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ORIGINAL ARTICLE

Effects of different fire severity levels on soil chemical and physical properties in Zagros forests of western Iran

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Abstract

The study focused on the effect of different intensities of fire on physical and chemical properties of soil in Zagros forests of western Iran. The dominant tree species in these forests is oak (*Quercus persica*). Three sites were selected; high severity burned site (HS), low severity burned site (LS) and control (not burned) site (C). Soil chemical properties such as: organic matter (OM), the total nitrogen (N), NO_3-N, soluble potassium (K), soil phosphorus (P), pH, soil electrical conductivity (EC), cation exchangeable capacity (CEC), base cations (Ca, Mg, Na), CO_2 and soil physical properties such as saturation percentage (SP), bulk density (BD), sand, clay and silt percentages were assessed in soil samples. To determine significance of differences among the three observed sites and most effective variables in the separation of sample plots, one-way analysis of variance and principal component analysis were used, respectively. Mean pH, N, NO_3- N, OM, SP, P, K, and CEC at HS site were lower than at the sites with other fire intensities but the EC value for HS site was higher in comparison with other sites observed. According to Duncan's test, mean BD value for HS site was higher when compared with other sites but SP value was comparatively lowest. At LS site, mean sand content was lowest and the amount of silt was highest, in comparison with other sites. The results showed that observed fire severities had significant effects on physical and chemical properties of soil, yet fire low severity and control sites were very similar to each other in terms of investigated factors. Therefore, it can be concluded that low-severity fire regime has no significant influence on soil properties. In a management strategy, controlled low-severity fire regime can be an alternative management tool in improving soil conditions.

Key words

fire severity, soil properties, Zagros forests, PCA

Introduction

In most ecosystems, disturbance is an important agent of variation in community structure and composition. The variation of characteristics of disturbance agents, such as frequency, size, and severity strongly affect ecosystem properties and processes (Hino and Tsutom 2009). Wildfires are one of critically important disturbance agents in forest ecosystems (Cairney and Bastias 2007). In recent decades, the number of fires has increased in most regions of the Mediterranean lands (Morino et al. 1998). How soils are affected by fire and how much impact a fire has on an ecosystem are largely determined by how severely a fire burns. Fire severity reflects the duration and amount of energy that is released and available to alter various components of an

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ecosystem, whereas soil burn severity reflects the impact of fire on soils owing to heat at the soil surface (Heather and White 2008). Some studies have shown that not all forest fires are inherently bad and can be used as a tool for forest management (Hutchinson et al. 2005). If forest is affected by one or more damaging agents, depending on their severity, the balance of forest ecosystem may be impaired or even destroyed. Fires can change plant composition and forest structure, as well as destroy biomass, alter soil chemical and physical properties and increase soil susceptibility to erosion (Busse et al. 1996; Boerner et al. 2009). Fires may also play a significant role in regulating ecosystem productivity and diversity by enhancing mineralization of nutrients stored in organic matter (Rastad 2009). Many physical, chemical, mineralogical and biological forest soil properties can be affected by fires. The effects are chiefly a result of burn severity, which consists of peak temperatures and fire duration. Climate, vegetation and topographic conditions of burnt area control resilience of the soil system; some fire-induced changes can even be permanent.

Fires can lead to important changes in physical and chemical properties of forest soils including: increased bulk density and altered physical structure (Rastad 2009; Arocena and Opio 2003), increased soil cation stocks (Franklin et al. 2003; Liechty et al. 2005) and decreased carbon (C) and nitrogen (N) stocks in surface soils (Johnson and Curtis 2001). Forests of Iran cover an area of about 12.4 million ha and comprise 7.4% of the total country area. Zagros woodlands with an area of approximately 5 million ha account for almost 40% of Iran's forests (Sagheb-Talebi et al. 2004). These woodlands provide a home and livelihood for approximately 10% of Iran's population. The woodlands stretch from north to south along the Zagros Mountains in western part of the country. This region has sub-Mediterranean, semi-arid temperate climate and mainly consists of deciduous, broadleaf trees where oaks (*Quercus* spp.) are the dominant tree species (Olfat and Pourtahmasi 2010). Zagros forests have been impacted by various factors, especially scarcity of regional development opportunities, low literacy and high dependence of residents on forest resources for livelihood. Then again, fires which constitute the principal disturbance in Zagros forests generate substantial soil heterogeneity at patch and landscape scales. Although fires have been one of the major problems in forest ecosystems in the Zagros Mountains, especially in recent years, fire effects on physical and chemical soil properties in Zagros region have been up to date poorly studied. The aim of this study was to address fire severity effects on physical and chemical soil attributes in Zagros forest ecosystem. Understanding the severity of fire and its effects on forest soils can allow improving management of valuable forest ecosystems as adequate and proper information is very important for efficient management.

Material and Methods

Study area

The study area is located in the province of Ilam, within Zagros forests, in west of Iran, between 63.7000 and 64.1000 East longitudes and 37.41000 and 37.39000 North latitudes in UTM zone 38. Elevation and slope ranges are from 1200 m to 1350 m and from 5% to 10%, respectively. Average annual precipitation and tempera-

Tab. 1. Characteristics of study sites and determinant factors of fire severity

Site	Physiographic factors			Canopy (%)	Occurrence	Signs				
	Elevation (m)	Aspect	Slope (%)			Fire Duration (hours)	Burned understory vegetations	Burned the collar – tree	Burned whole trunk	Burned tree canopy
HS	1350	Flat	5–10	25–50	summer	> 24	a	a	b	c
LS	1250	Flat	5–10	25–50	summer	5	b	c	–	–
C	1320	Flat	5–10	25–50	–	–	–	–	–	

HS – over 50 percent of trees with burn marks and cover the floor completely burned; LS – less than 25 percent of trees are burn marks and the floor covering is easy to see; C – unburned site; a – completely; b – splotchy; c – rarely.

ture are 500 mm and 18.2°C. The minimum recorded temperature is 3°C in December and the maximum recorded temperature is 28°C observed in July. The lowest and highest rainfalls occur in July and February, respectively.

Two forest sites burned in 2009 were selected for this study. It should be mentioned that after 2009, the events such as fires or other disturbance agents did not occur in the forest sites studied. The sites encompassed high severity burned site (HS), low severity burned site (LS), and control (unburned) site (C). Qualitative and quantitative characteristics of these areas such as vegetation, climatic conditions and physiographic factors were similar to each other. The dominant tree species is oak (*Quecus persica* Jaub & Spach) and in fact more than 90% of these areas are covered by this species. The area of each experimental site was approximately 25 ha.

Sampling methods and soil analyses

To determine the fire severity, the seasons of fire occurrence, fire duration (hours), visible signs of fire on trees (burning of root collar, trunk and crown) were recorded in 2009 in each selected site (tab. 1). In all sites, soil sampling was performed in 2010 using the systematic-random sampling method (100 m*100 m). In each site, 25 quadrate sample plots (400 m^2) were determined (75 plots in total). In order to study physical and chemical properties of soil influenced by different fire intensities, there were randomly taken samples from 0–20 cm soil layer in each plot and then mixed to obtain one composed soil sample (Maranon et al. 1999). All soil samples were air dried and sieved through a 2 mm sieve. The Bouyoucos hydrometer method was used to determine soil texture. Organic matter (OM), total nitrogen (N) and soluble potassium (K) were assessed using the Walkely and Black rapid titration method (Black 1979) as well as Kjeldah and flame photometry methods, respectively. Soil pH and electrical conductivity (EC) were determined by means of digital pH meter and the conductivity bridge. Soil cation exchangeable capacity (CEC) was determined based on NH4OAc extraction (Sumner and Miller 1996) and the summation of exchangeable Ca, Mg, Na, K, and H^+. Base cations (Ca, Mg, and Na) were extracted by leaching 3 g of air dried soil with successive aliquots of 1 M NH_4OAc, pH 7, to total 60 ml. Base cation concentrations of the leachate was determined by ICP-AES (Kalra and Maynard 1991). Saturation percentage (SP) was measured by the standard gravimetric method (Jafarei 2001). Soil bulk density (BD) was determined by the un-disturbed soil core method (Blake and Hartge 1986). Soil CO_2 evolution measurements were carried out using TIM 850 Titration Manager (Sedigi 2011). Assessments of NO_3- were performed with Auto Analyzer (Brooks et al. 1989) and those of soil phosphorus were carried out with a spectrophotometer and the Olsen method (Mallarino 2003).

Data analyses

Normality of the data obtained was checked with the Kolmogorov–Smirnov test. Cochran's test was used to examine homogeneity of variances. One-way ANOVA was used to test effects of fire severity on each of the soil variables investigated, and Duncan's test was applied for comparisons between mean values. All these analyses were carried out with SPSS v.11.5 software. For the joint comparison of topsoil variables, principal component analysis (PCA) was carried out using Statistica 6.0 software. PCA was performed for 14 factors in 100 plots to determine most effective variables in the separation of sample plots. For multivariate analyses the software PC-ORD Ver.3.0 was used.

Results

Soil chemical properties

The results of ANOVA showed that the fire severity had significant effects on soil chemical properties such as pH, N, OM, NO_3-N, P, K, EC, CEC and CO_2 (tab. 2). Based on Duncan's test, the mean values of pH, N, NO_3-N, OM, SP, P, K and CEC in HS area were lower than those obtained in other sites observed. However, the value of EC was higher in HS area in comparison with other sites (fig. 1).

Soil physical properties

The results showed that the fire severity significantly influenced some soil physical attributes such as SP, BD and sand and silt contents (tab. 3). According to Duncan's test mean BD in HS area was higher than in other sites observed, but SP was the lowest. In LS site, mean sand content in soil was lowest and the amount of silt was highest when compared with other sites (fig. 1).

Tab. 2. Soil chemical properties in regions with different fire severity (mean ±SD)

Soil properties	Sites						P value
	LS		HS		C		
	Mean	SD	Mean	SD	Mean	SD	
pH (H_2O)	6.900	0.090	6.68	0.130	7.235	0.074	0.000**
EC (dS/m)	0.500	0.020	1.32	0.181	0.487	0.040	0.000**
N (%)	0.646	0.042	0.52	0.043	0.517	0.040	0.001**
OM (%)	6.134	0.800	3.70	0.774	5.750	0.100	0.002**
NO_3-N (ppm)	18.400	1.960	14.70	2.160	18.000	2.620	0.000**
P (ppm)	2.500	0.470	2.01	0.166	2.400	0.350	0.010*
CEC (Cmolc/kg)	2.200	0.350	1.60	0.370	2.000	0.360	0.001**
K (ppm)	158.300	45.800	42.30	9.460	218.000	44.873	0.002**
CO_2	0.230	0.040	0.17	0.047	0.254	0.043	0.001**

Means in columns denoted with same letter are not significantly different (ANOVA-protected Duncan's multiple range test);
* – significant at $\alpha < 5\%$; ** – significantat $\alpha < 1\%$; different letters indicate significant differences.

Tab. 3. Soil physical properties between regions with different fire severity

Soil properties	Sites						P value
	LS		HS		C		
	Mean	sd	Mean	sd	Mean	sd	
BD (gr/cm^3)	1.24	0.04	1.35	0.05	1.2	0.079	0.002*
Sand (%)	27.80	3.58	44.80	5.15	28.6	2.590	0.000**
Clay (%)	27.20	2.38	25.20	3.76	27.2	2.500	0.532ns
Silt (%)	45.00	2.40	30.00	2.59	44.1	2.300	0.000**
SP (%)	44.00	7.70	29.00	10.80	42.8	13.010	0.001**

Means in columns denoted with same letter are not significantly different (ANOVA-protected Duncan's multiple range test);
ns – not significant; * – significant at $\alpha < 5\%$; ** – significant at $\alpha < 1\%$; different letters indicate significant differences.

Results of multivariate analysis

In this study, PCA was used to verify likelihood of classifying soil properties according to different severity of fires. It was performed for 14 factors in 100 plots to determine most effective variables differentiating sample plots (tab. 4 and fig. 2). Broken-stick Eigenvalues for the data set indicate that the first two principal components (PC1 and PC2) resolutely captured more variance (3.25 and 2.25, respectively). The first two principal components together accounted for 59.57% of the total variance in the data set. This means that the first and second principal components are by far the most important for representing variation of the different soil characteristics in our study. Considering correlations between variables and components, the first principal component includes pH, NO_3-N, K, P, CO_2, BD, sand, silt, SP, whereas the axis 2 reflects a gradient of EC, N and OM. The first ordination axis showed positive correlations with BD and sand and negative correlations with pH, NO_3- N, K, P, CO_2, silt and SP (tab. 4). The second ordination axis was positively correlated with EC and negatively correlated with N and OM. Figure 2 shows a plot of three groups against their values for the axes 1 and 2. In the diagram, the distance between plots points out to a degree of similarity and dissimilarity in environmental factors. The plots located within the positive direction of the axis 1 have positive correlation with the factors of this direction (BD and sand). The plots of control

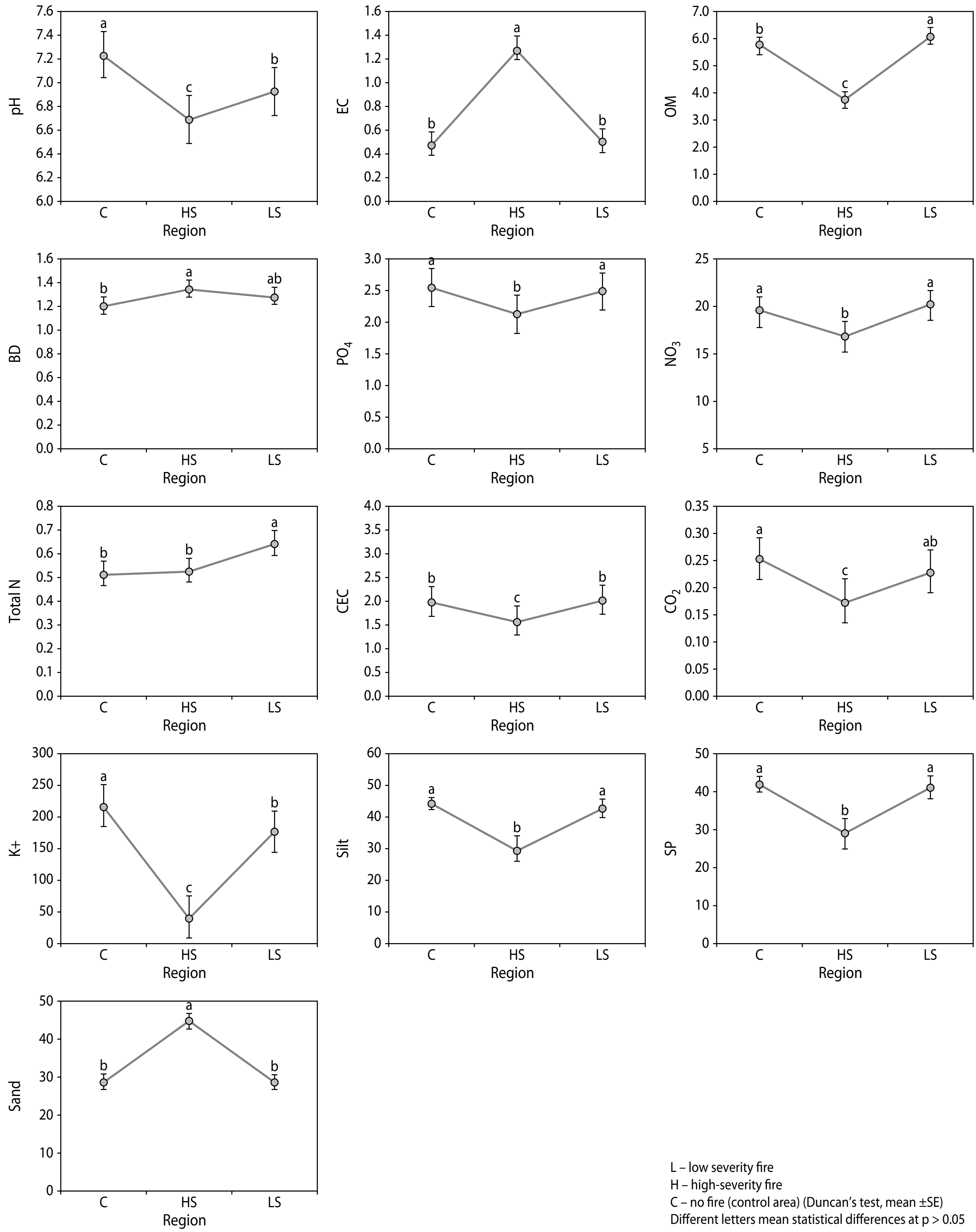

Fig. 1. Soil properties in regions with different fire severity

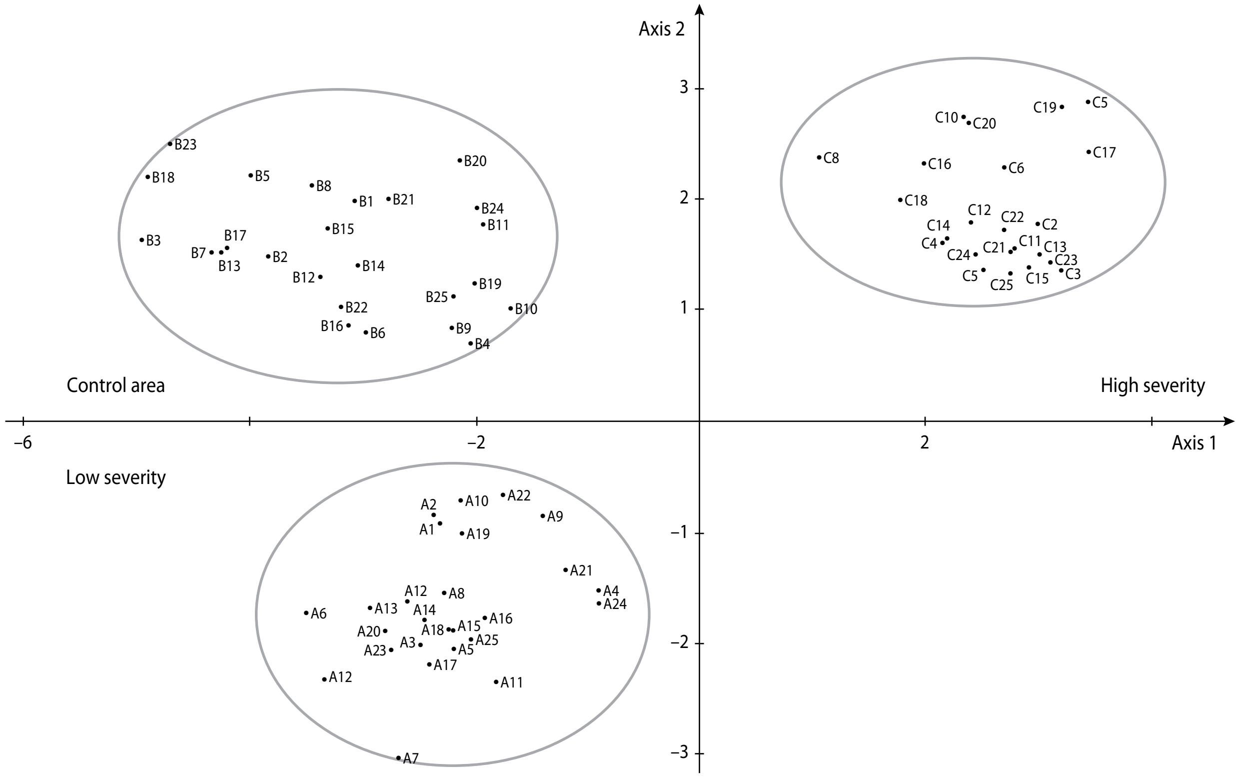

Fig. 2. PCA-ordination diagram of fire severity region groups related to soil physical and chemical properties

area show the strongest correlation with the negative direction of the axis 1. The LS region has the strongest correlation with the negative direction of the axes 1 and 2. The plots of HS region specify a group that has stronger correlation with the positive direction of the axes 1 and 2 (fig. 2). Based on the position of the control area in the second quarter of the diagram, one can tell that this group had stronger correlation with the negative direction of the axis 1. Therefore, this set was related the most with variables situated within the negative direction of the axis 1 (pH, NO_3-N, K, P, and CO_2, BD, silt and SP). Because of larger distance between this group (control area) and the axis 2, this group showed weaker correlation with the factors of axis 2. HS region showed maximum correlation with EC, BD and sand. On the contrary, LS region, which is placed within the negative direction of the axes 1 and 2, showed maximum relationship with the variables such as pH, NO_3-N, N, K, P, CO_2, BD, sand, silt and SP (tab. 4).

Tab. 4. Correlation matrix of soil attributes in the study area (PCA method)

Soil attributes	Axis 1	Axis2
pH	0.835^{**}-	0.135^{ns}
EC	0.597^{*}	0.603^{**}
N	0.028^{ns}-	0.840^{**}-
OM	0.004^{ns}-	0.878^{**}-
NO_3- N	-0.732^{**}	0.316
P	-0.619^{**}	0.006^{ns}
CEC	0.556^{*}	-0.480^{*}
K	0.881^{**}-	0.007^{ns}
CO_2	-0.637^{**}	0.005^{ns}
BD	0.657^{**}	0.069^{ns}-
Sand	0.887^{**}	0.084^{ns}
Clay	0.300^{*}-	0.151^{ns}-
Silt	-0.892^{**}	0.024^{ns}-
SP	-0.717^{**}	0.195^{ns}-

^{ns} – not significant; * – significant at $\alpha = 5\%$); ** – significant at $\alpha = 1\%$.

Discussion

Chemical soil properties

It seems that the main reason of carbon decrease in HS area can be volatilization of organic matter and conversion of organic matter to ash (Binkley et al. 1992; MacKenzie et al. 2004). Large amount of surface organic matter is destroyed due to fire and usually high loss of organic matter occurs after a fire. This can cause changes in soil physical and chemical properties, temporary vegetation losses and finally – soil erosion (DeBano 1998). Total and absorbable nitrogen contents in HS were found to be less than those observed in LS region. Fire increases nitrogen availability in the short time period, but this trend can be changed in the long time (Duran et al. 2010). The effect of forest fires on N availability is important, because nitrogen is one of the most common limiting factors to forest productivity (Fisher and Binkley 2000; Rau et al. 2009). Our results showed that soil sampled from HS site had higher EC and pH values than those observed in other sites. The fire severity steadily increases soil pH and EC values (Creighton and Santelices 2003). Soil pH increases immediately following severe debris burning (Bauhus et al. 1993) and this effect typically remains for several years. HS site had the lowest CEC value. In general, burning tends to reduce soil CEC values (Ekinci 2006; Hatten et al. 2005), however, the results of this study showed that in one year following the fire in LS site, CEC returned to usual levels. When organic matter of soil is removed by fire, CEC can be diminished (Giovannini et al. 1988). However, charcoal added to soil has been shown to increase CEC if charcoal has time to age (Liang et al. 2006). In this study, the results showed that OM loss in HS site influenced a decrease of CEC value. Organic matter also provides chemically active exchangeable cations, including NH4+, K, Ca and Mg (Waring and Running 2007). Although the amount of organic matter in HS site was reduced, yet one year after the fire – CEC value was not at desirable level in this region. The results showed that with increasing severity of fires the amount of potassium decreased. Rastad (2008) reported potassium loss due to the transmission of ash particles after fire as runoff or erosion form. One year after the fire, available soil P in HS site was less than in LS and C sites, and this difference was statistically significant. Fire directly affects K and P availability in soil by altering chemically forms of these elements, and also indirectly – by altering soil temperature, pH, and water flow. Soil P content generally depends on soil temperature during a fire and tends to increase in burned soils (Marion et al. 1991; Kutiel and Shaviv 1993). Duguy et al. (2007) observed a decrease in total and available phosphorus in soil following the fire in eastern Spain. It seems that low-severity fires have a positive effect on phosphorus contents in soil (Rau et al. 2009). The results of this study showed that saturated moisture content was reduced with increasing severity of fire as shown in PCA diagram. The highest saturation percentage was observed in LS and C sites. Are et al. (2009) showed that moisture content was reduced after the fire, on account of low organic matter contents in burned area and reduced water holding capacity in soil. Boyer and Miller (1994) found that burning pine trees could reduce soil moisture saturation percentage. Soil carbon dioxide decreases with increasing fire severity. Fire can destroy a lot of trees, terrestrial animals, microorganisms, fungi and bacteria, thus the amount of carbon dioxide in soil decreases owing to dereduced number of breathing organisms in soil (Sedighi 2011).

Physical soil properties

PCA results obtained in this study showed that BD was directly correlated with the severity of fire. BD values increase as a result of collapsing soil organo-mineral aggregates (Giovannini et al. 1988) and sealing due to clogging of soil pores by ashes or freed clay minerals (Durgin and Vogelsang 1984). This implies reduction of soil water holding capacity (Boyer and Miller 1994; Fayos 1997), and consequent accentuation of soil runoff and surface erosion (Martin and Moody 2001). In particular, with the loss of soil organic matter soil aggregate stability is compromised, contact surfaces between soil particles change and BD usually increases (Badia and Marti 2003; Seymour and Tecle 2004; DeBano et al. 2005). Reduction of silt amounts in soil is expressed, at the same time as fire directly affects many soil properties during its occurrence and immediately after (Knicker et al. 2005).

Conclusions

The fire severity had an impact on soil physical and chemical properties one year after the fire. This effect was more evident in the case of soil chemical properties.

Soil physical and chemical properties are still far from ideal at high fire severity site (HS). On the other hand, low fire severity site (LS) does not show any significant changes in its soil properties and other characteristics being similar to control site (C) LS site indicates positive effect of fire on some soil properties, such as CEC, OM content and SP. Based on this study, it seems that in some cases, controlled low-severity fires as a management strategy can be advisable tools in improving soil conditions,.

References

Are K.S., Oluwatosin. G.A., Adeyolanu O.D.,Oke A.O. 2009. Slash and burn effect on soil quality of an Alfisol: Soil physical properties. *Soil and Tillage Research*, 103, 4–10.

Arocena J.M., Opio C. 2003. Prescribed fire-induced changes in properties of sub-boreal forest soils. *Geoderma*, 113, 1–16.

Badia D., Marti C. 2003. Plant ash and heat severity effects on chemical and physical properties of two contrasting soils. *Arid Land Research and Management*, 17, 23–41.

Bauhus J., Khanna P.K. Raison R.J. 1993. The effect of fire on carbon and nitrogen mineralization and nitrification in an Australian forest soil. *Australian Journal of Soil Research*, 31, 621–639.

Binkley D., Richter D., David M.B., Caldwell B. 1992. Soil chemistry in a loblolly/longleaf pine forest with interval burning. *Ecological Applications*, 2, 157–164.

Black C.A. 1979. Methods of soil analysis. *American Society of Agronomy*, 2, 771–1572.

Blake G.R., Hartge K.H. 1986. Bulk density. In: Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods, 2nd Edition (ed.: A. Klute). SSSA Book Series 5, Madison Wisconsin, USA, 363–375.

Boerner R.E., Huang J., Hart S.C. 2009. Impacts of fire and fire surrogate treatments on forest soil properties: A meta-analytical approach. *Ecological Applications*, 19, 338–358.

Brookes P.D., Stark J.M., McInteer B.B., Preston T. 1989. Diffusion method to prepare soil extracts for automated nitrogen-15 analysis. *Soil Science Society of America Journal*, 53, 1707–1711.

Fayos B.C. 1997. The roles of texture and structure in the water retention capacity of burnt Mediterranean soils with varying rainfall. *Catena*, 31, 219–236.

Boyer W.D.,Miller J H. 1994. Effect of burning and brush treatments on nutrient and soil physical properties in young longleaf pine stands. *Forest Ecology and Management*, 70, 311–318.

Busse M.D., Cochran P.H., Barrett J.W. 1996. Changes in ponderosa pine site productivity following removal of understory vegetation. *Soil Science Society of America Journal*, 60, 1614–1621.Cairney J., Bastias B. 2007. Influences of fire on forest soil fungal communities. *Canadian Journal of Forest Research*, 37 (2), 207–215.

Creighton M.L.,Santelices R. 2003. Effect of wildfire on soil physical and chemical properties in a Nothofagus glauca forest, Chile. *Revista Chilena de Historia Natural*, 76 (4), 16.

DeBano L.F., Neary D.G., Folliott P.F. 1998. Fire's Effects on Ecosystems. John Wiley & Sons, New York, pp. 352.

DeBano L.F., Neary D.G., Ffolliott P.F. 2005. Soil physical properties. *General Technical Report RMRS-GTR-42*, 4, 29–51.Duguy B., Rovira P., Vallejo R. .2007. Land-use history and fire effects on soil fertility in eastern Spain. *European Journal of Soil Science*, 58, 83–91.

Duran J., Rodríguez A., Fernández-Palacios J.M., Gallardo A. 2010. Long-term decrease of organic and inorganic nitrogen pools due to pine forest wildfire. *Annals of Forest Science*, 67 (2), 1–7.

Durgin P.B., Vogelsang P.J. 1984. Dispersion of kaolinite by water extracts of Douglas-fir ash. *Canadian Journal of Soil Science,* 64, 439–443.

Ekinci H. 2006. Effect of forest fire on some physical, chemical and biological properties of soil in Çanakkale. International Journal of Agriculture and Biology, 8,(1), 102–106.

Fisher R.F., Binkley D. 2000. Ecology and Management of Forest Soils. Wiley, New York, pp 489.

Franklin S.B., Robertso P.A., Fralish J,S. 2003. Prescribed burning effects on upland *Quercus* forest structure and function. *Forest Ecology and Management*, 184, 315–335.

Giovannini G., Lucchesi S., Giachetti M. 1988. Effects of heating on some physical and chemical parameters related to soil aggregation and erodibility. *Soil Science*, 146, 255–261.

Hatten J., Zabowski D., Scherer G., Dolan E. 2005. A comparison of soil properties after contemporary wildfire and fire suppression. *Forest Ecology and Management*, 220, 227–241.

Heather E., White R. 2008. Soils Under Fire: Soils Research and the Joint Fire Science Program. United States. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report, PNW-GTR-759, pp. 24.

Hino T., Tsutom H. 2009. Effects of disturbance history and environmental factors on the diversity and productivity of understory vegetation in a cool-temperate forest in Japan. *Forest Ecology and Management,* 257, 843–857.

Hutchinson T.F., Sutherland E.K., Yaussy D.A. 2005. Effects of repeated prescribed fires on the structure, composition, and regeneration of mixed-oak forests in Ohio. *Forest Ecology and Management*, 218, 210–228.

Jafarei M. 2001. Experimental methods for physical and chemical properties of soil. Theoretical and practical principles. First publication. Tehran. Published by Neday Zoha. , pp. 286.

Johnson W.J., Curtis P.S. 2001. Effects of forest management on soil C and N storage: meta analysis. *Forest Ecology and Management*, 140 (2/3), 227–238.

Kalra P., Maynard D.G. 1991. Methods Manual for Forest Soil and Plant Analysis. Information Report, NOR-X-319 Forestry Canada, Edmonton, AB., pp. 93.

Knicker H., Gonzalez-Vila F.J., Polvillo O., Gonza´lez J.A., Almendros G. 2005. Fireinduced transformation of C- and N- forms in different organic soil fractions from a Dystric Cambisol under a Mediterranean pine forest (*Pinus pinaster*). Soil Biology and Biochemistry, 37, 701–718.

Kutiel P., Shaviv A. 1993. Effects of soil type, plant composition, and leaching on soil nutrients following a simulated forest fire. *Forest Ecology and Management*, 53, 329–343.

Liang B., Lehmann J., Solomon D., Kinyangi J., Grossman J., O'Neill B., Skjemstad J.O., Thies J., Luizao F.J., Petersen J., Neves E.G. 2006. Black carbon increases cation exchange capacity in soils. *Soil Science Society of America Journal*, 70, 1719–1730.

Liechty H.O., Luckow K.R., Guldin J.M. 2005. Soil chemistry and nutrient regimes following 17–21 years of shortleaf pine-bluestem restoration in the Ouachita Mountains of Arkansas. *Forest Ecology and Management,* 204, 345–357.

MacKenzie M.D., DeLuca T.H., Sala A. 2004. Forest structure and organic horizon analysis along a fire chronosequence in the low elevation forests of western Montana. *Forest Ecology and Management,* 203, 333–343.

Mallarino A.P. 2003. Field calibration for corn of the Mehlich-3 soil phosphorus test with colorimetric and inductively coupled plasma emission spectroscopy determination methods. Soil Sci. Soc. Am. J. 67, 1828–1934.

Maranon T, Ajbilou R, Ojeda F and Arroya J. 1999. Biodiversity of Woody Species in Oak Woodland of Southern Spain and Northern Morocco. *Forest Ecology and Management,* 115, 147–156.

Marion G.M., Moreno J.M., Oechel W.C.1991. Fire severity, ash deposition, and clipping effects on soil nutrients in chaparral. *Soil Science Society of America Journal*, 55, 235–240.

Martin D.A., Moody J.A.2001. Comparison of soil infiltration rates in burned and unburned mountainous watersheds. *Hydrological Processes*, 15, 2893–2903.

Moreno J.M., Vázquez A., Vélez R. 1998. Recent history of forest fires in Spain. In: Large Fires (ed.: J.M. Moreno). Backhuys Publishers, Leiden, The Netherlands, 159–185.

Olfat A.M., Pourtahmasi K. 2010. Anatomical Characters in Three Oak Species (Q. Libani Q. Brantii and Q. infectoria) from Iranian Zagros Mountains. *Australian Journal of Basic and Applied Science*, 4 (8), 3230–3237.

Rastad H. 2009. Study of fire effect on soil physical and chemical properties and regeneration at conifer stands of Guilan provience. Case study Siahkal forests. M.S. Thesis. University of Gillan, pp. 95.

Rau B.M., Johnson D.W., Blank R.R., Chambers J.C. 2009. Soil carbon and nitrogen in a Great Basin pinyon–juniper woodland: Influence of vegetation, burning, and time. *Journal of Arid Environments*, 73, 472–479.

Sagheb-Talebi K., Sajedi T., Yazdian F. 2004. Forests of Iran [in Persian with English summary]. Research Institute of Forests and Rangelands, Iran, pp. 28.

Sedighi M. 2011. Study of fire effects on under-story plant spicies composition and soil physical and chemical properties in Guilan-Iran (Case study: Saravan). M.S. Thesis. University of Gillan, pp. 95.

Seyour G., Tecle A. 2004. Impact of slash pile size and burning on ponderosa pine forest soil physical properties. *Journal of the Arizona-Nevada Academy of Science*, 37, 74–82.

Waring R.H., Running S.W. 2007. Forest Ecosystems: Analysis at Multiple Scales, third edition, Academic Press, San Diego, CA, pp. 440.