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Trace Elements Content in Soils from the Pine Forests of Western Transbaikal after Low Fires

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Abstract

Study of the impact of forest fires on ecosystems pine forests of the Western Transbaikalia is of great importance due to the large environmental damage to their functioning. The pyrogenic transformation of the microelement content in soils and plants from western Transbaikal (Republic of Buryatia) has been studied. As is found, ground fires, under the studied conditions, lead to the transformation of soil properties and slightly elevated concentrations of Mn, Zn, Cu, and Pb in the surface soil (0–40 cm). It has been also found that the soil Fe: Mn ratio becomes lower. A pyrogenic transformation of the soil properties, the elemental composition in particular, is shown to be traced over several years after the fire.

Keywords: Trace Elements, Soil, Pine Forests, Low Fire.

Introduction

Surface fires that drastically transform forest ecosystems also cause environmental pollution. This, in turn, results in both ecological and economic damage (Kondratyev and Grigoryev, 2003). Over the last decade, catastrophic fires in Siberia that annually devastate thousands of hectares (1 h (ga) = 2.5 acres) of forest have became far more frequent. Krasnoyarsk and Zabaykalsky krai, Irkutsk oblast, the Republic of Tuva, and the Republic of Buryatia, which are located in the Siberian Federal District, are amongst the regions which most suffer from fires (Bryukhanov, 2009). In 2008, according to Rosstat data, forest fires occurred on 466.3 ha in the Siberian Federal District. In 2009, 2010, and 2011, this area was 432, 172.6, and 572.4 ha, respectively. The Republic of Buryatia had 1265 forest fires in 2008, 1331 in 2009, 686 in 2010, and 1334 in 2011, devastating 9800, 197000, 30400, and 79 300 ha of forest (Okhrana…, 2010; Federal…). Climate change is one of the reasons for frequent forest fires, because global warming leads to more and more risk of fires (Kondratyev and Grigoryev, 2003).

The influence of forest fires on natural ecosystems is multifactorial and complex. First and foremost, the natural equilibrium between separate components of the forest ecosystems is destroyed in fire. Forest fires also affect, in a multidimensional way, soil as an imminent part of the forest community. Any fire leads to the transformation of chemical and biological properties of soil. How strong the impact of the pyrogenic factor is, as well as how quickly the soil system is recovered, depends on the type of forest fire, fire intensity, and the ecological stability of the forest community in general and its components in particular (Maksimova, 2011; Burlakova et al., 2002).

Fires affect vegetation to form its mosaic and multiple-aged structure and temporarily decrease ecological diversity (Maksimova, 2011). Obviously, this leads to changes in the concentration of trace elements, because plants, in general, reflect the chemical composition of the environment where they grow and develop.

The area we studied is located in the basin of Lake Baikal. The influence of fires on the soil-formation process is the most thoroughly investigated in this area (Krasnoshchekov, 2009; Shcherbov et al., 2008; Gyninova and D. P. Sympilova, 1999).

For this reason, finding out how the forest fires affect ecosystems is of special interest.

The aim of this work is to study the influence of the surface fires on the content of trace elements (ME) in the forest soils.

1. Objects and Methods

In this study we investigated the soddy-podbur soils of the west side of the Tsagan-Daban crest (Tarbagataiskii raion, Republic of Buryatia) together with the vegetation that was associated with them. The soils in question were located beneath the burns of different time periods. Because in this area there is almost no place without traces of fire, a site 65- to 67-km from the sample area was taken as the control.

Sample plots were established in the deluvial part of slopes at an altitude of 637–761 m:

P. 1-08 dead pine forest affected by the surface fire of the mean intensity in 2008; projective cover of the herbaceous layer 10%; h 761 m; coordinates: 51°37'510" N 107°51'183" E;

P. 3-08 grass–herb pine forest affected by the surface fire of the mean intensity in 2005; projective cover of the herbaceous layer 15%; h 637 m; coordinates: 51°44'070" N, 107°47'863" E;

P. 2-09 scarce-herb pine forest affected by surface fire in 2000; projective cover of the herbaceous layer 10 to12%; h 653 m; smoothed site of the low part of train; coordinates: 51°44'310" N, 107°49'372" E;

P. 2-08 Rhododendron–herb pine forest affected by the surface fire of the mean intensity in 1998; projective cover of the herbaceous layer 7 to10%; h 671 m; coordinates 50°40'753" N, 107°48'072" E;

P. 1-09 dead pine forest (recent burn) affected by the surface fire of the mean intensity in 2009; herbaceous cover is completely destroyed; h 655 m; coordinates: 51°43'980" N, 107°49'068" E;

P. 6-07 dead pine forest; projective cover 10%; 700–800 m from the Khilok River (right bank) to the southeast; deluvial train of the southwestern side of the Stanichnii crest; surface fire of the mean intensity in 2000;

P. 7-07 (control) 50 m north of the P. 6-07 sample plot; grass Astragalus dead pine forest; projective cover 15 to 20%.

The investigated area is included in the Selenginskii District of the Transbaikal pyrogenic region (Sofronov et al, 1999). The surface fires of different intensities that occur in this area are the most frequent. The time period and the intensity of fires were determined according to the height of the fire traces left on the trunks, the degree of crown damage, and the burn completeness of the other forest fuel materials (Vakurov, 1975). The data of the forest fire maps and the forest service were also included.

Physical and physicochemical soil properties were studied according to the generally accepted soil-science methods (Agrochemical Methods, 1975). The total ME content and the iron content were determined by the atomic absorption method using the AAnalist 400 (PerkinElmer) instrument after the preliminary dissociation of the ME by the mixture of acids. The liable ME forms were determined after extraction in the acetic-ammonia buffer (pH 4.8).

2. Results and Discussion

The studied soils are characterized by slightly acidic or neutral pH, a low content of humus, and a light granulometric texture (Sosorova, 2010). The main consequences of the postpyrogenic transformation of the morphological, physicochemical, and chemical properties of soils are discussed elsewhere (Shakhmatova, 2011a; 2011b).

Our results showed that the most intensive transformation occurs in the upper soil horizons where a new short organogenic pyrogenic horizon (YApir) is formed. This horizon differs from the natural ones by its chemical and physicochemical properties. Depending on the fire intensity, all the forest litter may be destroyed, as well as, sometimes, part of the litter – humic-accumulating horizon (OAY), which is consistent with the data of other authors (Burlakova, 2002; Sapozhnikov, 2001; Krasnoshchekov, 2010). Burning of the litter and the living soil cover leads to a release of a large amount of ash constituents. Moreover, fires lead not only to the burning out of vegetation and dead parts of plants, but also to the influence of high temperatures on the organogenic soil horizon. This results in the transformation of physical and chemical properties of soil. According to previous studies (Shakhmatova, 2011a), a decrease in soil moisture and an increase in the soil unit weight are observed. The same was true for the pyrogenic burozems of the Amur value (Nazarkina, 2009). Other authors (Tarabukina and Savinov, 1990) have found that the pyrogenic impact led to a decrease in the soil acidity in the upper horizons, an increase in the content of potassium and labile elements in plants, and an increase in both the specific and unit weights (Tsvetkov, 2006). This is consistent with our data and the data of E.Yu. Shakhmatova (Shakhmatova, 2011a, 2011b). As was noted earlier, these changes obviously affect the content of trace elements in both soil and the plants that grow in this soil.

The transformation of the chemical content of soils, including trace elements, depends on the fire intensity and ecological conditions. As was observed (Krasnoshchekov, 2009), the fires of the intermediate and high intensities result in a considerable increase in the content of chemical elements in the organo-pyrogenic horizon of the gray-humic soils which, in turn, leads to the enrichment of this horizon in Zn, Co, Cd, and Pb. At the same time, the amount of Cu and Ni is decreased. In the "band" pine forests located in the subarid forest steppes of Altai Krai, the content of Pb and Cd in the litter ash is slightly increased (Bakhareva, 2009).

As was found in this study, forest fires lead to an increase in the ME content in the upper soil layer (0–40 cm deep (Table 1). In the first postpyrogenic year, the total content of Mn, Zn, Cu, Ni, Cr, Pb, and Cd is observed to be increased 1.2- to 2- fold in the upper (0–50 cm deep) soil layer (in the litter and, in part, in the humus horizon) as compared to the lower horizons and control. The ME contents in the lower horizons are similar. It should be noted that the concentration of manganese is significantly increased in the pyrogenic horizons. In the following years, the ME are distributed according to the soil profile, which is a result of the soil formation and the ME washout, which depends on the chemical and physical erosion. The total content of Mn, Zn, Cu, Ni, and Pb was increased and the total content of Cr and Cd was decreased within a year after the fire in the upper soil layer (0–50 cm deep). We found also that, during the first postpyrogenic year, the Fe : Mn ratio (Table 1) became lower because of the elevation of the total content of Mn. Within five post-pyrogenic years (p. 3-08) the content of Mn, Zn, and Cu is still relatively high in the 0- to- 1-cm-deep soil layer compared with the soil-forming rocks and other horizons. After 8–10 years (p. 2-08 and p. 2-09), both the content of MEs and their profile distribution approach the initial state. The total ME content does not exceed the maximum allowable concentration (MAC) (Sokolov, 1999).

Table 1: The total content of trace elements in soddy podbur soils
(mg/kg of air dried substance)

Horizon, depth (cm)	Fe, %	Mn	Zn	Cu	Co	Ni	Cr	Pb	Cd	$\frac{\text{Fe}}{\text{Mn}}$
P. 1–08, herb pine forest. Low fire, 2008. In the year of the fire										
O, 0–1	1.40	785	66.7	10.4	17.3	23.0	90.7	32.1	1.7	17.8
AYpir, 1–5	1.17	684	37.8	6.0	16.8	20.8	85.9	29.2	1.7	17.1
BF1, 5–27	1.74	262	31.0	8.5	19.6	24.4	100.7	28.3	1.6	66.4
BF2, 27–38	1.56	252	24.8	7.6	19.0	19.6	92.0	20.6	1.6	61.9
BC, 38–112	1.01	292	17.8	5.3	18.0	13.0	84.3	24.9	1.5	34.6
C, 112–120	0.98	216	19.3	4.3	14.2	8.9	74.8	21.0	1.4	45.4
Pl–08, 0–20	–	496	34.1	3.4	15.7	22.3	100.9	37.1	1.8	–
P. 1–08, herb pine forest (repeat, June 30, 2009). 1 year after the fire										
BF1, 5–27	2.53	344	34.4	7.9	18.7	24.0	75.6	32.9	1.1	73.5
BF2, 27–38	2.55	267	29.4	10.6	21.2	23.3	86.2	36.5	1.3	95.5
BC, 38–112	1.68	239	25.8	7.1	15.2	17.9	58.5	33.5	1.8	70.3
P. 3–08, grass–herb pine forest. Low fire, 2003. 5 years after the fire										
O, 0–1	1.64	684	111.4	12.3	18.8	16.7	115.8	29.7	1.2	24.0
AYBF, 1–8	1.62	660	51.9	7.7	20.2	15.4	118.0	29.0	1.4	24.5
BF, 8–40	1.67	258	38.9	7.5	19.6	14.1	115.0	27.0	1.3	64.7
BC, 40–55	1.29	235	21.8	5.4	19.6	11.3	92.4	33.7	1.2	54.9
C, 55–98	0.87	179	21.1	4.5	15.8	10.5	72.1	29.8	1.0	48.6
P. 2–09, rhododendron–herb pine forest, Fire 2001. 8 years after the fire										
O, 0–1.5	1.17	385	54.5	10.3	16.2	10.8	76.8	36.8	1.5	30.4
AY, 1.5–4	1.28	326	37.9	7.4	14.8	16.1	89.6	33.1	1.6	39.3
BC, 4–7/9	1.40	259	32.2	7.4	15.3	16.7	86.1	32.3	1.3	54.1
AY1 buried, 7/9–14	2.09	472		10.6	17.4	23.4	100.8	33.5	1.5	44.3
BFI, 14–24	1.35	265	37.4	7.2	16.8	24.4	99.5	32.7	1.4	51.0
BF2, 24–42	1.22	296	39.4	8.0	14.7	24.7	107.2	31.4	1.4	41.2
BF3, 42–56	1.50	266	30.3	7.5	19.4	23.4	90.0	41.2	1.4	56.4
AY2pir buried, 56–68	2.13	270	33.1	7.9	19.8	22.0	79.9	36.3	1.4	78.9
BC,68–93	1.50	238	28.0	7.0	17.6	18.9	69.6	36.8	1.2	53.2
C, 93–102	2.08	282	30.2	7.3	17.7	17.4	75.0	36.8	1.3	73.8
P. 2–08, rhododendron–herb pine forest. Low fire, 1998. 10 years after the fire										
O, 0–1	1.29	442	44.9	7.9	17.1	19.9	86.5	27.2	1.4	29.2
AYpir, 1–4	1.30	454	52.9	7.6	17.9	21.0	98.7	28.8	1.6	28.6
BFi, 4–24	1.28	302	34.2	7.1	21.2	20.5	110.8	24.5	1.5	42.4
	1.91	295	41.2	9.0	20.9	21.2	116.4	31.8	1.5	64.7

CI, 35–50	0.97	222	17.4	5.7	16.5	11.6	90.0	25.8	1.3	43.7
C2, 50–63	0.93	203	15.6	5.2	17.0	10.7	82.0	23.2	1.3	45.8
C3, 63–97	0.92	191	13.3	5.4	16.0	5.8	79.8	20.3	1.1	48.2
P. 1–09, dead pine forest. Low fire, 2008. 1 years after the fire										
O, 0–1	1.23	876	113.9	12.9	18.1	21.8	85.0	42.0	1.1	14.0
AYpir, 1.5–4/5	1.55	914	261.4	6.9	18.2	23.0	87.7	49.6	1.2	17.0
ABF1, 4/5–20	1.30	219	28.4	4.9	17.1	15.8	84.0	25.0	0.8	59.4
BFI, 20–40	1.25	201	27.6	5.8	16.5	17.4	84.2	28.3	0.9	62.2
CI, 40–59	1.04	175	29.8	5.0	15.7	11.1	71.1	34.1	0.6	59.4
C2, 59–100	1.24	234	16.3	5.5	16.6	12.9	81.0	35.9	0.8	53.0
P. 6–07, dead pine forest. Low fire, 2000. 7 years after the fire										
O, 0–2	2.77	945	29.9	13.3	20.8	15.3	66.8	26.0	1.0	29.3
AYpir, 2–10	2.85	779	39.3	9.8	18.9	12.2	60.7	23.7	0.8	36.6
B, 10–38	2.72	497	34.5	11.2	18.4	12.2	61.2	23.8	1.3	54.7
BC, 38–80	2.74	667	36.2	9.7	16.9	12.9	58.1	24.2	1.3	41.1
		P. 7–07, dead pine forest (control)								
O, 0–2	2.13	498	34.0	7.3	13.4	8.1	52.6	22.9	1.3	42.8
AY, 2–3/19	2.48	742	37.4	9.5	16.1	9.9	55.8	25.0	1.4	33.4
B, 13/19–36	2.75	561	35.5	9.6	15.3	12.6	59.8	24.8	1.8	49.0
BC, 36–70	3.34	618	37.4	10.2	13.3	13.9	62.5	27.9	1.3	54.0
MAC, OAC [30]	–	1500	110	23	50	35	–	32	5.0	

In general there was no significant pyrogenic transformation of the ME composition in the studied soils. This seems to follow from the fact that the basic features of the content and profile distribution of the chemical elements result from the soil-forming rocks. The soil formation affects them, specifically manifested as biogenic accumulation and both the physicochemical and mechanical migration of elements. This manifestation, in turn, depends on the climatic, geo- morphological, landscape–geochemical, and other features of the specific area (Syso, 2007). Also, both time and fire intensity affect the MEs content in the pyrogenic soils.

Since different groups of the MEs and heavy metals (HMs) are characterized differently in the pyrogenic soils, their content and distribution cannot be described unambiguously [щербов 15]. According to these authors, Cd, Pb, and Hg migrate from the soil-vegetation cover the most quickly.

The HM labile forms are the most dangerous because they are biochemically active and can be accumulated in living organisms (Egoshina and Shikhova, 2008).

The results of an analysis of the labile ME forms are shown in Table 2. The highest concentration of the labile ME forms was found in the 0–40 cm deep layer, which is consistent with their total content. The liability of Mn, Co, Cr, Pb, and Cd decreases with depth. In general, the abundance of the labile forms of Zn, Cu, and Co in the studied soils is evaluated as low (according to the scale published in (Aleksandrova, 2001), while the abundance of Mn is high.

The content of the labile forms of elements in the studied soils is significantly lower than MAC according to some authors (Aleksandrova, 2001; Methodological Recommendations, 1999) and they belong to group I (no contamination), taking into account the scale for soil grouping, which is used to ecologically and toxically evaluate soils (Methodological Recommendations, 2003). On the one hand, this evidences in favor of the good state of soils. However, on the other hand, the data suggest a low abundance of labile forms of elements in plants and, respectively, high sensitivity of soils to farming, clear cutting, and fires, when the chemical elements are removed from the soil–plant system.

As early as within the first postpyrogenic year, the liability of Mn, Zn, Ni, Co, Cr, and Cd is increased. As is shown in Table 2, fractions of the labile ME forms fluctuate between a trace amount and as much as 10%, with the exception of manganese (up to 33%). This suggests the absence of significant technogenic pressure on the studied area. It is thought that the fraction of the labile ME forms in non contaminated soils is 5–20% of their total amount (Vodyanitskii and Bol'shakov, 1998). In 2009, the soil liability of the MEs was higher than in 2008 because of the relatively high soil humidity in that period.

Table 2: The content of liable forms of heavy metals in the soddy podbur soils (mg/kg)

Horizon, depth (cm)	Mn		Zn		Cu		Co		Ni		Cr		Pb		Cd	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
P. 1–08, herb pine forest. Low fire, 2008. In the year of the fire																
0,0–1	153.3	19.5	3.25	4.9	0.23	2.2	0.66	3.8	0.16	0.7	1.70	1.9	1.29	4.0	0.06	3.5
AYpir, 1–5	187.7	27.4	3.22	8.5	0.11	1.8	0.47	2.8	0.17	0.8	1.51	1.8	1.15	3.9	0.05	2.9
BF1, 5–27	20.3	8.0	0.43	1.4	0.15	1.8	0.57	2.9	0.10	0.4	1.49	1.6	1.39	4.9	–	–
BF2,27–38	13.9	5.5	1.39	5.6	0.24	3.1	0.48	2.7	0.04	0.2	0.63	0.7	1.20	5.8	–	–
BC, 38–112	6.0	2.0	0.88	4.9	0.26	4.9	0.10	0.5	0.06	0.5	0.46	0.6	0.69	2.8	–	–
C,112–120	1.8	0.8	1.47	7.6	0.25	5.8	0.17	1.2	–	–	–	–	0.68	2.5	0.01	0.7
P. 1–08, herb pine forest. Low fire, 2008 (repeat). 1 year after the fire																
BF1, 5–27	69.5	20.2	0.75	2.2	0.63	8.0	0.37	2.0	0.07	0.3	2.40	3.2	1.35	4.1	0.01	0.9
BF2,27–38	25.8	9.7	5.01	17.1	1.18	11.1	0.63	3.0	0.15	0.6	1.31	1.5	1.54	4.2	0.02	1.5
BC, 38–112	9.6	4.0	0.69	2.7	0.90	12.7	0.17	1.1	0.04	0.2	0.70	1.2	1.05	3.1	0.01	0.5
P. 3–08, grass–herb pine forest. Low fire, 2003. 5 years after the fire																
BF1, 4–24	227.2	33.2	11.43	10.3	0.29	2.4	0.75	4.0	0.28	1.7	1.91	1.6	3.12	10.5	0.12	8.6
BF2,24–35	177.4	26.8	1.24	2.4	0.16	2.1	0.38	1.9	0.10	0.6	0.67	0.6	1.50	5.2	0.04	2.0
CI, 35–50	17.5	6.8	2.13	5.5	0.40	5.3	0.47	2.4	0.10	0.7	0.96	0.8	1.50	5.5	0.03	1.8
C2, 50–63	6.4	2.7	1.05	4.8	0.23	4.3	0.13	0.7	0.08	0.7	0.20	0.2	1.15	3.4	–	–
C3,63–97	4.2	2.3	0.50	2.4	0.25	5.6	0.11	0.7	0.07	0.7	–	–	0.87	2.9	–	–
P. 2–09, rhododendron–herb pine forest, Fire 2001. 8 years after the fire																
AY, 1.5–4	100.0	30.6	2.97	7.8	0.20	2.7	0.34	2.3	0.20	1.9	0.85	0.9	1.97	5.4	0.06	3.7
BC, 4–7/9	43.5	16.7	0.51	1.6	0.24	3.2	0.27	1.8	0.05	0.3	0.88	1.0	1.37	4.3	0.02	1.5
AY1 buried, 7/9–14	135.5	28.6	7.95	6.0	0.17	1.6	0.43	2.5	0.20	0.9	1.08	1.1	1.36	4.0	0.05	3.3
BF1,14–24	79.3	29.8	4.94	13.2	0.25	3.5	0.44	2.6	0.13	0.5	0.53	0.5	1.40	4.3	0.02	1.4
BF2,24–42	44.2	15.0	1.18	3.0	0.34	4.3	0.32	2.2	0.10	0.4	0.66	0.6	1.47	4.7	0.02	1.4
BF3, 42–56	18.0	6.7	3.86	12.7	0.41	5.5	0.21	1.1	0.14	0.6	0.15	0.2	1.27	3.1	0.02	1.4
AYl pir buried, 56–68	19.2	7.1	0.43	1.3	0.37	4.7	0.26	1.3	0.13	0.6	0.33	0.4	1.32	3.6	0.03	2.1
BC, 68–93	4.6	1.9	1.21	4.3	0.28	4.0	0.15	0.9	0.08	0.4	–	–	1.06	2.9	0.02	1.7
C, 93–102	12.5	4.4	0.45	1.5	0.35	4.8	0.26	1.5	0.06	0.3	–	–	1.13	3.1	0.02	1.5
P. 2–08, rhododendron–herb pine forest. Low fire, 1998. 10 years after the fire																
BF1, 4–24	34.2	11.3	0.58	1.3	0.41	5.8	0.12	0.6	0.18	0.9	1.30	1.2	1.08	4.4	0.01	0.7
BF2, 24–35	15.8	5.4	0.43	0.8	0.52	5.8	0.29	1.4	0.17	0.8	0.62	0.5	1.15	3.6	0.03	2.0
C–l, 35–50	4.9	2.2	0.35	1.0	0.27	4.7	0.14	0.8	0.05	0.4	0.61	0.7	0.84	3.3	0.03	2.3
C2,50–63	2.8	1.4	0.39	1.0	0.23	4.4	0.07	0.4	0.05	0.5	0.77	0.9	0.77	3.3	0.04	3.0
C3,63–97	1.7	0.9	0.59	4.4	0.22	4.1	0.08	0.5	0.05	0.9	1.10	1.4	0.74	3.6	–	–

P. l–09, dead pine forest. Low fire, 2008. 1 years after the fire																
AYpir, 1.5–4/5	223.4	24.4	4.81	1.8	0.21	3.0	0.67	3.7	0.30	1.3	1.50	1.7	1.85	3.7	0.10	8.3
ABF1,4/5–20	22.2	10.1	0.56	2.0	0.24	4.9	0.48	2.8	0.09	0.6	0.92	1.1	1.31	5.2	0.02	2.5
BF1,20–40	9.7	4.8	0.32	1.1	0.38	6.6	0.46	2.8	0.06	0.3	0.96	1.1	1.46	5.2	0.01	1.1
CI, 40–59	2.1	1.2	0.30	1.0	0.21	4.2	0.11	0.7	0.10	0.9	0.81	1.1	1.02	3.0	0.01	1.7
C2, 59–100	1.6	0.7	0.31	1.9	0.15	2.7	0.15	0.9	0.17	1.3	0.50	0.6	0.99	2.8	–	–
MAC, [33, 34]	140		23.0		3.0		5.0		4.0		6.0		6.0		0.2	

(1) liable form, (2) percentage of the total content, and (–) not found.

Thus, the soils in question have a low total content of MEs, including their labile forms, which depends on the elemental composition of the underlying acidic rocks, specific soil genesis, climate, and soil physico-chemical properties.

Conclusions

(1) The studied soils have a low content of trace elements and their liable forms. As was found, forest low fires lead to an inconsiderable total increase in the liable forms of Mn, Zn, Cu, and Pb in the soil layer at a depth of 0–40 cm. Also, the Fe: Mn ratio is decreased in soil.

(2) Our study showed that the pyrogenic transformation of the soil properties, the elemental composition in particular, is observed over a few years after fire.

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