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EFFECT OF FIRE ON SOIL NUTRIENT AVAILABILITY IN FORESTES OF GUILAN, NORTH OF IRAN

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Abstract: Fires are happened in the many forests locating in north of Iran, annually. Fires have changed some chemical properties in soils during the combustion process. Hence, this study has focused on Effect of fire on soil nutrient availability. Soil samples were collected from three depths (0-3, 3-6 and 6-9 cm) under the forest floor one month after the fire in three forests (Pilimbra, Lakan and Saravan). These areas are covered by pine trees (*pinus taeda*). Results of this study indicated that the fire significantly increased sand, pH, EC and BS while significantly decreased clay, organic carbon and CEC in comparison with unburned soil. Significant effect of fire limited to first and second depth and decreased with increasing of depth. Furthermore, the fire significantly increased soluble K, Ca, Mg, exchangeable K and available P. Effects of the fire on soil micronutrient was limited to available (DTPA extractable), iron and it had not significant effect on other micronutrient. Overall, fire effects on soil were directly related to the depth of burn and the surface layer had most significant difference between burned and unburned soils. Higher availability of nutrients in the soil during fire may be associated with the addition of ash.

Keywords: Burned soil, Exchangeable cations, Forest fires, Soil micronutrient.

1. INTRODUCTION

The most significant changes in chemical properties of the surface soils are likely to result from the addition of ash and partially burned material (Certini, 2005; Murphy et al., 2006). When the vegetation and surface litter are burned, ash usually provides an increase in the pH of soil, as well as an increase in nutrients available to plants (Knoepp et al., 2008).

Wildfire can dramatically alter the concentrations, forms, and depth distribution of nutrients in soils (Neff et al., 2005). After a fire, there is an increase of available nutrients in soil, mainly in the form of water-soluble components of ash (Pyne, 2001). The availability of nutrients generally is increased by the combustion of soil organic matter and the increase is strictly depended upon type of nutrient, burnt tree species, soil properties, and pathway of leaching processes (Kutiel & Shaviv, 1992). One month after a wildfire, available Ca, Mg, and K in the soil of a Q. rubra *Populus grandidentata* forest was significantly higher than pre-fire levels, but after further 3 months the increases were almost gone (Adams & Boyle, 1980). Niemeyer et al., (2005) were reported that the distinct increase in leaching of Ca might be due to the high Ca concentrations in the ash. High amounts of Ca mobilised after burning remain unused by the regenerating vegetation, and thus were to be found to a high proportion in the leachate. Responses of available soil P to burning are variable and more difficult to predict than those of other nutrients (Raison et al., 1990). Phosphorus volatilizes at temperatures of about 1,418 °F (770 °C) (Certini, 2005). The results of some studies (Serrasolsas & Khanna, 1995; Ross et al., 1997; Giardina & Rhoades, 2001) showed that available P increased in surface layer of soil.

Effects of fires on soil can vary greatly among different ecosystems depending on the severity (a combination of fire line intensity and duration according to Keeley, 2009) and frequency of fires. Volatilization of nitrogen and destruction of organic matter occur above 200°C, but temperatures higher than 760°C need to volatilize phosphorus and potassium, and even higher, above 1000°C, to volatilize calcium and magnesium (DeBano, 1990).

Fires in the north of Iran normally occur in autumn when forest floor litter dries as hot-dry winds cause a short period of drought. These are mostly surface fires that rarely exceed 10–30 cm in flame height under normal fuel and humidity conditions (Banj Shafiei et al., 2010). The main purpose of this research was investigating short-term impacts of wildfire on soil nutrient and micronutrient of three forest soils under pine trees (*pinus taeda*) in Guilan province, north of Iran.

2. MATERIALS AND METHODS

2.1. Field description and soil sampling

This study was conducted within three artificial forests in Guilan province, the north of Iran. The studied areas in Lakan area, lying between 37° 10´ northern latitude and 49° 35´ eastern longitude, Saravan area lying between 37° 6´ northern latitude and 49° 39´ eastern longitude and Pilimbra area lying between 37° 35´ northern latitude and 49° 4´ eastern longitude (Fig. 1). The areas are covered by pine trees (*Pinus taeda*). Fires happened during summer season (dates of 2ed and 3rd July in Lakan site, 10th July in Saravan site and 11th July in Pilimbra site in 2009 year). Abbreviated environmental information and classification of the studied sites are presented in Table 1. Based on soil sites were classified as Hapludalfs (USDA, 2010) and Luvisols (IUSS, 2006).

Mean annual precipitation at the nearest meteorological station (Rasht synoptic station for Lakan and Saravan areas and Pilimbra (Nehalestan) climatology station for Pilimbra area) is 1359 and 2045.4 mm for Lakan, Saravan and Pilimbra, respectively, without any dry season. Average of annual temperature is 16°C for Lakan and Saravan sites and 19°C for Pilimbra site, respectively. Average of annual relative humidity in percent are 81.5 and 82.5 in Lakan, Saravan and Pilimbra, respectively, and with high relative humidity especially in the summer (94 and 89 %). The soil moisture and temperature regimes are Udic and Thermic respectively. Soil sampling carried out closely from three depths (0-3, 3-6 and 6-9 cm) during summer season.

2.2. Laboratory analysis

After removing large stones, the soil samples were air-dried and passed through a 2 mm mesh sieve; then they were stored in paper bags prior to analyses. Particle size distribution was determined by the hydrometer method (Gee & Or, 2002). Soil pH was determined using a 1:1 (w/v) soil/water (Thomas, 1996). Electrical conductivity (EC) was determined in a saturation extract of soil using conductivity meter (Rhoades, 1996). Organic carbone (OC) was determinate according to the Walkley–Black wet oxidation method (Nelson & Sommers, 1996). Cation exchange capacity (CEC) was determined by saturation with 1 M ammonium acetate (NH_4OAc) at pH 7.0 (Sumner & Miller, 1996). Soluble and exchangeable cations (Ca, Mg, Na and K) were extracted using water and 1 M NH_4OAc (pH 7.0) and were determined by atomic absorption and flame emission spectrometer (Suarez, 1996; Helmke & Sparks, 1996). Available phosphorus by Olsen method (Kuo, 1996) and total nitrogen by Kjeldahl method (Bremner, 1996) were determined.

Micronutrient such as iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) were extracted by Diethylenetriaminepentaacetic acid (DTPA) extractor. Ultimately, all of them were measured by atomic absorption spectroscopy (Loeppert & Inskeep, 1996; Gambrell, 1996).

2.3. Statistical analysis

The experiment was performed as a 3×3×2 (sites × depths × fire status) factorial experiment in a randomized complete blocked design (RCBD), with three replications. Statistical analysis of data including normality test, analysis of variance, and comparisons of means was performed by using SAS program (SAS Institute, 2002). Comparison of means was carried out; using Tukey's Studentized Range (HSD) tests at $P<0.05$. Moreover, correlation coefficients between parameters were performed by using SPSS program (SPSS, 2007).

3. RESULTS

3.1. Effect of fire on soil properties

The results of analysis of variance (ANOVA) on texture and chemical characteristics such as pH, EC, OC, CEC and base saturation (BS) showed that studied sites had significant effect on all of characteristics expect BS. Furthermore, fire had significant effect on all of characteristics except silt content (Table 2). The results of comparison of mean for studied sites (Table 2) showed that Pilimbra site had maximum content of clay in comparison with other sites. Furthermore, Lakan site had maximum content of sand and EC, while Saravan site had maximum content of silt, pH, OC and CEC in comparison with other sites. In addition, fire significantly increased sand, pH and EC values and significantly decreased clay, OC and CEC values in comparison with unburned soil. Change of depth had significant effect on all of characteristics. Based on clay, pH, EC, OC, CEC and BS significantly decreased by depth, while silt and sand significantly decreased by depth (Table 2). The changes of sand in depths of burned and unburned soil showed that the maximum content of sand in the third depth (6-9 cm) in burned and unburned soils and minimum content of sand in the first depth (0-3 cm) in unburned soil were observed (Fig. 2a).

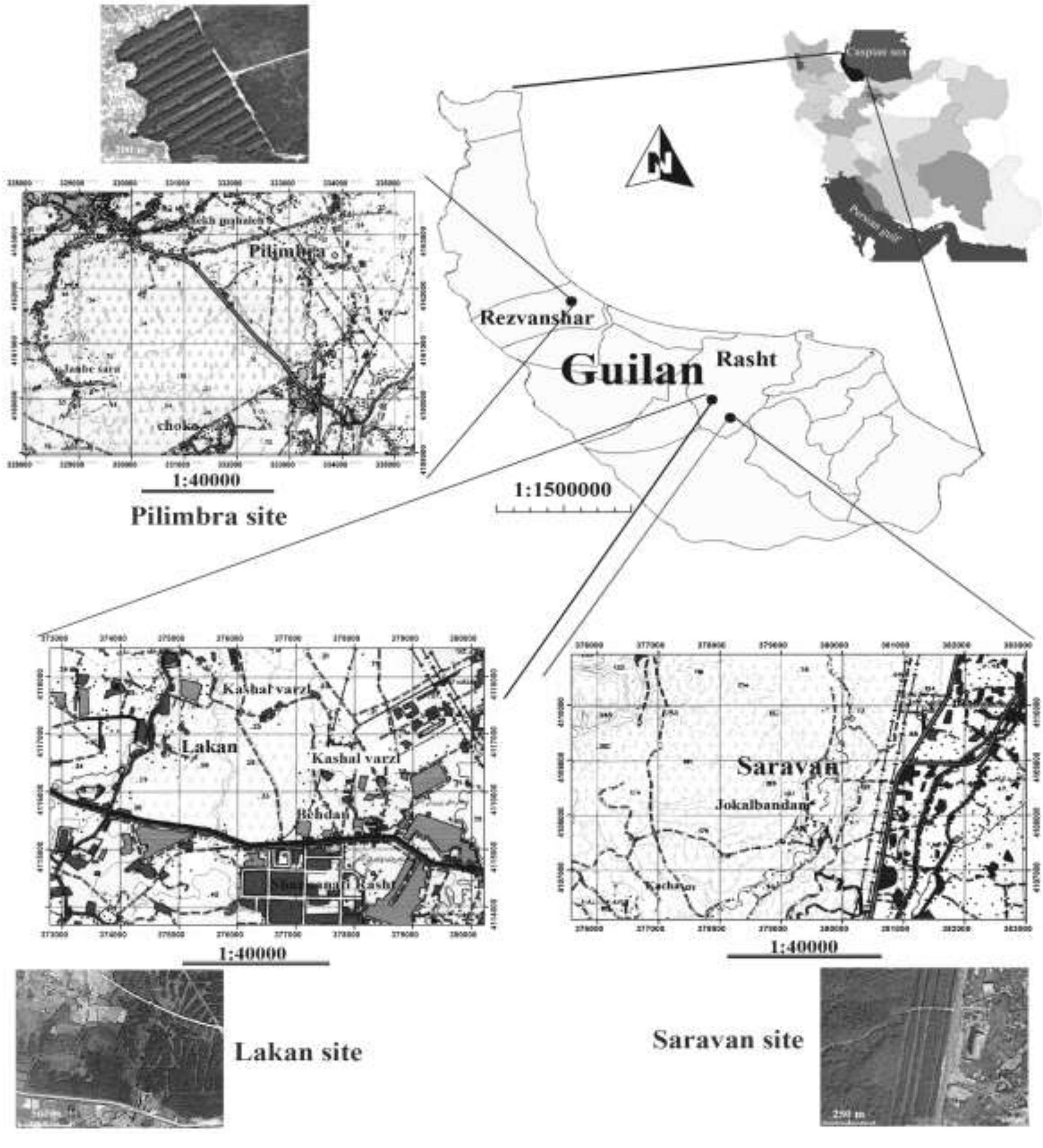

Figure 1. Study areas in Guilan province, north of Iran

Table 1. Environmental information and classification of soil profiles

Site	Slope (%)	Elevation (m)	Soil classification	
			WRB systems†	Soil taxonomy‡
Pilimbra	Undulating 0.5-3	39	Cutanic Luvisols (Clayic Chromic)	Ultic Hapludalfs
Lakan	Undulating 0.5-2	41	Gleyic Cutanic Luvisols (Clayic Chromic)	Oxyaquic Hapludalfs
Saravan	Undulating 0.5-2	71	Cutanic Luvisols (Clayic)	Ultic Hapludalfs

† IUSS Working Group WRB (2006).
‡ Soil Survey Division Staff (2010).

Table 2. Analysis of variance and mean comparison effects site, fire status and soil depth on texture and chemical properties

S.O.V	df	Mean square							
		Texture			pH	EC	OC	CEC	BS
		Clay	Silt	Sand					
Replicate	2	75.5	100	200	0.14	0.00	0.83*	14.4	0.48
Site (S)	2	53179**	113276**	271314**	0.93**	0.35**	3.72**	182.3**	1.17
Fire status (F)	1	5007**	78	3833**	4.38**	1.86**	11.31**	193.4**	6.7*
Depth (D)	2	59835**	13814**	19109**	1.64**	0.53**	29.25**	353.2**	4.8**
S×F	2	869**	1125**	22	0.49**	0.15**	1.60**	103.4**	0.21
S×D	4	4873**	4316**	3111**	0.07	0.03	0.39*	3.4	1.3
F×D	2	1580**	160	757**	1.69**	0.15**	2.55**	6.3	1.13
S×F×D	4	714**	733**	207	0.03	0.005	0.54*	2.1	0.27
Error	34	82	1537	117	0.06	0.01	0.023	7.77	0.43
CV (%)		3.7	2.6	3.8	4.7	11.6	8.3	10.5	10.6
		($g.kg^{-1}$)				($dS.m^{-1}$)	($g.kg^{-1}$)	($Cmol^{+}.kg^{-1}$)	%
Site									
Pilimbra		304 a	519 a	177 c	5.1 b	0.78 c	29.7 a	26.3 b	36.1 a
Lakan		200 c	383 b	417 a	5.4 a	1.06 a	25.5 b	23.4 c	38.1 a
Saravan		226 b	522 a	252 b	5.5 a	0.92 b	33.5 a	29.8 a	42.1 a
Fire status									
Burned		233 b	476 a	291 a	5.6 a	1.11 a	24.3 b	24.6 b	43.1 a
Unburned		253 a	473 a	274 b	5.0 b	0.73 b	34.9 a	28.4 a	34.4 b
Depth									
0-3 cm		297 a	444 c	259 b	5.7 a	1.11 a	45.1 a	31.1 a	46.3 a
3-6 cm		252 b	480 b	268 b	5.2 b	0.87 b	26.5 b	26.0 b	35.5 b
6-9 cm		182 c	498 a	319 a	5.1 b	0.78 c	17.2 c	22.3 c	34.6 b

* and ** significant at level of 5 and 1%, respectively, Means, in each column, with similar letters are not significantly different at the 5% probability level using Tukey's test. S.O.V-Sources of variation, df- Degree of freedom

Table 3. Mean comparison for interaction effect between site, fire status and soil depth on clay, silt, organic carbon and soluble K.

Site	Fire status	Depth	Clay	Silt	OC	Soluble K
			($g.kg^{-1}$)			($mmol.L^{-1}$)
Pilimbra	Burned	0-3 cm	315 b	517 de	33.67 e	0.15 a
		3-6 cm	282 de	522 cde	26.65 efg	0.12 ab
		6-9 cm	278 de	532 cd	16.25 ijk	0.095 bc
	Unburned	0-3 cm	353 a	492 fg	50.70 c	0.067 cd
		3-6 cm	325 b	509 ef	30.68 ef	0.06 cde
		6-9 cm	273 e	537 bcd	20.41 ghij	0.056 de
Lakan	Burned	0-3 cm	228 fgh	375 j	23.92 fghi	0.055 e
		3-6 cm	215 h	375 j	15.99 ijk	0.052 e
		6-9 cm	113 j	417 i	9.75 k	0.045 ef
	Unburned	0-3 cm	293 cd	345 k	65.00 a	0.038 ef
		3-6 cm	240 f	358 jk	24.44 fgh	0.038 ef
		6-9 cm	110 j	427 i	14.17 jk	0.033 ef
Saravan	Burned	0-3 cm	298 c	447 h	42.64 d	0.03 ef
		3-6 cm	217 gh	555 ab	31.46 ef	0.03 ef
		6-9 cm	158 i	540 bc	18.46 hij	0.029 ef
	Unburned	0-3 cm	292 cd	487 g	54.60 b	0.027 ef
		3-6 cm	232 fg	565 a	29.64 ef	0.013 f
		6-9 cm	160 i	538 bc	24.44 fgh	0.01 f

Means, in each column, with similar letters are not significantly different at the 5% probability level using Tukey's test.

Fire significantly increased sand on the first and second depth (3-6 cm) of burned soil in comparison with unburned soil, but this had not significant effect in the third depth. Moreover, fire significantly increased pH in the first and second depth of burned soil in comparison with unburned soil (Fig.

2b). The pH value was maximum in the first depth of burned soil. The pH values were significantly higher in burned soil in comparison with unburned soil (Fig. 2c). The EC value was maximum in the first depth of burned soil and decreased with increasing of depth. The EC values significantly were more in the depths of burned soil in comparison with unburned soil (Fig. 2d). The EC values were significantly higher in burned soil in comparison with unburned soil (Fig. 2e).The CEC values in burned soil were lower in comparison with unburned soil, but it was significant in Lakan site (Fig. 2f).

Mean comparison for interaction effect between site, fire status and soil depth on clay showed that the unburned soil in the first depth of Pilimbra site and unburned soil in the third depth of Lakan site had maximum (353 $g.kg^{-1}$) and minimum (110 $g.kg^{-1}$) content of clay in comparison with other soils, respectively (Table 3). Clay content between burned and unburned soil in Pilimbra and Lakan site in the first and second depth was significant, but any significant difference was not observed in Saravan site.

Moreover, the maximum (565 $g.kg^{-1}$) and minimum (345 $g.kg^{-1}$) content of silt observed in unburned soil in the second depth of Saravan site and unburned soil in the first depth of Lakan site, respectively (Table 3). The silt content between burned and unburned soil only had significant different in the first depth in all of sites. The maximum (65.00 $g.kg^{-1}$) and minimum (9.75 $g.kg^{-1}$) content of OC observed in unburned soil in the first depth of Lakan site and burned soil in the third depth of Lakan site, respectively (Table 3). The OC content between burned and unburned soil in Pilimbra and Saravan site only in the first depth was significant, but Lakan site had significant difference in the first and second depth of soil.

3.2. Effect of fire on soil nutrient

The result of ANOVA on soil nutrients showed that the studied sites had significant effect on all of soil nutrient expect soluble K, exchangeable Na, K and available P. Furthermore, fire had significant effect on soluble K, Ca and Mg, exchangeable K and available P (Table 4). In addition, changes of depth had significant effect on all of soil nutrients expect soluble and exchangeable Na. The results of comparison of mean for studied sites (Table 4) showed that Pilimbra site had maximum concentration (3.1 $g.kg^{-1}$) of N, Lakan site had maximum concentration (0.16 $mmol.L^{-1}$) of soluble Na and Saravan site had maximum concentration of soluble and exchangeable of Ca and Mg.

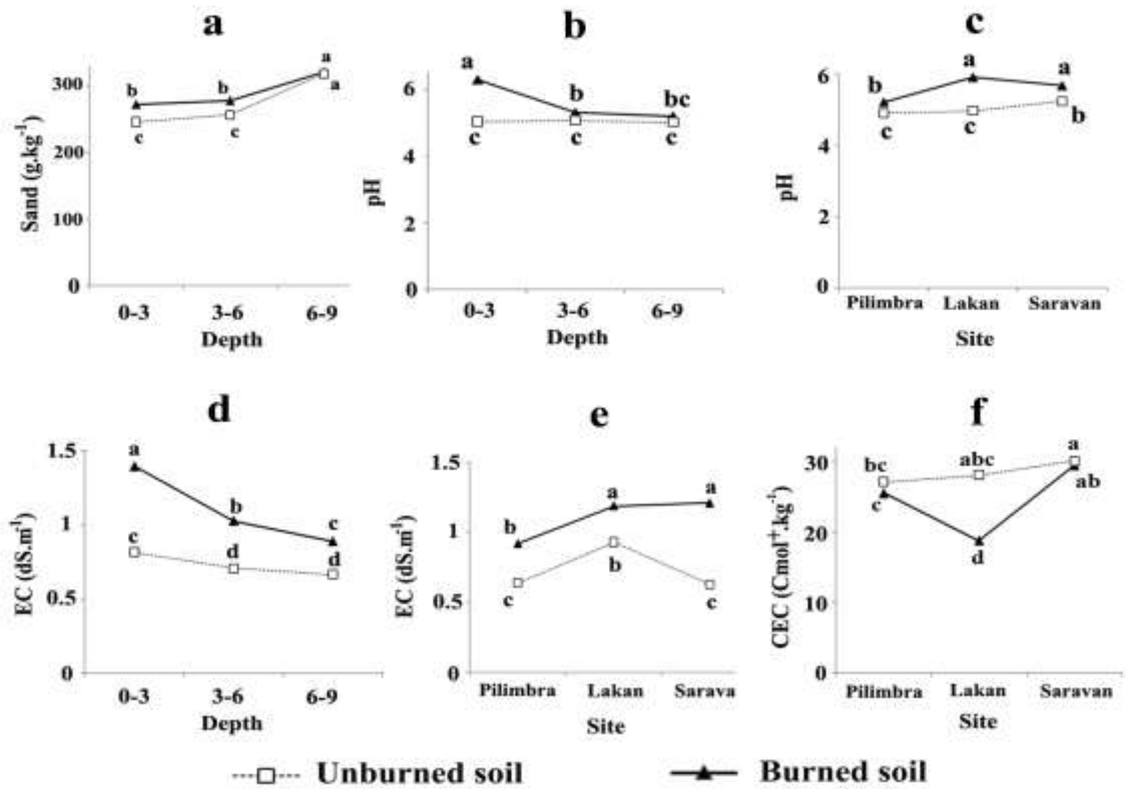

Figure 2. Effects of depth and sites on soil properties in burned and unburned soils; a- sand content in different depths, b- pH values in different depths, c- pH values in different sites, d- EC values in different depths, e- EC values in different sites and f- CEC values in different sites in burned and unburned soils.

Likewise, burned forest significantly increased soluble K, Ca and Mg and exchangeable K and available P concentrations. Moreover, the soluble and exchangeable K, Ca, Mg, N and P concentrations were decreased by depth.

The maximum (2.22 $mmol.L^{-1}$) and minimum (0.57 $mmol.L^{-1}$) concentration of soluble Ca were observed in the first depth (0-3 cm) of burned soil and the third depth of unburned soil, respectively (Fig. 3a). The concentration of soluble Ca in the first and second depths had significant difference between burned and unburned soil, but in the third depth had not significant difference.

Furthermore, the burned soil of Saravan site had maximum concentration of soluble Ca (2.07 $mmol.L^{-1}$) in comparison with other sites (Fig. 3b). The Lakan and Saravan sites had significant difference between burned and unburned soils, but in Pilimbra this difference was not significant.
In addition, the maximum concentration of exchangeable K (0.56 $Cmol^{+}.kg^{-1}$) was observed in the first depth of burned soil that had significant different with unburned soil, but any significant difference was not observed between burned and unburned in the second and third depths (Fig. 3c). The burned soil of Saravan site had maximum concentration of exchangeable K (0.41 $Cmol^{+}.kg^{-1}$) in comparison with other sites. Based on Lakan and Saravan sites had significant difference between burned and unburned soils, but this difference was not significant in Pilimbra site (Fig. 3d). Moreover, the maximum (3.2 $g.kg^{-1}$) and minimum (2.11 $g.kg^{-1}$) concentration total N were observed in the unburned soil of Pilimbra and burned soil of Lakan sites, respectively (Fig. 3e). Based on there were not any significant difference in Pilimbra and Saravan sites and only significant difference was observed in Lakan site. The changes of available P in burned and unburned soil showed that the maximum concentration of available P was observed in the first depth of burned soil (Fig. 3f). Moreover, the available P concentration had significant difference only in the first depth between burned and unburned soils.

Mean comparison for interaction effect between site, fire status and soil depth showed that the maximum (0.15 $mmol.L^{-1}$) and minimum (0.01 $mmol.L^{-1}$) concentration of soluble K was observed in the first depth of burned soil in Pilimbra site and the third depth of unburned soil in Saravan site, respectively (Table 3).

Table 4. Analysis of variance and mean comparison effects site, fire status and soil depth on nitrogen, phosphorous, soluble and exchangeable cations

S.O.V	df	Mean square									
		Soluble cations				Exchangeble cations				N	P
		Na	K	Ca	Mg	Na	K	Ca	Mg		
Replicate	2	0.01	0.001	0.01	0.002	0.001	0.000	0.04	0.02	0.011	0.02
Site (S)	2	0.08**	0.001	0.27**	0.01*	0.004	0.01	1.9**	0.3**	0.3**	0.99
Fire status (F)	1	0.000	0.06**	0.19**	0.05**	0.000	0.06**	0.2	0.05	0.05	10.1**
Depth (D)	2	0.029	0.038**	0.23**	0.05**	0.004	0.4**	4.3**	0.64**	1.9**	74.6**
S×F	2	0.004	0.014**	0.13**	0.003	0.012	0.06**	0.09	0.07	0.1**	0.44
S×D	4	0.018	0.013**	0.04**	0.01**	0.004	0.004	0.47	0.03	0.02	2.21
F×D	2	0.009	0.01**	0.03**	0.002	0.001	0.03**	0.11	0.03	0.04	21.1**
S×F×D	4	0.015	0.01**	0.06	0.003	0.001	0.003	0.04	0.02	0.01	1.27
Error	34	0.01	0.002	0.008	0.002	0.007	0.003	0.11	0.38	0.02	0.97
CV (%)		29.0	21.8	18.6	18.6	15.7	11.4	13.0	11.7	7.4	20.5
		($mmol.L^{-1}$)				($Cmol^{+}.kg^{-1}$)				($g.kg^{-1}$)	
Site											
Pilimbra		0.11 b	0.06 a	0.53 b	0.21 b	0.31 a	0.27 a	6.06 b	2.9 ab	3.1 a	23.6 a
Lakan		0.16 a	0.05 a	1.37 a	0.29 ab	0.28 a	0.25 a	6.03 b	2.35 b	2.46 b	31.8 a
Saravan		0.07 b	0.04 a	1.43 a	0.31 a	0.30 a	0.30 a	8.91 a	3.15 a	3.08 a	27.6 a
Fire status											
Burned		0.1 a	0.07 a	1.42 a	0.23 a	0.30 a	0.32 a	7.37 a	2.9 a	2.99 a	35.2 a
Unburned		0.1 a	0.04 b	0.8 b	0.13 b	0.29 a	0.23 b	6.34 a	2.7 a	2.77 a	20.1 b
Depth											
0-3 cm		0.13 a	0.08 a	1.7 a	0.27 a	0.28 a	0.45 a	9.92 a	3.51 a	4.1 a	54.6 a
3-6 cm		0.09 a	0.04 b	0.9 b	0.14 b	0.30 a	0.23 b	6.09 b	2.57 b	2.6 b	17.7 b
6-9 cm		0.11 a	0.03 b	0.7 b	0.12 b	0.30 a	0.14 c	4.99 b	2.31 b	1.9 c	10.7 b

* and ** significant at level of 5 and 1%, respectively, Means, in each column, with similar letters are not significantly difference at the 5% probability level using Tukey's test, S.O.V-Sources of variation, df- Degree of freedom

Table 5. Analysis of variance and mean comparison effects site, fire status and soil depth on micronutrients.

S.O.V	df	Mean square			
		Fe	Mn	Zn	Cu
Replicate	2	0.88	11.5*	0.59*	0.000
Site (S)	2	38.3**	31.6**	1.33**	0.53**
Fire status (F)	1	90.78**	0.16	0.10	0.01
Depth (D)	2	19.36**	99.9**	6.70**	0.000
S×F	2	23.00**	7.26*	1.22**	0.11**
S×D	4	1.78	3.05	0.28	0.02
F×D	2	8.22*	0.24	0.05	0.001
S×F×D	4	2.48	1.93	0.10	0.008
Error	34	2.77	2.7	0.14	0.01
CV (%)		13.8	19.6	22.1	9.56
		($mg.Kg^{-1}$)			
Site					
Pilimbra		193 a	63 b	3.28 b	1.69 a
Lakan		135 b	71 b	2.68 b	0.98 b
Saravan		129 b	101 a	4.70 a	1.56 a
Fire status					
Burned		121 b	80 a	3.80 a	1.42 a
Unburned		184 a	77 a	3.29 a	1.40 a
Depth					
0-3 cm		176 a	127 a	5.83 a	1.40 a
3-6 cm		157 a	58 b	3.15 b	1.42 a
6-9 cm		123 b	51 b	1.67 c	1.41 a

* and ** significant at level of 5 and 1%, respectively, Means, in each column, with similar letters are not significantly difference at the 5% probability level using Tukey's test, S.O.V-Sources of variation, df- Degree of freedom

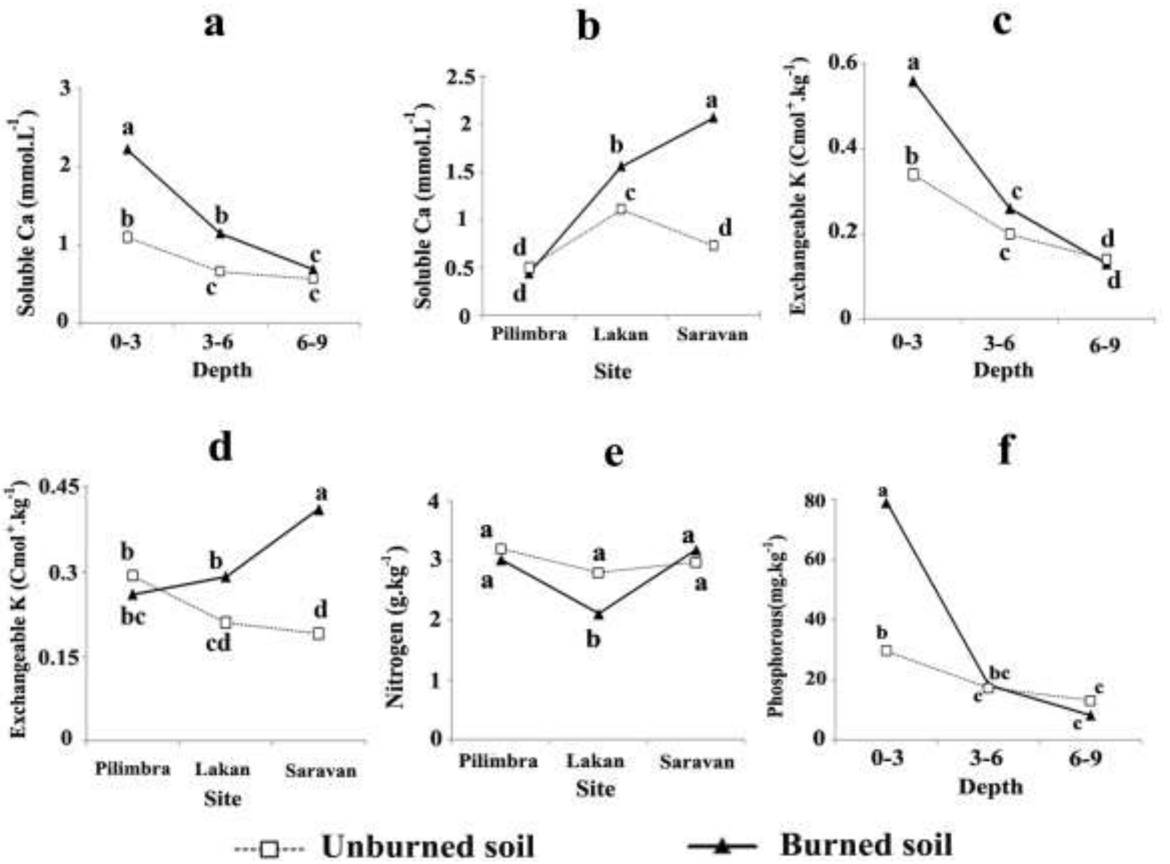

Figure 3. Effects of depth and sites on soil nutrient in burned and unburned soils; a- soluble Ca in different depths, b- soluble Ca in different sites, c- exchangeable K in different depths, d- exchangeable K in different sites, e- N concentration in different sites and f- P concentration in different depths in burned and unburned soil

Based on there was significant difference only in Pilimbra site (in all of depths), but there were not any significant differences in Lakan and Saravan sites. The results of Pearson correlation study showed a significant positive correlation between cations (soluble and exchangeable cations except Na) with pH, EC, OC and CEC in burned soil (Table 6).

3.3. Effect of fire on soil micronutrient

The result of ANOVA on soil micronutrients showed that the studied sites had significant effect on all of soil micronutrients. Furthermore, the only significant effect of fire was on Fe (Table 5) and fire had not significant effect on the other soil micronutrients. In addition, changes of depth had significant effect on all of soil nutrient expect Cu. The results of comparison of mean for studied sites (Table 5) showed that Pilimbra site had maximum concentration of Fe and Cu and Saravan site had maximum concentration of Mn and Zn in comparison with other sites. Moreover, fire significantly decreased Fe but it had not significant effect on the other soil micronutrients. In addition, Fe, Mn and Zn significantly decreased with depth but this change was not significant about Cu concentration.

The maximum (229.35 $mg.kg^{-1}$) and minimum (105.92 $mg.kg^{-1}$) concentration of available Fe were observed in the first depth of unburned soil and the third depth of burned soil, respectively (Fig. 4a). Based on there was significant difference in the first and second depths between burned and unburned soils. Moreover, the maximum (216.99 $mg.kg^{-1}$) and minimum (74.7 $mg.kg^{-1}$) concentration of available Fe were observed in unburned soil of Pilimbra site and burned soil of Lakan site, respectively (Fig. 4b).

There was significant difference between burned and unburned soils in Pilimbra and Lakan sites. The maximum (109.16 $mg.kg^{-1}$) and minimum (47.58 $mg.kg^{-1}$) concentration of available Mn were observed in unburned soil of Saravan site and unburned soil of Pilimbra site, respectively (Fig. 4c). The only significant difference between burned and unburned soils was observed in Pilimbra site and other sites had not significant difference. In addition, the maximum (6.15 $mg.kg^{-1}$) and minimum (2.18 $mg.kg^{-1}$) concentration of available Zn were observed in unburned soil of Saravan site and unburned soils of Pilimbra site, respectively (Fig. 4d).

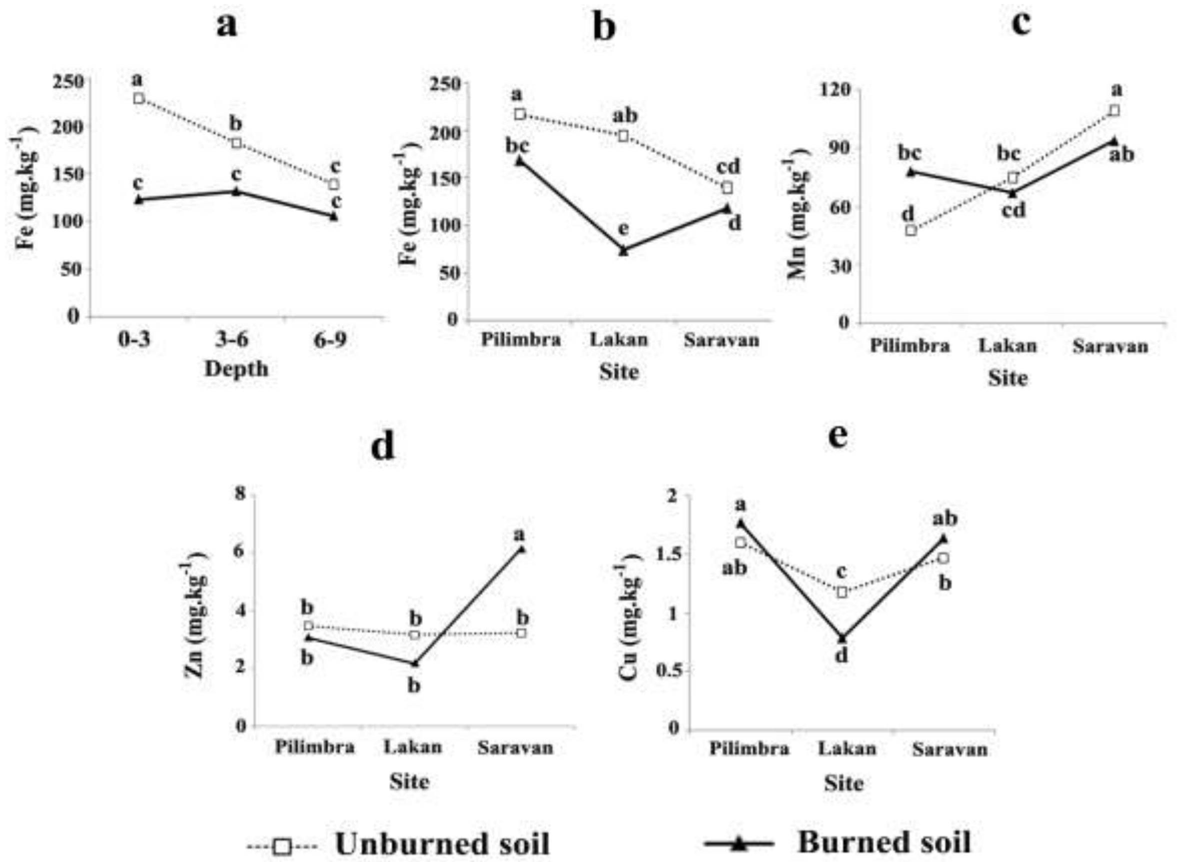

Figure 4. Effects of depth and sites on soil micronutrient in burned and unburned soils; a- Fe concentration in different depths, b- Fe concentration in different sites, c- Mn concentration in different sites, d- Zn concentration in different sites, and e- Cu concentration in different sites.

Based on, the only significant difference between burned and unburned soils was observed in Saravan site and other sites had not any significant difference. Fire significantly increased available Zn in burned soil in comparison with unburned soil in Saravan site. Furthermore, the maximum (1.77 $mg.kg^{-1}$) and minimum (0.79 $mg.kg^{-1}$) concentration of available Cu were observed in burned soil of Pilimbra site and burned soil of Lakan site, respectively (Fig. 4e).The only significant difference between burned and unburned soils was observed in Lakan site that available Cu was more in unburned soil.

4. DISCUSSION

During the process of soil heating, significant changes occurred in the physical and chemical soil properties that could be affected to future productivity and sustainability of sites. There was a trend toward lower clay content on the surface soils of burned sites. There were decreases of 9.1, 13.5 and 1.5% in the clay contents of the soil samples collected after burning from Sites Pilimbra, Lakan and Saravan, respectively. The decrease of clay was however compensated with increase of sand content. Hence, significant negative correlation between clay and sand content in burned and unburned soils confirmed this relation (Tables 6 and 7). Meanwhile, the silt content had not significant difference on the response to fire. Are et al. (2009) were reported decreases of 27 and 29% in the clay contents of the soil samples collected after burning. Fire significantly increased pH values in all the sites. The combustion of organic matter during a fire and the subsequent release of soluble cations trend to increase pH slightly (Knoepp et al., 2008). This difference was more in Lakan site that can be related with fire intensity (Knoepp et al., 2008). Certini (2005) were reported that increasing in soil pH because of organic acids denaturation.

The EC was increased in all the sites and depths that as a result of the release of inorganic ions from the combusted organic matter (Hernandez et al., 1997; Certini, 2005). The results of Prieto-Fernandez et al., (2004) showed that this increasing is temporarily. The most intuitive change soils experience during burning is the loss of organic matter. Depending on fire severity, the impact on the organic matter consists of slight distillation (volatilisation of minor constituents), charring, or complete oxidation (Certini, 2005). There were decreases of 24.8, 52.1 and 14.8% in the OC contents of the soil samples collected after burning from Sites Pilimbra, Lakan and Saravan, respectively.

Lakan site had maximum difference among of sites and decreasing of OC was occurred in the first and second depths while it was occurred in the first depth in other sites. The results of some reports (Kavdir et al., 2005; Pivello et al., 2010) confirmed my results. CEC sites are important storage places for soluble cations found in the soil (Knoepp et al., 2008). The amount of clay particles and organic matter are two important factors that related to CEC (Sumner & Miller, 1996). The results of this study showed a significant positive correlation between CEC, OC and clay in both of burned and unburned soils (Tables 6 and 7). Fire significantly decreased CEC values in comparison with unburned soil. This reduction can be related to decreasing of clay and destruction of humus compounds (Knoepp et al., 2008). Furthermore, there was increase of 20.2% in the BS values of burned soil in comparison with unburned soil. BS increases is as a consequence of the prevailing release of bases from the combusting organic matter (Certini, 2005).

In many studies, a significant increase in soil cation concentration following either prescribed burning or a wildfire has been reported (Raison et al., 1990, Soto & Diaz-Fierros, 1993, Neff et al., 2005). Cations found in the soil that are affected by fire include Ca, Mg, Na and K although these cations are not usually deficient in most wildland soils (Certini, 2005). The result of this study showed that fire significantly increased all of soluble cations except soluble Na. Moreover, the only significant effect of fire on exchangeable cations was on K. K seems to have a special role in nutrient recycling during a fire because a large proportion of this element is contained in the plants and litter (DeBano & Conrad, 1978). Khanna & Raison (1986) were reported that concentrations of cations, such as Ca, Mg, and K, increase considerably in the soil solution immediately following burning (Khanna & Raison, 1986). Khanna et al., (1994) were reported that K is easily soluble but with a residual component (about 30%) which is not solubilised by further dilution while Ca and Mg relatively insoluble but at degree related to dilution.

Nitrogen is highly volatile elements, requiring relatively low temperatures (200–300°C) to volatilize (Boerner, 1982). However, except for Lakan site, the other sites did not show significant difference between burned and unburned soils. The results of Kutiel & Naveh (1987) in a pine forest soil showed that total nitrogen decreased about 25% but available forms of nitrogen were much higher.

Table 6. Pearson correlation coefficients between studied properties in burned soils

		Texture			pH	EC	OC	N	P	Soluble cations				Exchangeble cations				CEC	BS	Micronutrient			
		Clay	Silt	Sand						Na	K	Ca	Mg	Na	K	Ca	Mg			Fe	Mn	Zn	Cu
Texture	Clay	1																					
	Silt	0.24	1																				
	Sand	0.8** −	0.8** −	1																			
pH		0.17	0.6** −	0.3	1																		
EC		0.29	−0.33	0.04	0.7**	1																	
OC		0.69**	0.27	0.6** −	0.4*	0.7**	1																
N		0.7**	−0.2	0.6** −	0.5**	0.7**	/94** 0	1															
P		0.4*	−0.3	−0.1	0.7**	0.8**	0.6**	0.7**	1														
Soluble cations	Na	−0.05	−0.3	0.34	0.2	0.3	−0.05	0.1	0.4	1													
	K	0.6**	−0.14	−0.3	0.5*	0.6**	0.5**	0.5*	0.6**	0.01	1												
	Ca	−0.01	−0.37	0.25	0.68**	0.84**	0.4*	0.41*	0.6**	0.16	0.5*	1											
	Mg	0.25	−0.26	0.02	0.5**	0.7**	0.4*	0.3	0.6**	0.2	0.55**	0.76**	1										
Exchangeble cations	Na	0.25	0.32	−0.4	−0.14	−0.16	0.14	0.03	−0.11	0.5** −	0.04	−0.3	−0.24	1									
	K	0.5**	−0.22	−0.16	0.7**	0.9**	0.8**	0.8**	0.8**	0.15	0.6**	0.7**	0.65**	−0.08	1								
	Ca	0.5**	0.12	−0.4*	0.6**	0.7**	0.8**	0.7**	0.7**	0.06	0.6**	0.6**	0.5**	−0.1	0.8**	1							
	Mg	0.6**	0.31	0.6** −	0.4*	0.6**	0.8**	0.7**	0.5**	0.1	0.6**	0.4*	0.47*	−0.1	0.7**	0.9**	1						
CEC		0.7**	−0.5*	0.7** −	0.28	0.5**	0.9**	0.7**	0.5*	−0.14	0.55**	0.42*	0.4*	0.16	0.7**	0.8**	0.85**	1					
BS		0.4	−0.2	−0.1	0.6**	0.7**	0.6**	0.5**	0.7**	0.21	0.55**	0.57**	0.5**	−0.3	0.6**	0.88**	0.78**	0.5*	1				
Micronutrient	Fe	0.6**	0.6**	0.8** −	−0.3	−0.2	0.4*	0.4*	−0.01	−0.2	0.05	−0.4*	−0.22	0.28	0.024	−0.19	0.4*	0.5*	−0.04	1			
	Mn	0.4*	0.04	−0.3	0.46*	0.6**	0.6**	0.7**	0.66**	0.11	0.62**	0.49**	0.34	−0.15	0.7**	0.8**	0.7**	0.7**	0.7**	0.15	1		
	Zn	0.34	0.18	-0.32	0.24	0.63**	0.62**	0.6**	0.4*	-0.12	0.4*	0.66**	0.53**	0.17	0.6**	0.46*	0.43*	0.64**	0.26	−0.21	0.58**	1	
	Cu	0.52**	0.72**	-0.8**	-0.32	-0.29	0.41*	0.34	-0.13	-0.23	0.22	-0.16	0.09	0.18	0.06	0.5**	0.65**	0.6**	0.39*	−0.21	0.58**	0.05	1

* and** Significance at the 5% and 1% level (df for total parameters = 26).

Table 7. Pearson correlation coefficients between studied properties in unburned soils

		Texture			pH	EC	OC	N	P	Soluble cations				Exchangeble cations				CEC	BS	Micronutrient			
		Clay	Silt	Sand						Na	K	Ca	Mg	Na	K	Ca	Mg			Fe	Mn	Zn	Cu
Texture	Clay	1																					
	Silt	0.15	1																				
	Sand	−0.7**	−0.7**	1																			
pH		−0.22	−0.28	−0.05	1																		
EC		0.19	−0.8**	0.4*	−0.12	1																	
OC		0.65**	−0.25	−0.3	0.005	0.6**	1																
N		0.7**	−0.2	−0.4**	−0.15	0.5**	0.94**	1															
P		0.4*	−0.3	−0.3	0.11	0.57**	0.77**	0.76**	1														
Soluble cations	Na	0.07	−0.5**	0.34	−0.4*	0.5**	−0.04	0.07	0.11	1													
	K	0.4*	−0.3	−0.05	−0.6**	0.34	0.14	0.28	0.05	−0.25	1												
	Ca	0.12	−0.6**	0.36	0.11	0.78**	0.4*	0.41*	0.48*	0.34	0.27	1											
	Mg	0.4*	−0.5*	0.03	0.1	0.76**	0.77**	0.7**	0.7**	0.24	0.22	0.76**	1										
Exchangeble cations	Na	−0.34	0.11	0.15	0.11	−0.1	−0.08	−0.12	−0.15	−0.4*	−0.25	−0.17	−0.3	1									
	K	0.8**	−0.21	−0.4*	−0.3	0.33	0.7**	0.8**	0.4*	0.17	0.55**	0.24	0.43*	0.28 −	1								
	Ca	0.34	0.001	−0.24	0.3	0.37	0.7**	0.6**	0.7**	0.06	−0.12	0.2	0.6**	0.25 −	0.33	1							
	Mg	0.36	0.03	−0.27	0.25	0.3	0.6**	0.6**	0.5**	0.12	0.025	0.2	0.45*	0.07 −	0.4*	0.7**	1						
CEC		0.5*	−0.16	−0.2	0.26	0.37*	0.8**	0.7**	0.65**	−0.2	−0.2	0.27	0.6**	0.03 −	0.48*	0.61**	0.4*	1					
BS		0.1	0.11	−0.17	0.15	0.22	0.37	0.36	0.43*	0.23	0.23	0.1	0.4*	−0.2	−0.14	0.83**	0.75**	0.1	1				
Micronutrient	Fe	0.7**	−0.34	−0.22	−0.5**	0.4*	0.6**	0.6**	0.5*	0.23	0.24	0.22	0.38	0.24 −	0.56**	0.21	0.26	0.38*	0.04	1			
	Mn	0.24	−0.12	−0.1	0.32	0.4*	0.7**	0.7**	0.64**	−0.14	−0.25	0.4	0.7**	0.01	0.4*	0.67**	0.46*	0.53**	0.5*	0.12	1		
	Zn	0.68**	-0.29	-0.27	-0.11	0.39*	0.89**	0.9**	0.7**	0.28	0.23	0.54**	0.78**	-0.2	0.7**	0.53**	0.38	0.68**	0.23	0.59**	0.69**	1	
	Cu	0.45*	0.6**	-0.7**	-0.01	-0.4*	0.10	0.16	0.12	-0.1	0.21	-0.28	-0.08	-0.2	0.20	0.21	0.33	-0.16	0.41*	0.13	0.07	0.05	1

* and** Significance at the 5% and 1% level (df for total parameters = 26).

Forest fires have not necessarily the same impact on soil P as on N, because losses of P through volatilization or leaching are small. Nevertheless, the combustion of vegetation and litter causes impressive modifications on biogeochemical cycle of P. The high and significant increasing of available P in the first depth showed in this study that could be related high amounts available P was found in the ash thus, P remain in the system. The results of some studies (Serrasolsas & Khanna, 1995; Niemeyer et al., 2005) showed this fact.

The behaviour of micronutrients, such as Fe, Mn, Cu and Zn with respect to fire is not well known because specific studies are lacking (Certini, 2005). The results of this study showed that the only significant effect of fire was on Fe and it had not significant effect on the other micronutrients. García-Marco & González-Prieto (2008) were reported that immediately after the fire, available Fe content (extracted by DTPA) decreased in burnt soils.

The fire-induced depletion of Fe levels could be associated with losses by convection in smoke columns (García-Marco & González-Prieto, 2008) and/or conversion to insoluble oxidized forms in soils, which have been reported for several nutrients (Khanna & Raison, 1986; Brye et al., 2002). Fire had not significant effect on available Mn, Zn and Cu. Blank et al., (1995) were reported no significant difference on Mn extracted by DTPA between burned and unburned soils. Higher levels of Cu were observed in the unburned soil in Lakan site that might be due to lower pH values, as acidity increases the availability of these elements (Pivello et al., 2010).

5. CONCLUSION

The increased soil nutrient availability following fire results from the addition of ash, forest floor leachates, and soil organic matter oxidation products as the result of fire. The results of this study showed that fire had significant effects on soil soluble cations. In contrast, the only significant effect of fire on exchangeable cations limited to K. Overall, in all cases, there were a tendency towards higher levels of soil nutrients in burned soil. However, some of the soluble nutrients deposited in the ash may be lost from the site by erosion if not immediately absorbed by plants. The effects of fire on soil micronutrient were few and limited to Fe and can be related to pH and OC in soil. Probably temperatures in the soil were not high enough to volatilize even these elements.

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