10.31195/ejejfs.568734

Eurasian Journal of Forest Science

2019 7(2): 145-156

http://dergipark.gov.tr/ejejfs

Investigation of natural resilience capacity of soil features affected by low severity ground wildfire after three years in Mediterranean forest ecosystem

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Abstract
Wildfires are one of the succession dynamics in the ecosystem, however forest ecosystems have natural resilience capacity to combat with natural disturbance regimes depend on local ecologic properties. This study was conducted to evaluate natural resilience capacity status of the soil's physical, chemical and hydrological features exposed to low severity ground wildfire after three years in the Bulutoglu village, Kahramanmaras. Particle size distribution, soil reaction (pH), electrical conductivity (EC), organic matter content (OM), dispersion ratio (DR), moisture content (MC), field capacity (FC), colloid/moisture equivalent (CM), particle density (PD), bulk density (BD) and porosity ratio (PR) analysis were performed on two groups of soils (burned and unburned counterpart). The environmental sensitivity index (ESI) include soil, vegetation, climate, and management quality of the study area was determined by MEDALUS methodology. According to the results, there is no environmental sensitivity in the study area. It was determined that the negative effects of soil properties improved significantly after three years from the wildfire except for the PR and BD values. There was no statistically significant difference between the analyzed two soil samples groups. It was concluded that the difference between the bulk density and porosity ratios is not only due to the effects of the fire but also with grazing pressure, especially on the unburned area. According to the results, the burned area suffered from low severity ground wildfire has substantially been naturally rehabilitated itself within three years. Environmentally sensitivity (ESI) of the study area was a play an important role in the recovery of soil features. Additionally recommended avoiding some activities that will compress the soil for increasing natural resilience capacity after a wildfire.

Keywords: Ground wildfire, Soil ecology, Resilience capacity, Fire ecology

INTRODUCTION

Wildfires have occurred in nature since the beginning of life on our planet. Generally all most of all forest fires are caused by human activities (92%) in Turkey (GDF, 2013). Although wildfire is a common disturbance factor in Mediterranean forest ecosystems, wildfires are a part of the ecosystems and secure the sustainability of the ecological cycles (Eiten 1992; Lasanta and Cerdà 2005; Mataix-Solera et al. 2011; Keesstra et al. 2014; Pereira 2015, Verma et al. 2012).
One of the most affected ecological factors is the soil by wildfire. Wildfire can change the soil properties with different degrees. This change in soil properties depends on local conditions such as fire regime (severity, duration and repetition) (Flannigan et al. 2000) and also topography, vegetation or microclimate (Certini 2005).

Changes in the physical and chemical properties of the soil due to destruction of the natural vegetation after forest fires, adversely affect the infiltration ratio, porosity ratio, and water storage capacity (Ferreira et al. 2005; Martin and Moody 2001; Neary et al. 1999). Robichaud (2000) stated that fires can decrease from 10% to 40% soil hydraulic conductivity.

After forest fires, soil organic matter changes as quantity and also affects soil structure with burned and charred materials and erosion (Knicker et al. 2005; Rumpel et al. 2006). Although organic ash deposits occurring immediately after the fire are particularly effective in reducing the surface flow in the hills (Cerda and Doerr 2008), they may reduce the hydraulic conductivity by obstructing the pores in depression areas. Organic matter losses affected other chemical and physical properties such as cation exchange capacities (Ulery et al. 2017) and aggregate stability. Response of aggregate stability to forest fires is complex, there are different opinions about the effect of fire. Because aggregate stability depends on how the organic matter content affects other relevant properties such as soil microbiology, water repellency and soil mineralogy (Mataix et al. 2011).

Scientific studies show that each ecosystem has its own "fire regime". Fuel accumulation ratio is also an important factor in the wildfire. Especially in the Mediterranean Basin where the potential fuel accumulation ratio is greater than the ratio of decomposition. It has been determined that plants develop adaptability capabilities to survive after wildfire (Kalabokidis 1999; Christensen 1994; Pausas and Vallejo 1999; Neyiyci 1988; Tavsanoglu 2009). Monitoring the changes in health indicators in forest soil after the wildfire is important as it can create data set in functional forest management plans as well as reclamation works in burned areas.

Understanding how the natural resilience power of the soil develops could give us an idea about the adaptation capacity of the ecosystem to wildfires. This study was carried out in the burned and unburned of the forests of Bulutoglu village, Kahramanmaras in order to reveal the change and temporal effects of low severity ground wildfire on some physical, chemical and hydrological properties of soil after three years in Mediterranean forest ecosystems.

MATERIALS AND METHOD

The research area is located around Bulutoğlu village Kel Ahmet Hill, on section 152 of Cinarpinar Forest Sub-district Directorate and it is 5 km away from the nearest settlement (Figure 1). The coordinates of the starting point of the fire is 37º 42' 13'' North latitudes – 36º 50' 11'' East longitudes. Average slope is 60%, altitude is 721 m and the predominant aspect is west of the study area. Study area size is 2.6 ha (burned area: 1.3 ha, unburned area: 1.3ha).

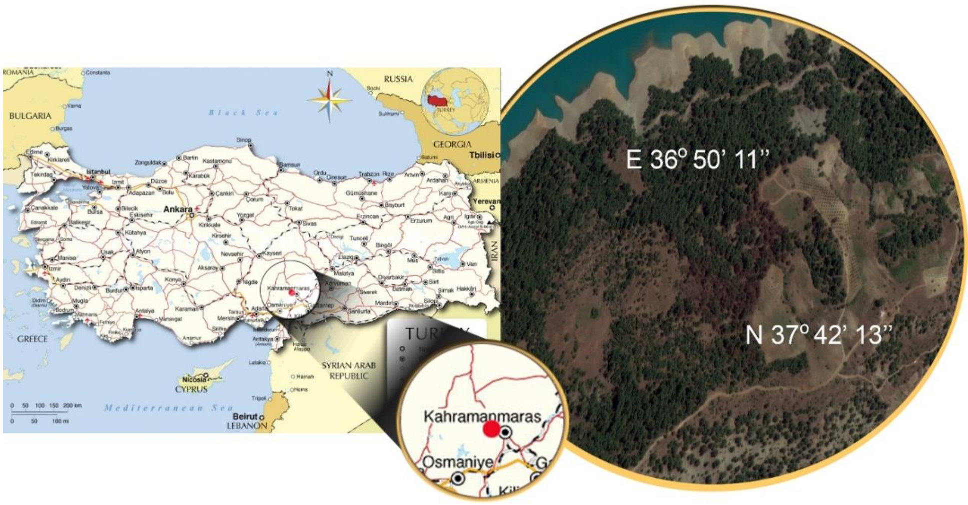

Figure 1. Location of the study area

Evaluation of severity of the fire

Fire severity is defined as the heat energy released by a fire in a unit of time. The severity of forest fires may vary from 20 kW/m to 100,000 kW/m, and >4000 kW/m is accepted as the upper limit for ecological effects (Bilgili 2014). In the research area, some tree deaths occurred in areas where fires were dominant and progressed with low-severity and slowly. It was intervened to the fire directly. It was obtained from post-fire records of the official documents that it had been a level 2 (10-500 ° C) ground fires. The effects of the low severity ground wildfire can be seen on the Google Earth images examined before and after the fire (Figure 2).

Figure 2. The study area before (2011) and after (2014) the wildfire (Google Earth, 2018)

The relative humidity of the research area is 18% and average temperature is 25ºC. The lowest average temperature was observed in January with 4.9°C and the highest in August with 28.5°C (DMI 2015). In the study area the dominant forest stand type is *Pinus brutia*. Furthermore, some of the recorded vegetation types are as; Turkish Red Pine (*Pinus brutia Ten.*), Juniper (*Juniperus spp*.), Oak (*Quercus sp*.), Storax (*Styrax Officinalis)*. In the study area, bedrock is very homogeneous and formed by a Calcium Carbonate.

Method
Soil sampling

The tree species and components are the same and the main species is *Pinus brutia*. No tillage and no reforestation were carried out and no trees were removed from the area after the low severity ground wildfire. The aspect is the same since burned and unburned areas are adjacent and part of the same geomorphology. Soil samples were taken from the same elevations and slopes.. The tree species and components are the same. The views are the same since they are the continuation of the same physiography. Soil samples were taken from the same elevations and slopes. Totally 108 surface soil samples were taken from 0-20 cm depth for analysis (27 disturbed soil and 27 undisturbed soil from each field). The disturbed soils samples depth (0-20 cm) was decided according to the effect of the fire severity after three years in the field survey. Although forest fires are generally effective on the upper horizon of the soil, the effects of the fire results vary depending on the amount of texture, structure and skeletal matter of the soil over many years. Due to the sandy soil in the research area and percolation

that occurred in the years after the fire, organic ash could be transported up to 20 cm in the horizon within macro pores in the study area.
Undisturbed soil samples were taken from 0-10 cm depth. Burned and unburned counterpart (control) area is presented in Figure 3.

Figure 3. Research Area (burned and unburned counterpart area)

Determination of environmental sensitivity index (ESI)

Environmental sensitivity to desertification of the study area analyzed and mapped applying DIS4ME. According to the MEDALUS methodology, some ecology parameters were used determination for quality index. Soil texture, drainage conditions, presence of rock fragments, soil depth, slope gradient, slope aspect, and parent material for Soil Quality Index (SQI); mean annual rainfall, slope aspect and aridity index for Climate Quality Index (CQI); vegetation type and plant cover for Vegetation Quality Index (VQI); land use intensity and policy enforcement for Management Quality Index (MQI) used with the following formula (1) (Kosmas et al. 1999). Desertification indicator system for Mediterranean Europe provided by DIS4ME (Desertlink 2004).

$$\mathbf{ESI} = (\mathrm{SQI} \times \mathrm{CQI} \times \mathrm{VQI} \times \mathrm{MQI})^{1/4} \quad (1)$$

Type of ESI values and ranges of indices were evaluated according to the following classification (Table 1).

Table 1. Types of ESI and ranges of indices in the karst ecosystem (Kosmas et al, 1999)

Type	Subtype	Range of ESI
Critical	C3	>1.53
Critical	C2	1.42-1.53
Critical	C1	1.38-1.41
Fragile	F3	1.33-1.37
Fragile	F2	1.27-1.32
Fragile	F1	1.23-1.26
Potential	P	1.17-1.22
Non affected	N	<1.17

Laboratory analysis

The particle size distribution of soil samples (PSD) was performed according to Bouyoucos hydrometer method (Irmak 1972; Gulcur 1974; Balci 1996). Dispersion ratio (DR) was performed according to Middleton (Ozyuvaci 1971; Balci 1996). The soil reaction (pH) was determined potentiometrically by the digital pH meter instrument in a 1 / 2.5 ratio of soil-pure water solution (Thomas 1996). Electrical conductivity (EC) was measured using EC meter in 1/2.5 ratio of soil-pure water solution (Rhoades 1982). Organic matter (OM) content was determined according to modified Walkley-Black method (Nelson and Sommer 1982). Field capacity (FC) was determined with Soil Moisture Pressure Plate (Gulcur 1974), Bulk density (BD) according to Ozyuvaci (1975), Particle density (PD) was determined by pycnometer method (Lutzh 1947). The porosity ratio (PO) was determined according to formula (1) (Oztan 1980) based on the relationship between BD and PD.

$$PR = (PD - BD)/PD \times 100 \quad [1]$$

Where;
PR = Pore volume (%),
PD = Particle density (gr/cm^{-3})
BD = Bulk density (gr/cm^{-3})

Colloid / Moisture Equivalent; the amount of clay obtained as a result of mechanical analysis was found by dividing the same soil by the ratio of moisture equivalents (Baver 1956). The Colloid / Moisture Index are assumed to be resistant to erosion if greater than 1.5.
Statistical analyses
All the analyses results were evaluated by using the SPSS statistical software. The t-test and Mann Whitney-U test were used to determine whether there was a difference between the means of the two groups (burned and unburned forest) (SPSS, 2012).

RESULT AND DISCUSSION

Determination of environmental sensitivity index (ESI) of the study area

Finally defined some physical ecologic qualities (SQI **x** CQI **x** VQI **x** MQI) were matched for definition of the ESI. Some local ecological features were used as Table 2.

Table 2. Some features were used for quality indexes

Quality Index	Features	Local values
SQI	Soil Depth	>75cm
	Slope Gradient	Step (18 to 35%)
	Texture	Sandy (SC, SiL, SiCL
	Parent Material	Sandstone, siltstone
	Drainage	Well drained
	Rock Fragment	Stony (20-60%)
CQI	Mean annual rainfall	>650mm
	Slope aspect	N,NW,N (<5%)
	Aridity index	<50
VQI	Vegetation type	Pines
	Plant cover	High (>40%)
MQI	Land use intensity	Low (sustainable)
	Policy enforcement	Complete (>75%)

Finally three subtype of sensitivity score (critical, fragile and potential) ranging from high sensitivity to low sensitivity were evaluated (Table 3).

Table 3. Quality indexes and ESI values

Quality index	Critical factors,%	Quality score	Quality class
SQI	21	1.26	Medium
CQI	0	1	Good
VQI	41	1.33	Medium
MQI	0	1	Good
	Sensitivity index	**Sensitivity score**	**Sensitivity class**
ESI	12	1.14	Area with no environmental sensitivity

Some soil features of the unburned (control) area

Considering the descriptive data from the unburned area which was not damaged by wildfire, the soil was determined to be erosion sensitive (DR >15) sandy loam, sandy clay with an average of porosity ratio was 22% (Table 4). Bulk density average was 1.97 gr/cm3. Fisher and Binkley (2000) states that heavy machines and humans activities are also effect on soil permeability and bulk density (Ampoorter vd., 2007). Average OM content was determined to be 3.86%.

Table 4. The descriptive statistics from of unburned (control) area

	N	Min	Max	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
pH	27	7.19	8.14	7.76	0.05	0.25	0.06	-0.86	0.45	0.03	0.87
EC (mmhos)	27	0.09	0.28	0.17	0.01	0.05	0.00	0.76	0.45	0.07	0.87
MC (%)	27	3.76	6.50	5.04	0.12	0.62	0.39	0.07	0.45	0.30	0.87
Sand (%)	27	56.35	81.77	66.68	1.45	7.54	56.83	0.47	0.45	-0.90	0.87
Silt (%)	27	7.11	21.05	14.31	0.74	3.83	14.69	0.21	0.45	-0.99	0.87
Clay (%)	27	8.59	29.48	19.01	1.04	5.40	29.17	-0.15	0.45	-0.88	0.87
DR (%)	27	10.07	32.43	24.20	1.02	5.33	28.36	-0.66	0.45	1.19	0.87
FC (%)	27	12.96	30.75	24.38	0.75	3.88	15.08	-0.75	0.45	1.46	0.87
CM	27	0.40	1.57	0.79	0.05	0.23	0.06	1.17	0.45	3.69	0.87
FP (%)	27	8.60	19.40	14.16	0.59	3.07	9.42	-0.20	0.45	-0.99	0.87
PD (gcm^{-3})	27	2.37	2.62	2.48	0.01	0.06	0.00	0.06	0.45	-0.36	0.87
PR (%)	27	5.51	46.52	22.52	2.23	11.60	134.66	0.69	0.45	-0.67	0.87
OM (%)	27	1.47	6.40	3.86	0.27	1.41	1.98	0.15	0.45	-0.85	0.87
BD gcm^{-3}	27	1.27	2.66	1.97	0.07	0.36	0.13	-0.02	0.45	-0.18	0.87

EC: Electrical Conductivity, DR: Dispersion Ratio, FC: Field Capacity, CM: Colloid/Moisture equivalent, FP: Fading Point, PD: Partical Density, PR: Porosity Ratio, OM: Organic Materials, BD: Bulk Density, MC: Moisture Content

Some soil properties of burned area

Descriptive statistics analyze results of soil samples affected by low severity surface ground wildfire that have occurred three years ago. The soils' average pH value is 7.78, clay ratio is 18.47%, EC value is 0.16, dispersion ratio is 25.39%, porosity ratio is 39.20% and organic matter (OM) ratio is 3.52% (Table 5). Organic matter, which contributes significantly to surface soil structure and porosity, can be adversely affected by wildfires (Neary et al. 1999). Knicker et al. (2006) reported that wildfires which do not damage the total vegetation lead to a considerable OM increase. In his study OM content was still decreased after three years of the wildfire (from 3.86 to 3.52 %).

After the forest fires, organic ash is formed by the burning of the organic matter on the topsoil. In the study area, organic ash layer depth was ranging between 0-1 mm after three years in the burnt Turkish Red Pine forest. And organic ash was leached into macro pores in the sandy soil (sand ratio is 64.38%) layers in the study area. The depth of the ash cover on the land surface is variable after fires. In California, 70 mm depth was reported in the oak forest (Ulery et al. 1993). Cepel (1998) state that the distribution of the macro pores in the soil directly affects the movement of water and air. Doerr et al. (2006) emphasized that, forest fires affect the conditions of water repellent in the soil. While some of the organic compounds are flying during the fire, other parts leaching in the soil layers and concentrating on the soil particles in the substrates. As a result, the soil which provides faster water saturation, passes to the surface flow. BD values were changed demand on soil texture, organic matter and ash content. After the wildfire, soil texture does not change but organic ash content would increase in the top layer. BD values were ranging 0.51-2.00 g cm^{-3}. Particle density changed between 2.20-2.56 g cm^{-3} in the study area (Table 5).

Table 5. The result of descriptive statistics analyses of burned area

	N	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
pH	27	7.17	8.14	7.78	0.05	0.24	0.06	-0.75	0.45	0.31	0.87
EC (mmhos)	27	0.08	0.26	0.16	0.01	0.04	0.00	0.80	0.45	0.67	0.87
MC (%)	27	3.80	13.20	5.36	0.33	1.70	2.89	3.96	0.45	18.61	0.87
Sand (%)	27	47.79	79.25	64.38	1.83	9.49	89.98	-0.02	0.45	-1.10	0.87
Silt (%)	27	6.29	23.26	17.15	0.80	4.16	17.34	-0.67	0.45	0.07	0.87
Clay (%)	27	8.52	30.44	18.47	1.26	6.53	42.65	0.09	0.45	-1.20	0.87
DR (%)	27	13.49	46.20	25.39	1.45	7.53	56.70	1.24	0.45	2.64	0.87
FC (%)	27	19.90	34.10	25.10	0.62	3.23	10.43	0.68	0.45	0.83	0.87
CM	27	0.38	1.44	0.73	0.05	0.25	0.06	0.90	0.45	1.18	0.87
FP (%)	27	7.90	19.90	13.43	0.67	3.51	12.30	0.20	0.45	-1.39	0.87
PD gcm^{-3}	27	2.20	2.56	2.45	0.01	0.07	0.01	-1.65	0.45	4.45	0.87
PR (%)	27	19.73	79.05	39.20	2.59	13.44	180.72	0.77	0.45	1.47	0.87
OM (%)	27	0.35	9.57	3.52	0.34	1.77	3.14	1.21	0.45	4.43	0.87
BD gcm^{-3}	27	0.51	2.00	1.49	0.06	0.32	0.11	-0.87	0.45	1.68	0.87

EC: Electrical Conductivity, DR: Dispersion Ratio, FC: Field Capacity, CM: Colloid/Moisture equivalent, FP: Fading Point, PD: Particle Density, PR: Porosity Ratio, OM: Organic Materials, BD: Bulk Density, MC: Moisture Content

Comparison of some soil features in burned and unburned counterpart area

In accordance with the structure of the study, t-test was applied in order to compare the two groups (burned and unburned area). Mann Whitney U test was used for comparing the values of PD, OM, CM, DR and MC out of none-normally distribution (Eymen 2007; Hollander & Wolfe 1973). The results of the Mann-Whitney U test are presented in Table 6. It is seen that "p" values for each feature is p>0.05, so there is no significant difference between the compared features after three years from the wildfire.

Table 6. Comparison of the both lands by Mann-Whitney U Test

	MC (%)	**DR (%)**	**PD (gcm^{-3})**	**OM (%)**	**CM**
Mann-Whitney U	329.500	322.000	298.000	305.500	306.000
Wilcoxon W	707.500	700.000	676.000	683.500	684.000
Z	-0.606	-0.735	-1.154	-1.021	-1.013
Asymp. Sig. (2-tailed)	0.545	0.462	0.249	0.307	0.311

MC: Moisture Content, DR: Dispersion Ratio, PD: Particle Density, OM: Organic Matter, CM: Colloid/Moisture equivalent

Eymen (2007) stated that paired sample t-test is the appropriate tool in measuring the two different datasets. There is a significant difference (p <0.05) at silt ratio, PR and BD mean values in the Table 7.

Table 7. T-test Analysis Results of both lands' averages

	t-test table						
						95% Confidence Intervals of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
pH	-0.327	52	0.745	-0.021	0.066	-0.156	0.112
EC (mmhos)	0.778	52	0.440	0.009	0.012	-0.015	0.034
Sand **(%)**	0.987	52	0.328	2.301	2.331	-2.377	6.980
Silt **(%)**	-2.609	52	0.012	-2.841	1.089	-5.027	-0.655
Clay **(%)**	0.331	52	0.742	0.539	1.630	-2.733	3.812
FC **(%)**	-0.736	52	0.465	-0.715	0.972	-2.665	1.235
FP **(%)**	0.822	52	0.415	0.737	0.896	-1.062	2.536
PR **gcm^{-3}**	-4.921	52	0.000	-18.621	3.784	-26.214	-11.027
BD **gcm^{-3}**	5.141	52	0.000	0.478	0.093	0.291	0.665

EC: Electrical Conductivity, DR: Dispersion Ratio, FC: Field Capacity, FP: Fading Point, PR: Porosity Ratio, BD: Bulk Density

It was observed that burned forest ecosystem recovered itself after 3 years from the low severity ground wildfire occurred in the study area. This recovery processes were affected by fire severity and other ecological conditions (related ESI value). Ecosystem would take a longer to reach a balance based on excessive fire intensity. This study results show that generally some soil features could rehabilitate itself after three years from low severity ground wild fire in area has low ESI value (Figure 4). Bradstock et al. (1995) reported that, a rapid recovery occurred after 4-7 years due to fire intensity after forest fires in the Australian eucalypt-dominated environments. Degraded soil structure after fires can be improved from 1 year to 10 years depending on the ecosystem conditions (Neary et al. 1999).

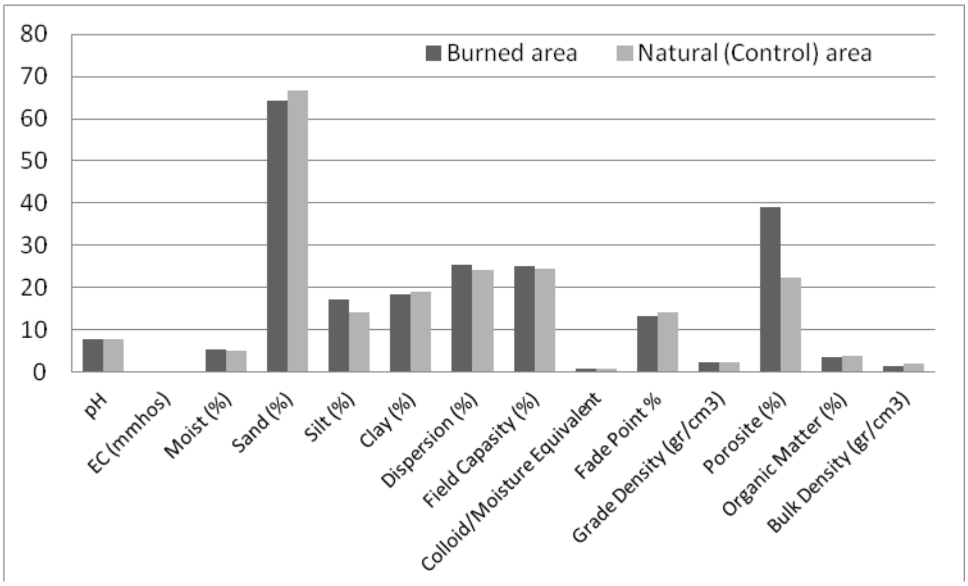

Figure 4. Change of soil features after three years from ground wild fire

Correlation analysis was performed between some soil properties, slope and elevation in the burned and unburned area. It is observed that the sand ratio values have a statistically significant ($p < 0.05$) positive relation with the elevation (Table 8). In cases the value of "p" is less than 0.05 and 0.01, it is accepted that there is a very significant difference between the two groups (Eymen 2007).
There was a statistically significant ($p < 0.05$) negative relationship between CN values and slope. Cepel (1998) emphasized that the change in soil properties in terms of elevation. It was determined that sand fractions were higher, silt and clay fractions were lower, BD and PD have low values as the elevation was increased. Negative significant sensitivity has been determined in the burned area especially in slope with FP, PR, OM and BD values (Table 8). Slope and topography are one of the most fire producers and severity depends on the interactions with other environmental conditions (Dunne and Leopold 1978; Neary et al. 1999). After wildfires, due to the increase in shear stress depending on the slope ratio with the acceleration of surface flow causes the transport of organic matter (Hyde et al. 2007). FP, PR and BD values are affected by OM. After three years of the low severity ground wildfire, the negative effects of the wildfire on the soil began to disappear however the negative effects of physiographic characteristics on the soil are still dominant (Table 8).

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Conclusion

In this research, the natural resilience capacity of the forest ecosystem was evaluated using some soil properties between unburned and burned counterpart area have affected by low severity ground wildfire.

Table 8. Correlations between the burned and unburned area depend on elevation and slope

Pearson Correlation	Units	Unburned		Burned	
Parameters		**Elevation**	**Slope**	**Elevation**	**Slope**
Sand	%	0,437*	0,159	-0,167	0,131
CM		-0,224	-0,390*	0,092	-0,194
FP	%	-0,264	-0,173	0,339	-0,430*
PR	%	-0,074	0,212	0,175	-0,654**
OM	%	-0,034	0,246	0,256	-0,664**
BD	$grcm^{-3}$	0,055	-0,224	-0,147	0,642**

CM: Colloid/Moisture Equivalent, FP: Fading Point, PR: Porosity Ratio, OM: Organic Matter, BD: Bulk Density

*. Correlation is significant at the 0.05 level (2-tailed)., **. Correlation is significant at the 0.01 level (2-tailed).

As a result of the analysis, although there were some differences between the two areas (burned and unburned counterpart) after three years of low-severity ground wildfire in Mediterranean forest ecosystem has no environmental sensitivity (ESI), it was observed that the ecosystem recovered itself in terms of soil properties. The natural resilience processes have affected by microclimate and other micro ecologic conditions. Therefore, subsequent rehabilitation studies will help to shorten the self-resilience period of the ecosystem. As a first improve the degraded soil healthy after wildfire can increase resilience capacity of the ecosystem. Especially should be avoid some activities may reason compact of the soil. If soil tillage is required should be done with manpower. Organic ash that has accumulated in sandy soil after the fire should be distributed homogeneously.

Acknowledgements

We would like to thank to the Kahramanmaras Regional Directorate of Forestry and Cinarpinar Directorate of Forestry for their support during fieldwork.

Conflict of Interest: The authors declare that they have no conflict of interest.

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Submitted: 22.05.2019 Accepted: 02.07.2019