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Effects of low-intensity fire on soil organic carbon stocks and physicochemical properties in the Mediterranean ecosystem

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Abstract

Due to inherent climate characteristics, forest fires are commonly encountered in the Mediterranean ecosystem. Forest fires influence water resources, flora, fauna, air quality and soil properties. This study was conducted to determine the effects of a low-intensity fire in Lapseki – Dışbudak village on soil physical and chemical properties. Soil samples were taken from 0-5 cm depth on unburned (control) and burned lands 1 month and 3 years after the fire and samples were analyzed for organic carbon stock, texture, aggregate stability, bulk density, pH, electrical conductivity (EC), lime, organic matter, organic carbon, exchangeable K, Ca, Mg, Na, and available Fe, Cu, Mn, and Zn.While the average pH, EC (dS m^{-1}), exchangeable Ca (mg kg^{-1}), Na (mg kg^{-1}), available Mn (mg kg^{-1}) and Zn (mg kg^{-1}) values were respectively measured as 6.37, 0.72, 3504.10, 34.97, 202.31 and 4.23 in burned lands in the 1st month after fire, the values were respectively measured as 6.25, 0.53, 2870.90, 24.89, 127.96 and 2.71 in control areas. At the end of the 3rd year, available Mn was measured as 81.69 mg kg^{-1} in burned lands and 53.58 mg kg^{-1} in unburned lands. It was concluded that at the end of 3 years, low-intensity fire was effective in improving soil properties.

Keywords: Low intensity fire, soil organic carbon stock, soil properties, soil nutrient.

Introduction

Forest fires constitute a serious problem especially in the Mediterranean climate zone with hot and dry summers (Alcañiz et al., 2016). The fires encountered in the Mediterranean ecosystem recently increased as related to land use change and climate change (Fernández-García et al., 2019). The Mediterranean climate domain extends to a much larger geographical scale globally including areas as far away as the southern parts of California, and some regions in Australia, New Zealand, and Argentina (Zdruli et al., 2011). There is some research on the effects of fires in the Mediterranean ecosystem on soil properties (Parlak, 2018; Hueso-Gonzalez et al., 2018; Fernandez- Garcia et al., 2019; Merino et al., 2019; Moya et al., 2021; Dindaroglu et al., 2021). Impacts of fires vary with the vegetation, topography, soil properties, fire severity and post-fire use conditions (Certini, 2005).

Soil organic carbon is a highly significant indicator in terms of land degradation neutrality, sustainable use of soils and mitigation of the negative impacts of climate change (Knicker, 2007; Yigini and Panagos, 2016). Organic carbon stocks in forest soils are largely influenced by fires (Lal, 2005). Vega et al. (2013) indicated that low intensity fire in *Pinus pinaster* stands did not increase soil organic carbon, available P and K levels. Stinca et al. (2020) indicated that fires in beech forests of southern Italy did not generate a change in organic C stocks.

Although research was conducted in Turkey about the effects of low intensity fires on soil physical and chemical properties (Ekinci, 2006; Kara and Bolat, 2009; Akburak et al., 2018; Camcı Çetin et al., 2019;

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Dindaroğlu and Turan 2019), there are no studies encountered in the literature about the effects of low intensity fires on soil available micro element contents (Fe, Cu, Mn, Zn). This study was conducted to determine the effects of low intensity forest fires encountered in the Mediterranean ecosystem on soil organic carbon stocks and some physicochemical properties (texture, aggregate stability, bulk density, pH, electrical conductivity, lime, organic matter, organic carbon, available P, K, exchangeable Ca, Mg, Na, available Fe, Cu, Mn, and Zn).

Material and Methods

Study area

Lapseki town in Çanakkale province is located in the southern Marmara section of Marmara region in the northwest of Biga peninsula. Lapseki is geographically positioned between 40° 20' north latitude and 26° 42' east longitude. Lapseki is surrounded by the Marmara Sea to the north, central town of Çanakkale to the south, the Dardanelles to the west and Biga town to the east (Figure 1). Lapseki has a semi-humid Marmara climate (a transitional climate between Mediterranean and Black Sea climates) (Koçman, 1993). According to long-term averages (1929 – 2020), total annual precipitation in Lapseki is 624 mm and the average temperature is 15.1 ºC (MGM, 2021). The slope in Dışbudak forest lands is about 9% and the forest mostly comprises red pine (*Pinus brutia* Ten.), kermes oak (*Quercus coccifera*), cretan rock rose (*Cistus creticus* L.), mock privet (*Phillyrea latifolia* L) and summer asphodel *(Asphodelus aestivus* Brot.). According to the World Reference Base for Soil Resources, Dışbudak forest soils are classified as Lithic Leptosol (WRB, 2015). In an anthropogenic fire case encountered in Lapseki-Dışbudak village in September 2006, about 5 ha forest land was burned, the organic layer was over-burned, but sub soil was not influenced.

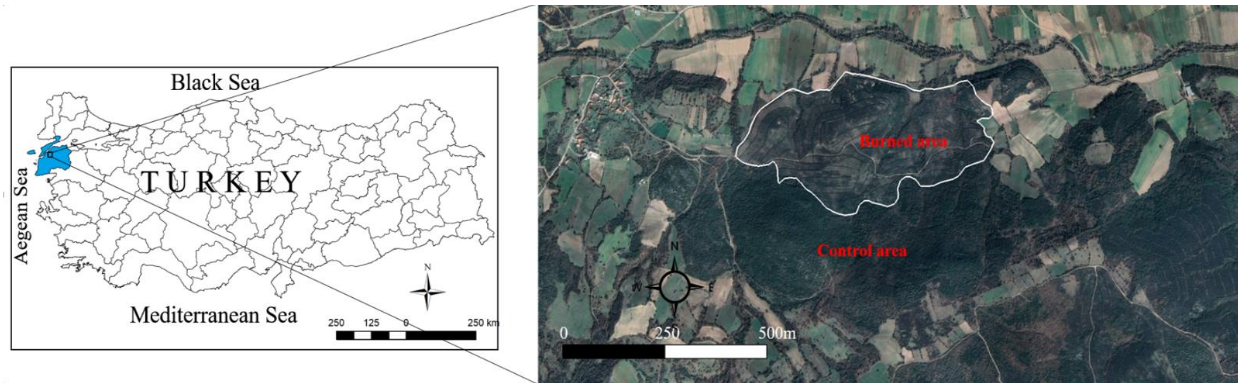

Figure 1. Location of study area

Soil sampling

Attempts were made to consider similar slope, aspect and elevation while taking samples from Lapseki-Dışbudak forest lands. In each sampling period (1 month and 3 years after the forest fire), 9 disturbed and undisturbed soil samples were taken from unburned (control) lands and 9 samples from burned lands and coordinates of the sampling points were recorded with a GPS (Global Positioning System) device. Samplings were made in accordance with the random sampling system. Following the careful removal of litter, soil samples were taken from 0 – 5 cm soil depth with a stainless-steel shovel and steel sampling cylinders. Soil samples were taken in the 1st month and 3rd year following the fire. A total of 36 disturbed and undisturbed soil samples were taken with 18 from unburned lands (9 samples x 2 periods x 1 depth) and 18 from burned lands. Soil samples were brought to the laboratory, air dried and passed through a 2 mm sieve.

Figure 2. Control lands (A) and burned lands (B) 1 month after the forest fire

Soil analysis

For texture analysis, 50 g soil sample was kept in 10% calgon solution overnight, then placed in 1130 ml glass cylinders and a hydrometer was used to examine sand, silt and clay fractions (Gee and Or, 2002). Aggregate stability, an indicator of changes in soil structure, was determined with micro aggregates less than 0.25 mm in diameter (Nimmo and Perkins, 2002). Soil bulk density was determined in undisturbed soil samples by drying samples in an oven at 105 ºC (Grossman and Reinsch, 2002). The pH of the samples was determined in saturated paste extract with a pH meter (Thomas, 1996) and electrical conductivity (EC) of the same extract was determined with an EC meter (Rhoades, 1996). Lime content was determined with a Scheibler calcimeter by measuring the CO_2 gas released when soil was contacted with HCl (Loeppert and Suarez, 1996). Organic matter and organic carbon were determined with the modified acid digestion method (Nelson and Sommers, 1996). For soils with a pH of less than 7, available phosphorus (P) was determined with the use of Bray and Kurtz's (1945) method; exchangeable potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) were determined in 1 N ammonium acetate (NH_4OAc) extracts from the samples. Extract K and Na contents were determined with the use a flame photometer (Helmke and Sparks, 1996) and available Ca and Mg contents were determined with an ICP-OES ((Inductively Coupled Plasma - Optical Emission Spectrometry) (Suarez, 1996). Available Fe, Cu, Zn, Mn and Zn contents were determined in 0.005 M diethyl triamine penta acetic acid (DTPA), 0.01 M calcium chloride ($CaCl_2$) and 0.1 M tri ethanol amine (TEA) mixture solution (pH: 7.3) extracts with the use of an ICP-OES device (Lindsay and Norvell, 1978).

Soil organic carbon stock (SOCS) was determined with the use of the soil depth equation (Gross and Harrison, 2018).

$$\text{SOCS (ton ha}^{-1}) = \text{BD x D x TOC x } 10^{\,8} \text{ cm}^2 \text{ ha}^{-1}$$

where, BD is bulk density (g cm^{-3}); D is sampling depth (m); and TOC is soil organic carbon content (g kg^{-1}).

Statistical analysis

For comparison of soil properties in control (unburned) and burned lands, the paired t-test was used for data exhibiting normal distribution and Mann-Whitney U-test was used for data without normal distribution. The Levene test was used to check variance homogeneity and Shapiro-Wilk test was used to check normality pre-conditions. Statistical analyses were conducted with the use of SPSS Statistical Package v.20.0 (IBM, 2011). Significant means were compared with the use of Duncan's test at $p<0.05$ significance level.

Results and Discussion

In the 1st month samples, differences in soil pH, EC, available Ca, Na, Mn and Zn contents of the control and burned lands were found to be significant at $p<0.05$ level, but the differences in SOCS and the other soil properties (sand, silt, clay, aggregate stability, bulk density, lime, organic matter, soil organic carbon, available P, exchangeable K, Mg, Fe, Cu, and Zn) were not found to be significant (Table 1). Increasing pH and EC levels of soil samples taken 1 month after the fire were attributed to soluble salts released during combustion of organic matter (Pereira et al., 2014; Muñoz-Rojas et al., 2016; Parlak, 2018). Soil temperature could not be measured during the forest fire. Effects of fire on pH largely relies on soil temperature during the fire event. Parlak (2011) indicated decreasing soil pH levels at 200 ºC, but increasing pH levels at 500 ºC. Merino et al. (2019) conducted a study in three study sites in central Spain (*Pinus nigra* forest, *Pinus pinaster* forest, *Cytisus oromediterraneus* shrubland) and indicated that prescribed fires did not alter the soil organic matter content. Kutiel and Inbar (1993) took soil samples from 0-5 cm depth around burned pine trees and reported increased exchangeable Ca and Na contents. Pardini et al. (2004) indicated that oak forest fire increased exchangeable Ca, but decreased exchangeable K content of the samples taken from 0-10 cm depth. Within 1 month of sampling following the fire, precipitation resulted in soil erosion in the study area. Caon et al. (2014) indicated that soil erosion resulted in loss of ash accumulated on the soil surface after the fire. Exchangeable cations (especially Ca^{2+} and Mg^{2+}) are not lost through volatilization, but lost through leaching and runoff (Parlak, 2018). Among the exchangeable cations, Ca^{2+} is influenced most by the fire. Lasanta and Cerdà (2005) reported high Ca concentration in runoff 7 months after the fire. Scharenbronch et al. (2012) reported that low-severity prescribed fire in USA oak forest increased extractable Na. Akburak et al. (2018) indicated that low-intensity prescribed fire slightly increased soil pH, but did not increase EC, organic carbon, available K and Mg contents. Kaptanoğlu et al. (2018) conducted a study in mixed broad-leaved and coniferous forest in northwest Turkey, Bursa-Uludağ, and indicated that surface fire increased soil pH and Ca. Camcı Cetin et al. (2019) reported low intensity forest fire in scots pine and black pine stands only increase the electrical conductivity among soil chemical parameters.

Relations of Fe, Cu, Mn and Zn-like micro elements with the fire are not known due to lack of specific studies (Certini, 2005). Gonzales Parra et al. (1996) indicated that total and available manganese contents significantly increased after fires. With fire-generated ash, Mn is released into soil in amorphous and crystalline oxide forms. Probably Fe, Cu and Zn also exhibit similar behavior with Mn and move slightly downward (Certini, 2005). García-Marco and González-Prieto (2008) indicated that controlled fire resulted in changes in the availability of micro elements in the short term, increased available Mn and Zn and did not influence Cu availability. Gómez-Rey et al. (2013) indicated that controlled fire in NW Spain did not change soil extractable Fe levels significantly. Norouzi and Ramezanpour (2013) indicated that forest fires did not have significant effects on soil available Cu content. Mitic et al. (2015) investigated the effects of forest fires in Vidlic mountain (Serbia) on soil Zn and Cu content and reported that fires influenced soil Zn content, but did not influence Cu content. Availability of soil nutrients is generally related to ash generated by the fire. Other researchers (Neill et al., 2007; Switzer et al., 2012; Roaldson et al., 2014; Chen et al., 2019) indicated that low-intensity fires did not influence soil carbon pools. Alcañiz et al. (2018) indicated that soil texture, bulk density, and soil aggregate stability did not change following a low-intensity fire. Alterations of soil physical properties by a fire depend on fire intensity, severity and recurrence (Parlak, 2018). Since soil temperature is not high in low-intensity fires, soil physical properties do not change.

Table 1. Soil organic carbon stocks and some physicochemical properties of soil samples were examined 1 month after the forest fire (mean ± standard deviation)*

Soil properties	Control area			Burned area			paired t-test (p)	Mann- Whitney U test (p)
SOCS (ton ha^{-1})	21.69	±	5.61	25.07	±	1.33		0.1120
Sand (%)	48.83	±	4.67	47.25	±	6.08		1.0000
Silt (%)	24.76	±	2.19	25.75	±	2.46		0.6588
Clay (%)	26.85	±	4.93	27.00	±	2.71		0.6272
Aggregate stability (%)	37.97	±	9.76	36.08	±	7.44		0.6588
Bulk density (g cm^3)	1.45	±	0.04	1.43	±	0.04		0.5660
pH	6.25	±	0.13 b	6.37	±	0.08 a		0.0273*
EC(dS m^{-1})	0.53	±	0.07 b	0.72	±	0.05 a		0.0009*
$CaCO_3$(%)	0.67	±	0.37	0.58	±	0.21	0.7240	
Organic matter (%)	5.16	±	1.35	6.03	±	0.28		0.0521
Organic carbon (g kg^{-1})	29.98	±	7.87	34.99	±	1.65		0.1853
Available P (mg kg^{-1})	17.22	±	6.24	18.77	±	7.64		0.8253
Exchangeable K (mg kg^{-1})	266.11	±	94.23	298.56	±	88.18		0.4268
Exchangeable Ca (mg kg^{-1})	2870.90	±	384.50 b	3504.10	±	210.30a		0.0006*
Exchangeable Mg (mg kg^{-1})	400.70	±	100.90	517.30	±	103.80		0.0521
Exchangeble Na (mg kg ^{1})	24.89	±	4.81 b	34.97	±	5.96 a		0.0036*
Available Fe (mg kg^{-1})	4.69	±	0.95	4.67	±	0.90		0.7510
Available Cu (mg kg^{-1})	1.47	±	0.48	1.35	±	0.14		0.7911
Available Mn (mg kg^{-1})	127.96	±	25.13 b	202.31	±	37.16 a		0.0020*
Available Zn (mg kg^{-1})	2.71	±	0.84 b	4.23	±	1.03 a		0.0081*

* The means indicated with different letters are significantly different at 5% level.

In soil samples taken in the 3rd year, only differences in Mn contents of the control and burned lands were found to be significant, but the differences in SOCS and the other soil properties were not found to be significant (Table 2). Fonseca et al. (2017) worked on a low severity fire in Montesinho Natural Park of northeast Portugal and indicated that soil organic matter, pH and EC values returned to pre-fire levels 36 months after the fire. Moya et al. (2019) took soil samples 3 years after a low-medium severity fire in *Pinus halepensis* Mill forest in the Mediterranean ecosystem and did not encounter significant changes in soil texture, organic carbon and pH. After the low-intensity fire in Lapseki-Dışbudak forest, 3 years were sufficient for the improvement of soil physicochemical properties. Low severity fires may have positive or negative effects on the environment, but previous studies mostly reported improved environments (Alcañiz et al., 2018). Low-severity fires may aid in replenishment of ecosystems and reduce the risk of forest fires.

Table 2. Soil organic carbon stocks and some physicochemical properties of soil samples were examined 3 years after the forest fire (mean±standard deviation)*

Soil properties	**Control area**	**Burned area**	**paired t-test (p)**	**Mann- Whitney U test (p)**
SOCS (ton ha^{-1})	16.03 ± 4.88	19.11 ± 2.72		0.2164
Sand (%)	47.09 ± 3.06	45.99 ± 3.17		0.2893
Silt (%)	26.39 ± 3.62	26.83 ± 2.58		0.5660
Clay (%)	26.50 ± 4.02	27.17 ± 2.38		0.9648
Aggregate stability (%)	46.28 ± 5.77	45.13 ± 10.29		0.8598
Bulk density (g cm^{3})	1.44 ± 0.05	1.45 ± 0.05		0.5660
pH	6.48 ± 0,20	6.80 ± 0,48		0.1223
EC(dS m^{-1})	0.42 ± 0,10	0.45 ± 0,12		0.6911
$CaCO_3$(%)	0.85 ± 0.22	0.79 ± 0.11		0.2510
Organic matter (%)	3.29 ± 0.33	3.02 ± 0.52		0.0703
Organic carbon (g kg^{-1})	22.40 ± 7.09	26.33 ± 3.63		0.1853
Available P (mg kg^{-1})	14.11 ± 2.61	16.00 ± 3.08		0.2004
Exchangeable K (mg kg^{-1})	251.67 ± 64.05	261.44 ± 37.00		0.6588
Exchangeable Ca (mg kg^{-1})	2533.00 ± 391.00	2628.00 ± 416.80		0.7239
Exchangeable Mg (mg kg^{-1})	341.65 ± 37.33	349.87 ± 28.56		0.6588
Exchangeble Na (mg kg ^{1})	24.04 ± 3.85	22.93 ± 4.07		0.6588
Available Fe (mg kg^{-1})	1.67 ± 0.19	1.98 ± 0.43		0.0637
Available Cu (mg kg^{-1})	0.87 ± 0.21	0.83 ± 0.14		0.8253
Available Mn (mg kg^{-1})	53.58 ± 16.00 b	81.69 ± 10.37 a		0.0027*
Available Zn (mg kg^{-1})	1.75 ± 0.37	1.98 ± 0.45		0.2893

* The means indicated with different letters are significantly different at 5% level.

Conclusion

This study was conducted to investigate the effects of a low-severity fire in the Mediterranean ecosystem on soil properties. At the end of the 3rd year after the fire, available Mn increased in burned lands, but the other soil properties (organic carbon stock, texture, agregate stability, bulk density, pH, electrical conductivity, lime, organic matter, organic carbon, exchangeable K, Ca, Mg, Na, available Fe, Cu, Mn, and Zn) did not change. Further research is recommended about low-intensity fires in different ecosystems including lands with a high risk of desertification. To prevent large fires with devastating impacts on the ecosystem, low-intensity fires could be recommended.

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