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The Response of Soil Physicochemical Properties in the Hyrcanian Forests of Iran to Forest Fire Events

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Abstract: When forest fires occur, highly complex effects on soil properties and hydrological processes are activated. However, in countries such as Iran, these consequences are not widely studied and there is a lack of studies. Therefore, the main aim of this study was to investigate the effects of wildfire on soil quality characteristics in a representative forest area located in the Hyrcanian forests, specifically, in the Zarrinabad watershed of Sari. For this purpose, four different sites, including unburnt natural (UNF), burned natural (BNF), unburnt plantation (UPF), and burned plantation forests (BPF) were selected. Soil sampling was performed at each site using the random, systematic method at a depth from 0 to 30 cm. To investigate the effects of fire on physical and chemical properties indicators, 10 plots with dimensions of 0.5 × 0.5 m were placed at a distance of 1.5 m from each other at each site. Soil samples were transported to the laboratory and their physical and chemical properties were determined. The results showed that the percentage of sand, silt, aggregate stability, soil hydrophobicity, organic carbon, organic matter, soil total nitrogen, absorbable potassium and phosphorus, electrical conductivity, and pH, increased significantly when the soil surface is burned ($p \leq 0.01$, $p \leq 0.05$). However, clay percentage, initial, final, and average infiltration in the burned areas showed a decreasing trend in comparison with other forest statuses. Furthermore, no significant effects were observed on the true and bulk density, porosity, and soil moisture ($p \geq 0.05$). These findings demonstrate that forest fire effects in Iran must be considered as a key topic for land managers because soil properties and hydrological processes are drastically modified, and land degradation could be irreparably activated.

Keywords: hydrological processes; Iran; land management; natural forest; soil properties

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1. Introduction

Soils are key components of natural and human-made ecosystems that control the flow and storage of water and nutrients, affecting biological, physical, and chemical processes [1]. It is well-known that soil is a major component of forest and pasture ecosystems, consisting of a mixture of mineral particles, organic matter (OM), water, air, and living organisms [2,3]. Moreover, soil contributes to the growth and development of natural ecosystems, which directly benefit humankind [4–6]. Nowadays, much research is conducted to demonstrate the importance of soils, but forest areas affected by fire after human intervention need to be further investigated [7–9], especially in countries such as Iran.

Forests account for 29% of the Earth's ecosystem and are scattered throughout the world [10]. The main factors contributing to soil degradation in forest ecosystems are soil erosion, soil contamination, earthquakes, floods, storms, and fires [11,12]. In forest ecosystems, major land degradation processes include fire, deforestation, erosion, and pollution [13]. One of the most common hazards of forest watersheds is forest fires [14–16]. Future changes in the fire regime effect the composition of forests in terms of species, as some of them are adapted to other ecological patterns. Therefore, designing sustainable fire management is a challenge due to the elevated increase in fire weather severity conditions, which could push current suppression capacity beyond a tipping point, resulting in a substantial increase in large wildfires [17]. Fire is common and highly vulnerable in most of the world's forest ecosystems [18], which can change the function of natural ecosystems. Albeit recently, this may be a serious threat because of their social, environmental, and economic impacts [19]. Fire is a significant factor in the dynamics of terrestrial ecosystems, influencing numerous attributes, functions, and processes [20], and is often aggravated by human activities such as deliberate and accidental fires [21,22]. Human negligence, intentional construction fires, and the increased acreage of agricultural land are the most common causes of human fires [23–25].

Various investigations have focused on inter-fire feedback on the physical and chemical properties of the soil [26–29]. Based on previous literature, the response to forest fires effects the soil in two ways: the combustion of organic matter and, indirectly, changes in other components of the ecosystem, such as physical and chemical properties [30–33]. Uncommon decreases in humidity or increases in temperature may involve a high probability of outbreaks of recent nearby fires [34], and cause soil degradation processes such as compaction, increasing the loss of soil moisture content and decreasing the porosity, with direct implications in runoff activation [35]. After a fire, forest pH and available soil nutrient concentrations are also modified [36,37]. In Asian countries like Iran, forest studies are rare and there is no land management program in vulnerable regions [38,39]. Iran is among the 56 poorest countries in the world in terms of forest quality, where thousands of hectares are burned each. Forest fires destroy more than 6000 hectares of forest lands of Iran every year [40]. Furthermore, according to FAO, between 1998 and 2002, an average of 6500 hectares of Iran's forests were destroyed annually by fire, which was related to climatic and human factors [41].

Currently, just a few studies have documented the impact of forest fires on Iranian soils. For example, Jafarian et al. [42] showed how infiltration changes during different seasons of the Charat watershed in the province of Mazandaran. They observed that areas without, or low-intensity, fire were not significantly different in terms of infiltration, but in severe areas, the final infiltration was lower than in other seasons. In another research, Magomani and Tol [43] showed that wildfire generates a significant negative impact on aggregate stability and bulk density, as well as other soil physical properties in semi-arid savannah environments in Iran. Alli et al. [44], in the forests of the Zaribar Lake watershed, showed that fire caused a significant increase in soil total nitrogen (STN), and in total phosphorus and extractable potassium in the short-term, respectively. However, in the long-term, only the extractable potassium returns reached stable levels. Arunrat et al. [45] reported that fire did not register significant changes in soil organic carbon (SOC), STN, and other soil properties (soil texture, available P, exchangeable K, Ca and Mg, bulk density, and OM), due to low fire intensity and short fire duration, and only pH and electrical conductivity significantly increased ($p \leq 0.05$).

The Hyrcanian forests of Northern Iran are one of the most important natural ecosystems and several studies agree that they play an important role in soil and water conservation, and in the livelihoods of indigenous populations [46]. However, forest fires are occurring there and land managers, stakeholders, and scientists, do not have enough information to understand how soils are responding. Consequently, there is always uncertainty regarding the negative or positive impacts of fire on soil properties and forest cover in the Hyrcanian lands. Thus, this study is intended to research the short- (2013), and long-term

(2019) effects of fire on certain soil properties (physicochemical and hydrological) in two different situations: natural, and planted forests.

2. Materials and Methods

2.1. Site Description

The study area is located close to the village of Zarrinabad in the city of Sari, in Northern Iran, near the Caspian Sea. For the present study, two similar areas, which were affected by fire in 2013, were selected. One of the areas has a plantation forest and the other one has a natural forest (Figure 1). The mean temperature, precipitation, and relative humidity of the studied area are 612.9 mm, 15.4 °C, and 60–77%, respectively. The forests are generally located in the lower part of the region from 385 to 750 m.a.s.l. The area of the fire in the planted forest was 17661 m^2 and in the natural forest 6074 m^2, with a general inclination of 30%. Trees are deciduous species including *Fagus*, *Qak*, *Carpinus betulus*, *Alnus*, *Ulmus minor*, *Parotica persica,* and *Gleditsia capsica*. Shrubs include *Mespilus germanica*, *Crataegus elbursensis*, *Crataegus monogyna,* and *Lycopersicum esculentum*. Regarding herbaceous and woody species of forest floor, we can find *Primula vulgaris*, *Rubus strigosus*, *Euphorbia antiquorum,* and *Polypodiopsida*.

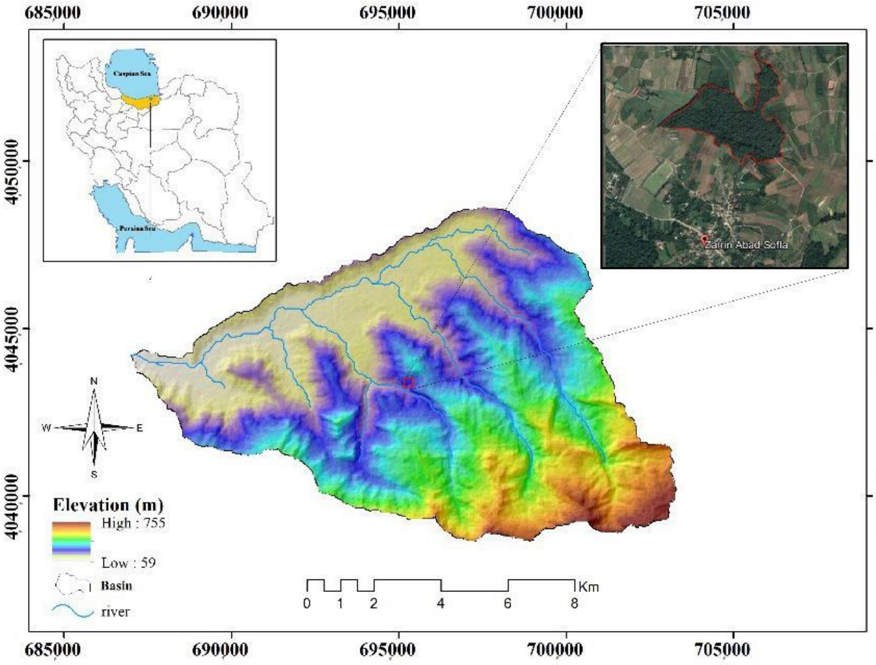


Figure 1. Location of the Zarrinabad village in the Mazandaran Province (Iran).

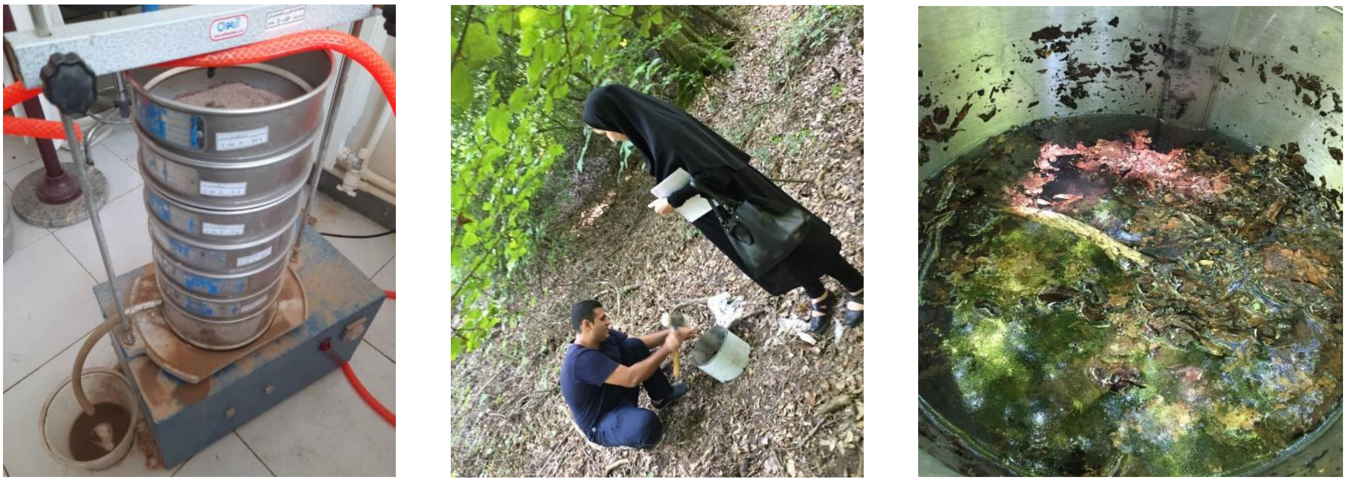
2.2. Study Area, Data Collection and Soil Sampling

In the study area, fires occurred without non-known reasons in natural and plantation forests in 2013. In July 2019, to study and compare the effect of fire on soil properties in these forests, unburnt treatments (controls) were considered. Finally, four treatments by means of unburnt natural (UNF), burned natural (BNF), unburnt plantation (UPF), and burned plantation forests (BPF) were selected (Figure 2). In order to avoid errors caused by spatial changes in soil characteristics, the control samples were selected in the vicinity of the treatment samples in such a way that there is no effect of fire in that place. The sampling direction was perpendicular to the slope, and the fire site should be selected in such a way that there are no differences in parent materials, topography (slope, direction, and height), physiography, and vegetation in the repeated sampling locations. To investigate the effects of fire on hydrological characteristics, erosion, and other qualitative factors of soil, 10 plots with dimensions of 0.5 × 0.5 m were established at a distance of 1.5 m from each other. Considering the control samples, this research had four treatments with 10 repetitions, and a total of 40 soil composite samples were collected from the investigated area. Soil sampling from 0–30 cm soil depth was carried out randomly and systematically from the area. After sampling, they were transferred to the laboratory. Subsequently, a soil sample was divided into two parts, air-dried, and sieved into a 2 mm sieve to remove the plant debris.

Figure 2. A view of the sampling area and natural forests.

2.3. *Measurement of Soil Physical Properties*

Soil moisture content was measured by the weighting and drying method, soil texture was estimated using the hydrometric method [47,48], bulk density using the gravel method [49,50], and true density with a pycnometer (Figure 3a). In detail, we will explain how porosity, aggregate stability, soil hydrophobicity and permeability were measured.



(**a**) (**b**)

Figure 3. View of laboratory (**a**) and field measurements (**b**).

2.3.1. Soil Hydrophobicity Measurement

Soil hydrophobicity is defined as the effort of wetting the soil with water [51]. This effect may be related to several variables, such as soil size, OM type, and mineralogical composition, among others. Soil hydrophobicity can therefore vary greatly from a spatial and temporal perspective [52]. A water droplet infiltration time test (WDPT) was used [53,54]. For each soil sample, a few drops of distilled water was placed on the soil surface using a micro-micropipette, and the time was grouped into different categories [55], as Table 1 shows.

Table 1. Soil hydrophobicity level based on the WDPT (water droplet infiltration time test) method.

Hydrophobicity Level	Time of WDPT (s)
No hydrophobicity	<5
Low hydrophobicity	5–60
High hydrophobicity	60–600
Severe hydrophobicity	600–3600
Very severe hydrophobicity	>3600

2.3.2. Soil Permeability

The water permeability of the soil was measured with a double-ring infiltrometer [56,57]. This device is characterized by a double-ring with diameters of 30 and 60 cm and a height of 25 cm, respectively [58–60]. We placed the double ring infiltrometer in the center of each plot and, with the help of a hammer, we stroked evenly on the edge of the ring to place them at a depth of 10–15 cm. After installing both rings and before pouring water into them, the bottom of the middle ring was covered with plastic foil to prevent the surface layer from corroding [61]. After pouring water into the middle and outer rings, the plastic of the middle ring surface was gently pulled and at this moment, the time was recorded with a stopwatch. Water level drop was recorded after different times using an Ashl (Figure 3b).

2.4. Measurement of Soil Chemical Properties

Soil pH was measured by the potentiometric method [62,63], electrical conductivity by an electric conduction device (EC meter) and preparation of soil and water extract with a ratio of 1:2.5 [64]. SOC was determined by the Walkley-Black method [65,66]. The “Van Bemmelen factor” of 1.724 has been used to calculate the final OM (%) as follows [67]:

$$\text{OM } (\%) = \text{SOC } (\%) \times 1.724 \quad (1)$$

Moreover, STN was estimated by the Kjeldahl method [68], soil-absorbable potassium using a flame photometer [69], and soil absorbable phosphorus was measured following the Olsen method [70,71].

2.5. Statistical Analysis

Using the SPSS v. 22 (software IBM, New York, NY, USA), the data normality test was performed, for which Kolmogorov-Smirnov tests were used [72,73]. Then, two-way ANOVA was used to compare soil characteristics in both paired conditions after obtaining the normality of the data. Additionally, the comparison of the average soil’s physical and chemical properties was carried out using the Duncan test at a confidence level of 1 and 5%. The Pearson coefficient is used to test the linear correlation between two random variables [74]. The value of this coefficient can vary between −1 to 1, where 1 means complete positive correlation, 0 means no correlation, and −1 means complete negative one.

3. Results

3.1. Physical and Chemical Properties of The Soil

Table 2 presents the results of the two-way analysis of the variance of the independent effect of the fire, the type of plot, and the interaction of the fire-affected area for different physical and chemical properties. Results obtained from the Pearson correlation analysis showed that there was no significant relationship at the 5% level between SOM and hydrophobicity level (Table 3). The results of comparing the means by the Duncan method showed that the natural BNF registered the highest aggregate stability (0.25%) and UPF the lowest (0.11%) (Figure 4a). The highest rate of hydrophobicity (12.26 s) was correlated with the BPF and the lowest with the UNF (2.03 s) (Figure 4b). True and bulk density was the highest (2.91, 1.77 g/cm^3) in the BNF, respectively, and registered the lowest true and bulk density (2.81 and 1.62 g/cm^3) in the UNF (Figure 4c, d). The percentage of soil porosity in the UNF obtained the highest rate (44.2%) and in the BPF the lowest (41.2%) (Figure 3e). Regarding the soil texture, the highest percentage of sand and silt (46.9 and 46%, respectively) was in the BNF, and the lowest in the UNF (31 and 39.3%, respectively) (Figure 4f, g). The percentage of clay in the UNF registered the highest rate (23%) and in the BPF reached the lowest (13.4%) (Figure 4h). The soil moisture content in the UNF obtained the highest rates (34.5%) and the BPF showed the lowest (26%) (Figure 4i). Regarding the initial, final, and average infiltration rates, in the UNF, we obtained the highest rate (145.85, 5.37 and 26.13 mm/min, respectively) the initial, and final infiltration rates in the BNF (37.5 and 1.8 mm/ min, respectively) and the average infiltration rate in the BPF (5.36 mm/min) were the lowest (Figure 4j–l).

Table 2. Two-way analysis of variance of soil physical properties in fire and non-fire treatments.

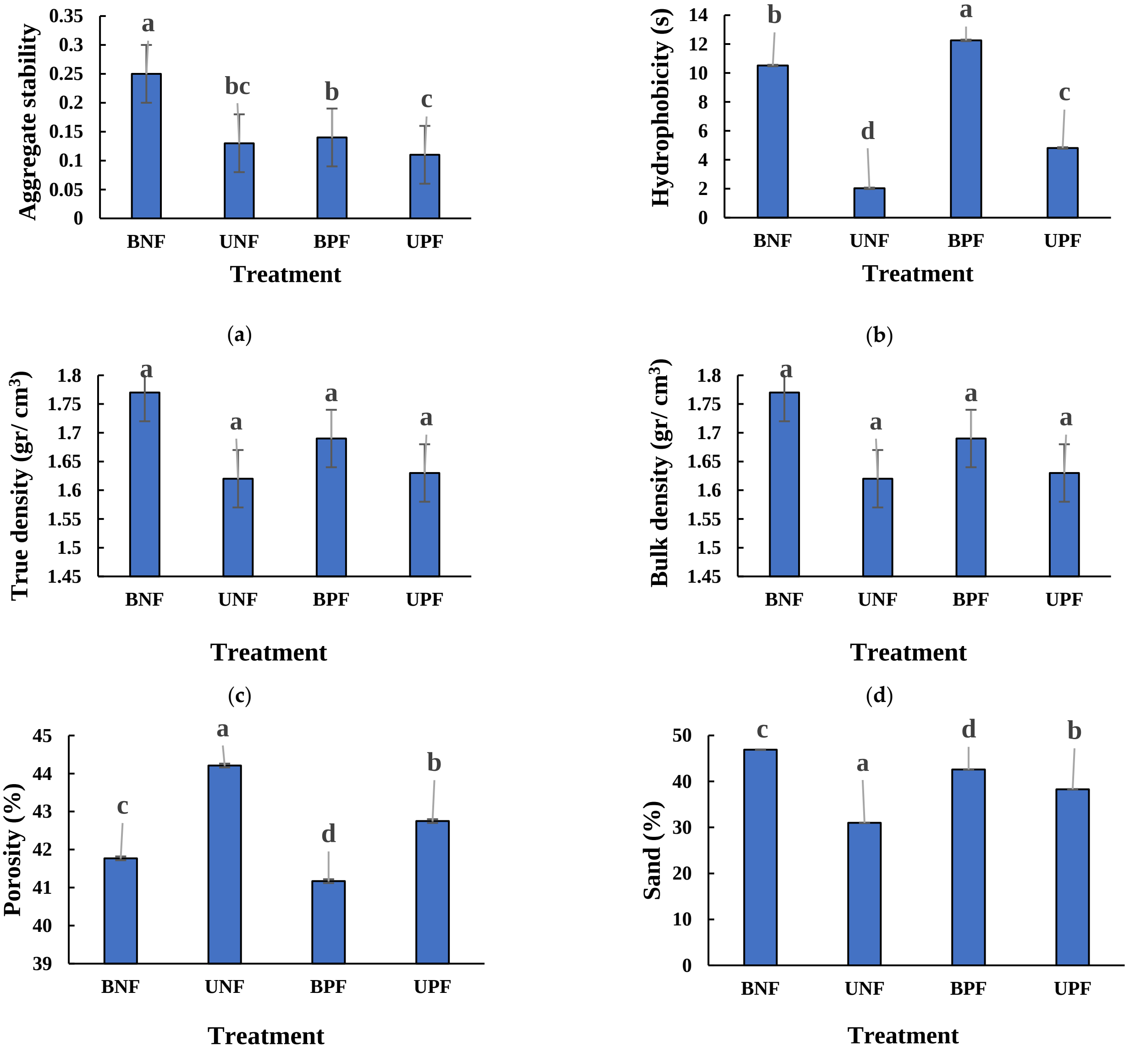
Factor	Treatment	F	Sig
Aggregate stability (%)	Fire	20.229	0.000 **
	Plot type	65.191	0.000 **
	Fire × Plot type	48.864	0.000 **
Hydrophobicity	Fire	370.778	0.000 **
	Plot type	29.983	0.000 **
	Fire × Plot type	1.611	0.21 ***
Bulk density	Fire	0.833	0.37 ***
	Plot type	0.084	0.77 ***
	Fire × Plot type	1.17	0.68 ***
True density	Fire	1.217	0.267 ***
	Plot type	5.345	0.057 ***
	Fire × Plot type	0.105	0.74 ***
Porosity	Fire	0.562	0.458 ***
	Plot type	0	0.994 ***
	Fire × Plot type	0.129	0.722 ***
Sand (%)	Fire	0.583	0.45 ***
	Plot type	22.762	0.000 **
	Fire × Plot type	7.712	0.009 **
Clay (%)	Fire	0.007	0.935 ***
	Plot type	10.179	0.003 **
	Fire × Plot type	11.783	0.002 **
Silt (%)	Fire	0.749	0.393 ***
	Plot type	10.652	0.002 **
	Fire × Plot type	0.405	0.528 ***
Soil moisture	Fire	3.36	0.07 ***
	Plot type	1.374	0.2 ***
	Fire × Plot type	0.363	0.5 ***
Initial infiltration (mm/min)	Fire	8.71	0.02 *
	Plot type	1.39	0.27 ***
	Fire × Plot type	31.27	0.0001 **
Final infiltration (mm/min)	Fire	496.9	0.000 **
	Plot type	502.475	0.000 **
	Fire × Plot type	67.303	0.000 **
Average infiltration (mm/min)	Fire	2.171	0.18 ***
	Plot type	6.125	0.035 *
	Fire × Plot type	36.317	0.000 **

*, ** Significant difference at the level of one and five per cent ($p \leq 0.01$), ($p \leq 0.05$). *** No significant difference at the 5% level ($p \geq 0.05$).

Table 3. Correlation between OM and hydrophobicity level.

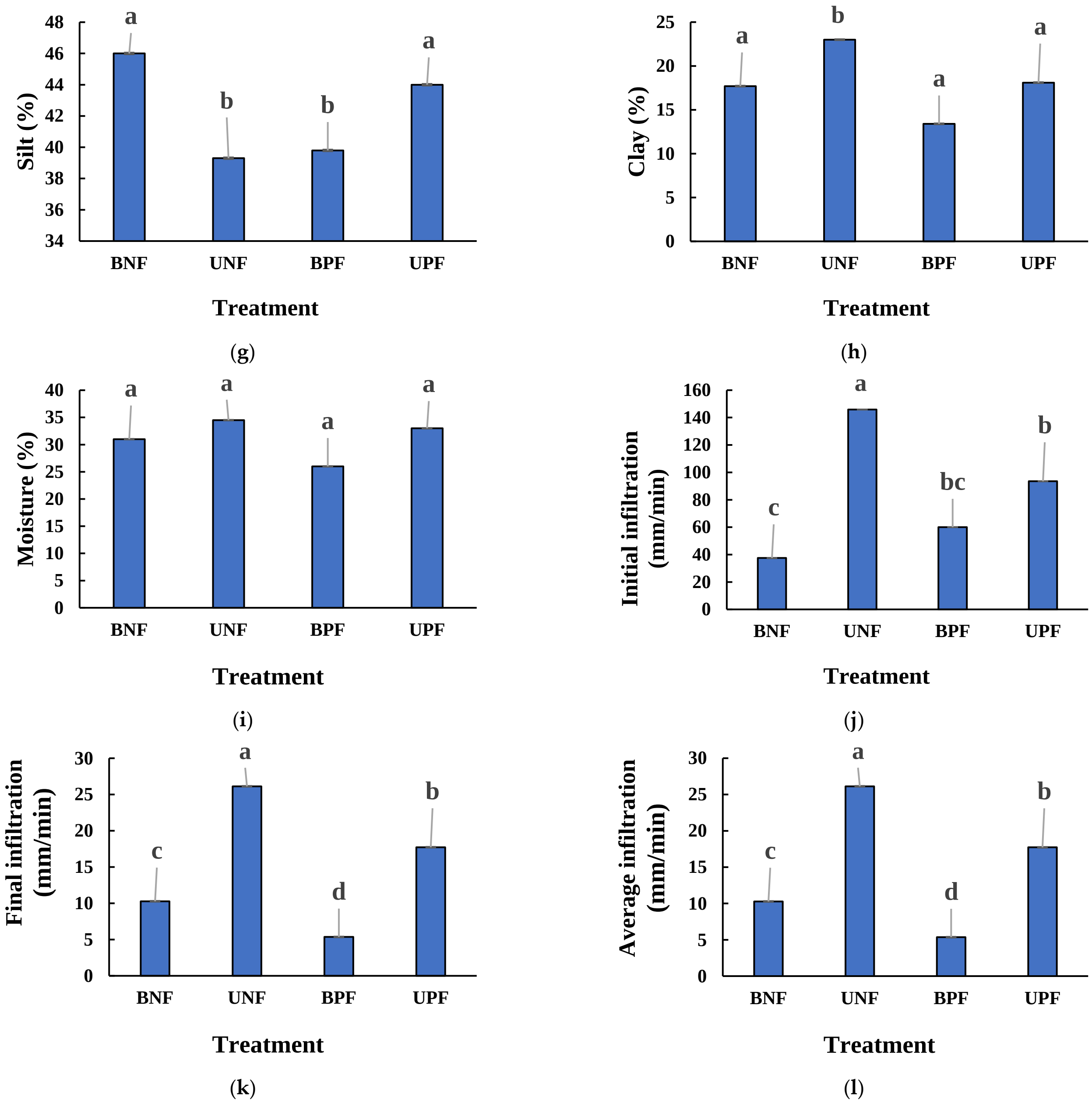
		Hydrophobic Level	**OM**
Hydrophobic level	Pearson correlation	1	−0.194
	Sig		0.232 ***
		Hydrophobic level	Organic material
OM	Pearson correlation	−0.194	1
	Sig	0.232 ***	

*** No significant difference at the 5% level ($p \geq 0.05$).



(**a**) (**b**) (**c**) (**d**) (**e**) (**f**)

Figure 4. *Cont.*



(**g**) (**h**)

(**i**) (**j**)

(**k**) (**l**)

Figure 4. Comparison of the average soil physical properties under different plot types (**a**–**l**); BNF: Burned Natural Forest, UNF: Unburnt Natural Forest, BPF: Burned Plantation Forest, and UPF: Unburnt Plantation Forest.

3.2. Soil Chemical Properties

Table 4 shows the results of a two-way analysis of variance considering the independent effect of fire, plot type, and the interaction of fire × plot type for different soil chemical properties. The results of comparing the means by Duncan's method showed that the BNF obtained the highest electrical conductivity (0.62 ds/m) and the UPF (0.47 ds/m) the lowest (Figure 5a). Additionally, pH was the highest in the BNF (6.52) and the lowest in the UNF (6.17) (Figure 5b). SOC and OM reached the highest amount in the BNF (5.26 and 9.02%, respectively) and the lowest values in the UPF (2.93 and 5.2%) (Figure 5c,d). Regarding this characteristic was found in the BNF (7.93 ppm) and the lowest in the UPF (4.24 ppm) (Figure 5e). Additionally, absorbable potassium registered the highest amount (560.87 ppm) in the BNF and the lowest (410.07 ppm) in the UPF (Figure 5f). Finally, the highest STN (0.3%) occurred in the BNF and the lowest levels (0.24%) in the UPF (Figure 5g).

Table 4. Two-way analysis of variance of soil chemical properties in fire and non-fire treatments.

Factor	Treatment	DF	F	Sig
pH	Fire	1	9.447	0.004 **
	Plot type	1	0.87	0.357 ***
	Fire × Plot type	1	1.113	0.294 ***
Electrical conductivity	Fire	1	3.91	0.04 *
	Plot type	1	2.509	0.122 ***
	Fire × Plot type	1	1.12	0.297 ***
Organic carbon (OC) (%)	Fire	1	1.167	0.28 ***
	Plot type	1	3.891	0.04 *
	Fire × Plot type	1	26.419	0.000 **
Phosphorus (ppm)	Fire	1	1.06	0.3 ***
	Plot type	1	0.4	0.53 ***
	Fire × Plot type	1	11.129	0.002 **
Potassium (ppm)	Fire	1	1.625	0.2
	Plot type	1	8.758	0.005 **
	Fire × Plot type	1	12.595	0.001 **
STN (%)	Fire	1	5.94	0.02 *
	Plot type	1	6.636	0.014 *
	Fire × Plot type	1	0.397	0.53 ***

*, ** Significant difference at the level of 1 ($p \leq 0.01$) and 5% ($p \leq 0.05$). *** No significant difference at the 5% level ($p \geq 0.05$).

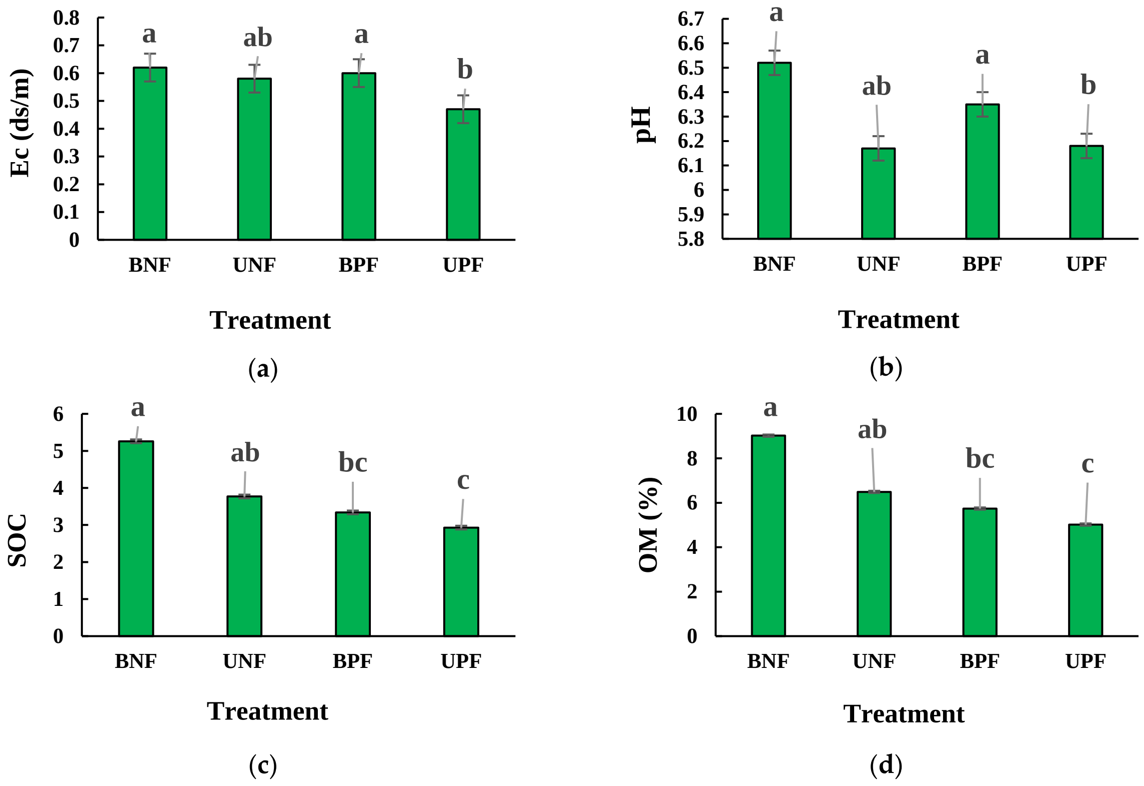
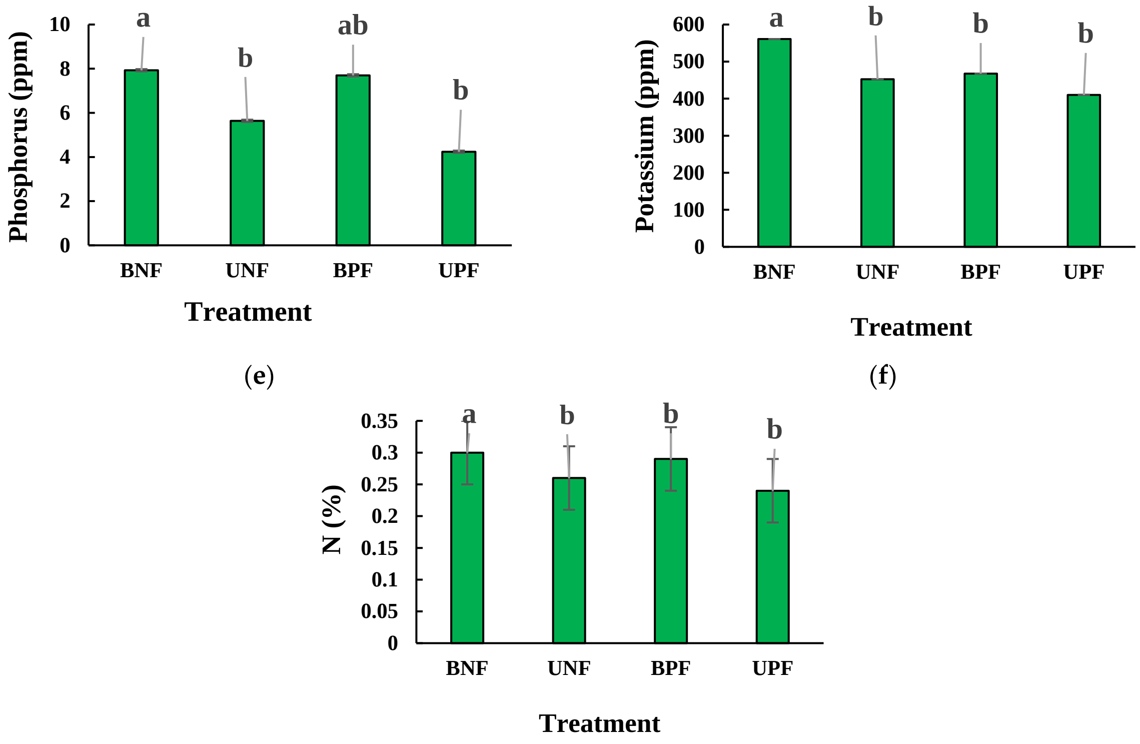


Figure 5. *Cont.*



(**e**) (**f**)

(**g**)

Figure 5. Comparison of the average chemical properties under different plot types (**a**–**g**); BNF; Burned Natural Forest, UNF: Unburnt Natural Forest, BPF: Burned Plantation Forest, and UPF: Unburnt Plantation Forest.

4. Discussion

In this study, fire demonstrated direct and indirect impacts on soils under different forest ecosystems. Direct effects include rapid combustion and the decomposition of litter, increased mineral availability, and changes in soil temperature and humidity. Although indirect effects from a fire are associated with changes in vegetation, these effects included the creation of cavities and the germination and growth of species that need more light in the early stages of growth.

4.1. The Effect of Fire on Soil Physical Characteristics

The response of aggregates to forest fires is complex and depends on the severity of the fire and how it affects other properties, such as OC and hydrophobicity. Aggregate stability is one of the most important factors affecting the flow and transfer of water into the soil. The effects of forest fires on aggregate stability also depend on various factors such as the severity of fires, changes in soil OM and the formation of hydrophobic materials [75]. In this research, results from variance analysis showed that fire increases aggregate stability, especially in the BNF, relative to other plot types. This is due to the formation of a hydrophobic layer (due to the burning of OM) on the outer surface of the aggregates, which as a strong bond prevents the separation of aggregates from each other [76]. The soil OM is considered a strong aggregating agent that holds sand, silt, and clay particles together into aggregates, and it is essential to realize the role it plays during and after burning [77]. The results of this research agree with the results of Rodríguez et al. [78] and Arcenegui et al. [75], while Garrido-Ruiz et al. [79] claimed that burning reduced aggregate stability.

According to the results, the rate of hydrophobicity has increased in BPF, relative to other treatments. This can be due to the burning of soil OM and the formation of hydrophobic compounds on the outer surface of soil particles, and OM can favor hydrophobicity due to the total or partial layer of the surfaces and pores of the soil particles, which form aggregates with hydrophobic organic substances, resulting in different degrees of hydrophobicity [80]. The source of hydrophobicity can be substances derived from plants (aromatic oils, resins, or other hydrophobic compounds), fungi and fungal micro-organisms, humic acids [81], decomposed plant material, and hydrocarbons. Increased soil hydrophobia can result in reduced soil and water content, followed by extensive runoff and soil erosion. Therefore, the decrease in soil nutrients in the years after the fire can be due to the hydrophobic nature of the soil, which is caused by the burning of soil organic matter (SOM), which agrees with the results of Robichaud et al. [82], Stoof et al. [83], and Malvar et al. [84].

Based on the results, the percentage of clay in the burned areas has significantly decreased compared to the unburned areas, and UNF treatment had the highest rate of clay relative to others. Under oak forest, Heydari et al. [85] stated that the clay content in the A horizon decreases following a high-intensity fire. These results agree with the study by Agbeshie et al. [86]. They also noted that the loss of clay particles following a fire led to a gain in sand particles. Likewise, the percentage of sand and silt in the burned areas increased significantly relative to the unburned, and the BNF treatment registered the highest rates of sand and silt relative to others. Granged et al. [87] also reported an increase in the percentage of sand particles as opposed to a decrease in clay particles. The reduction in the percentage of clay due to fire in this study can be attributed to the selective separation of clay particles by raindrops, and the occurrence of erosion after burning the vegetation and bare soil [88]. In this regard, Hamman et al. [89] considered the cause of coarse soil texture after a wildfire as the formation of coarse sand-like particles from clay and silt components due to heat caused by a fire at temperatures above 250 °C. Chowdhury et al. [90] approved that burning increases the amount of sand and silt.

The true and bulk density of the soil in this study increased after the fire, but this change was not statistically significant, which can be attributed to the improvement of aggregate stability after the fire. Additionally, the porosity of the soil did not decrease significantly after the fire. Norouzi [91] attributed the decrease in soil porosity due to fire to the increase in soil bulk density and the decrease in aggregate stability. Similarly, Cerdà and Doerr [92] reported that fire increases the bulk density of the soil, although the changes are not significant.

The results of this study showed that the percentage of soil moisture in the burned treatments decreased compared to the unburned treatments, but the difference was not statistically significant and improved to the level before the fire. This can be due to interactions within the soil and the gradual disappearance of the hydrophobic layer on the surface of soil particles. The results of this study are in disagreement with Fultz et al. [93] whose research concluded that combustion increases soil moisture, but is in agreement with Holden et al. [94], whose research concluded it reduces soil moisture.

The results of this study indicated that the fire in the soil reduced initial, final, and average infiltration. After a fire occurs, the soil surface is exposed to the formation of surface ridges and soil water repellency (hydrophobicity), which increases due to its continuity a few centimeters below the soil surface. In addition, reducing surface cover, such as soil litter, and increasing soil hydrophobicity, reduces the infiltration of water into the soil [31]. These results are in agreement with Tessler et al. [95], and Robichaud et al. [96] whose research concluded that fire burning reduces infiltration.

4.2. The Effect of Fire on Soil Chemical Characteristics

The amount of SOC in the BNF was higher than in other treatments. This can be due to reduced mineralization due to reduced biological activity. The reason for this is the reduction of mineralization due to the reduction of biological activities through the reduction of decomposition of humic substances due to burning, binding of organic carbon with minerals and protection against biochemical decomposition such as aromatic carbon compounds. The transformation of OM into very stable materials, such as the reduction of oxygen and carbon of alkyls and the production of short carbon chains, the production of hydrophobic materials on the soil surface, and the repeated introduction of nitrogen-fixing species in burnt treatments are other reasons [97]. There are various reports of the effects of fire on SOM, with some researchers increasing the amount of OC [98] and others decreasing the amount of SOC [15,99,100].

Soil total nitrogen had a similar process to SOC; measured STN increased after the fire. In this study, SOC content increased significantly due to fire. There was a high correlation between STN and SOC content. Therefore, an increase in STN can be the result of an increase in SOC due to fire. Based on research by Vermeire et al. [101], Gomez-Rey et al. [102], Badía et al. [103], and Montoya et al. [88], we showed that fire reduces STN. However, other studies presented contrary results, for example, Delijani et al. [104], who showed that burning increases the amount of STN.

In the present study, due to fire, the amount of phosphorus and potassium in the soil increased. The number of elements in the BNF was higher than in other treatments. The reason for the increase in the amount of phosphorus that can be used in fire treatment in this study can be due to the burning of OM from vegetation, which has increased the inorganic form of phosphorus and potassium in the soil. The direct supply of these elements in the form of ash into the soil provides an important source of readily available nutrients. The increase of soil phosphorus and potassium in the burned area is due to ash decomposition and the mineralization of organic phosphorus due to heat [103]. Phosphorus and potassium losses through evaporation have also been shown to be very small, while their release due to the decomposition of crop residues or the decomposition of OM by fire can be one of the main reasons for increased phosphorus in burnt soil [105]. Asadian et al. [106] agree that burning increases the amount of phosphorus.

The results of this study indicated that the electrical conductivity in the treatment of burns was significantly higher than in the control areas. Increasing the electrical conductivity of soils under fire increases the number of soluble salts resulting in the ignition of SOM. Additionally, the formation of carbon black after the fire, and the combination of ash with soil, are other factors that increase the electrical conductivity of soil after fire [107]. Fire in soils containing carbonates slightly increase soil pH [108]. Results from this study indicated that fire significantly increased soil pH. Increasing the pH value can be one of the benefits of fire because, with increasing soil reaction, especially in acidic soils, the ability to absorb elements in the soil increases [109]. Increased soil pH after a fire is due to the incomplete combustion of OM and the release of cations, such as calcium, potassium, magnesium, and phosphorus from the composition of OM, and the alkaline nature of ash and the combination of ash with soil, especially hydroxides released from mineral deposits. Abdulraheem et al. [110] and Arunrat et al. [45] confirmed that burning increases the amount of electrical conductivity and pH.

5. Conclusions

In this study, changes in chemical and especially physical characteristics of soil, such as hydrophobicity, and soil permeability over a short-term (7 years) in the forests of lower Zarrinabad, Mazandaran, were investigated. The results showed that fire in these forests has a critical role and effects soil quality characteristics and soil erodibility indicators. In addition, the response of soil quality factors is influenced by a variety of fire parameters, such as fire severity (e.g., amount of OM consumed), recurrence, fire season, and time after the fire. All of these factors have significantly different impacts on fire. In this study, the effect of fire on most of the studied factors was positive, due to the negative effects on hydrophobicity and soil permeability. It can be stated that the change in soil properties due to fire indicates the importance of fire and it is very important to evaluate the soil erodibility properties, as well as to study the changes made in the soil during the recovery period. Therefore, both short-term and long-term studies on the effects of fire on physical and chemical properties are necessary to clarify the role of fire on forest ecosystems.

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