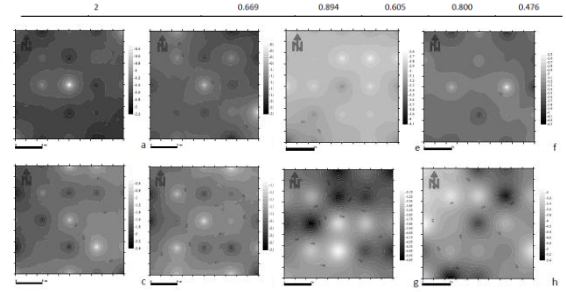
Figure 1. Soil water-extractable Al spatial distribution after the fire: a) unburnt area immediately after fire; b) burnt area immediately after fire; unburnt area 2 months after fire; c) burnt area 2 months afterbfire; d) unburnt area 2 months after fire; e) burnt area 5 months after fire; f) unburnt area 5 months after fire; g) burnt area 7 months after fire; h) unburnt area 7 months after fire; i) burnt area 9 months after fire; j) unburnt area 9 months after fire.

Table 4. Assessment of interpolation methods for calculation of the distribution of soil water-extractable Zn in the control area. RMSE values immediately after fire, 2, 5, 7 and 9 months after fire. The most accurate method is marked with an asterisk (*).

Method	Type	Immediately after fire	2 months	5 months	7 months	9 months
KRG	Ordinary (Point)	0.703	0.739	0.383	0.429	0.366
IDW	Power (1)	0.538*	0.586*	0.355*	0.407	0.309*
	Power (2)	0.563	0.609	0.357	0.402*	0.319
	Power (3)	0.595	0.641	0.361	0.403	0.33
	Power (4)	0.625	0.671	0.366	0.405	0.339
RBF	Inverse multiquadratic	0.567	0.615	0.357	0.403	0.317
	Multilog	0.659	0.704	0.382	0.411	0.353
	Multiquadratic	0.777	0.815	0.396	0.436	0.373
	Natural cubic spline	1.227	1.329	0.492	0.475	0.431
	Thin plate spline	0.971	1.016	0.434	0.458	0.4
LP	1	0.659	0.641	0.38	0.439	0.396
	2	0.737	0.711	0.4	0.454	0.41

Table 5. Assessment of interpolation methods for calculation of the distribution of soil water-extractable Zn in the burnt area. RMSE values immediately after fire, 2, 5, 7 and 9 months after fire. The most accurate method is marked with an asterisk (*).

Method	Type	Immediately after fire	2 months	5 months	7 months	9 months
KRG	Ordinary (Point)	0.665	0.792	0.587	0.719	0.466
IDW	Power (1)	0.564*	0.623*	0.478*	0.632	0.377*
	Power (2)	0.580	0.650	0.497	0.623*	0.396
	Power (3)	0.598	0.682	0.517	0.635	0.416
	Power (4)	0.614	0.712	0.534	0.657	0.432
RBF	Inverse multiquadratic	0.583	0.653	0.495	0.626	0.396
	Multilog	0.684	0.746	0.554	0.676	0.438
	Multiquadratic	0.701	0.854	0.610	0.789	0.494
	Natural cubic spline	0.909	1.231	0.701	1.222	0.668
	Thin plate spline	0.789	1.030	0.670	0.983	0.569
LP	1	0.643	0.793	0.593	0.728	0.447
	2	0.669	0.894	0.605	0.800	0.476



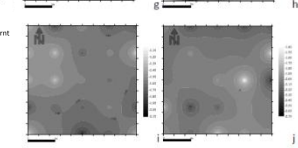


Figure 2. Soil water-extractable Fe spatial distribution after the fire: a) unburnt area immediately after fire; b) burnt area immediately after fire; unburnt area 2 months after fire; c) burnt area 2 months afterbfire; d) unburnt area 2 months after fire; e) burnt area 5 months after fire; f) unburnt area 5 months after fire; g) burnt area 7 months after fire; h) unburnt area 7 months after fire; i) burnt area 9 months after fire; j) unburnt area 9 months after fire.

Conclusions

Fire did not have implications on the distribution of soil water-extractable Al. In relation to soil water-extractable Zn significant differences were observed 5 and 9 months after the fire. The temporal variability of water-extractable Zn may be attributed to the natural seasonal variability of soil nutrients.

The spatial variability in both plots was enhanced by fire, and decreased through the post-fire period. The most accurate interpolation method was IDW in the majority of the cases, especially in soil water-extractable Zn. These differences might be due plant nutrients demand and different rates of soil water infiltration.

Acknowledgments

The authors are grateful to the projects, CGL2007-28764-E/BTE CGL2008-01632-E/BTE y CGL2009-06861-E/BTE, that funded FUEGORED (Spanish Network Fire Effects on Soils), to the Lithuanian research council for financing the project LITFIRE, Fire Effects on Lithuanian Soils and Ecosystems (MIP-48/2011), to the HYDFIRE Project (CGL2010-21670-C02-01) and to the *Comissionat per a Universitats i Recerca del DIUE de la Generalitat de Catalunya and to Dzukija National Park Staff.*

*Please consult references in the full paper published in Flamma