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EFFECT OF HEATING ON SOME PHYSICAL, CHEMICAL AND MINERALOGICAL ASPECTS OF FOREST SOIL

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ABSTRACT

The objective of this research was to determine the effects of heating at different temperatures on physical, chemical and mineralogical aspects of forest soils taken from Gallipoli Historical National Park. Soil samples were kept in a muffle furnace at different temperatures (25, 100, 200, 300, 400 and 500 °C). Soil heating lowered clay and silt contents and at some temperatures partially decreased the contents of pH, lime, total nitrogen (N), exchangeable calcium (Ca), magnesium (Mg), sodium (Na), and cation exchange capacity (CEC). It, however, caused on increase in sand, aggregate stability, electrical conductivity and a partial increase in exchangeable K, available phosphorus (P) and loss on ignition at some temperatures. Heating had different effects on soil color value and chroma while changing minerological components considerably.

Keywords: Controlled heating, soil properties, wildfire

ISITMANIN ORMAN TOPRAKLARININ BAZI FİZİKSEL, KİMYASAL VE MİNEROLOJİK ÖZELLİKLERİNE ETKİSİ

ÖZET

Bu araştırmanın amacı Gelibolu Tarihi Milli Parkından alınan orman topraklarını farklı sıcaklıklarda ısıtmanın toprakların fiziksel, kimyasal, minerolojik özelliklerine etkisini belirlemektir. Toprak örnekleri farklı sıcaklıklardaki (25, 100, 200, 300, 400 ve 500 °C) fırında 1 saat bekletilmiştir. Toprakların ısıtılması kil, silt, kısmen kimi sıcaklıklarda pH ve kireç, toplam N, değişebilir Ca, Mg, Na, KDK içeriğini düşürmüştür. Buna rağmen toprakların ısıtılması kum**,** agregat stabilitesi**,** elektriksel iletkenlik, kısmen bazı sıcaklıklarda değişebilir K, alınabilir P ve yanma kaybını artırmıştır. Toprakların ısıtılması toprak renginin valü ve kromaları üzerine farklı etkilerde bulunurken minerolojik bileşimlerini belirgin ölçüde değiştirmiştir.

Anahtar Kelimeler: Kontrollü ısıtma; toprak özellikleri; orman yangını

1. INTRODUCTION

Wildfires mainly cause destruction of ecosystems. Effects of fire on ecosystem have concentrated on those of flora, fauna and atmosphere (Moreno and Oechel 1991; Turner et al. 1994; Kasischke et al. 1995; Russell et al. 1999; Radho-Toly et al. 2001; Laughlin et al. 2004; Auld and Denham 2006; Hoinka et al. 2009). It is a common knowledge that fire has important influence on physical, chemical, biological and mineralogical characteristics of soils. Wildfires over short or long period might cause hydrological and geomorphological changes in the fire prone areas. On the hillslopes, more overland flow takes place, discharge increases, and a rise in channel changes, hillslope soil distribution and catchment sediment yield is seen (Shakesby and Doerr, 2006). These changes basically depend upon fire intensity, soil type and moisture, biomass of vegetation before and after fire and climatic conditions (Chandler et al. 1983). It is very hard to control fire intensity and fire residence on a land due to irregular fuel dispersion and climate. It is the reason that many researchers have conducted laboratory studies to determine effect of heat on physical, chemical and mineralogical aspects of soil (Sertsu and Sanchez

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1978; Giovannini et al. 1990; Fernandez et al. 1997; Marcos et al. 2007; Quintana et al. 2007; Mataix-Solera et al. 2008; Terefe et al. 2008). Sertsu and Sanchez (1978) stated that soil heating increased the soil pH, K, Ca, Mg, and Mn and heating three soils to 400 ^{0}C in the laboratory resulted in redder hues and brighter chromas. They suggested that the black color is due to charring of organic matter by heat conducted through the top layer of the during a fire. In the soils, the biological components are most susceptible to soil heating and are usually altered severely at temperatures between 100-150 ^{0}C (Ghuman and Lal, 1989). Substantial amounts of organic matter are lost at 300 ^{0}C and higher temperatures affect the composition of the minerals and soil texture (Kettering et al. 2000).

The purpose of this study is to determine effects of artifically controlled heating both on physical, chemical and mineralogical characteristics of soil.

2. MATERIALS AND METHODS

2.1. Site and Soil Sampling

Gallipoli Historical National Park (Figure 1), established in 1973 and included in the United Nations List of National Park and Protected Areas, covers 33 000 hectares at the southern end of the Gallipoli Peninsula on the Europaen side of the Dardanelles. The Peninsula, a thin (5 km wide at is narrowest) and 80 km long finger of land, juts into the northwest Aegean Sea to form on the northwest by the Gulf of Saros, one of the least polluted corners of the Aegean Sea, and to the east by the Dardanelles, a 70 km natural channel connecting the Aegean Sea and the Sea the Marmara. The areas is windy, average temperature is 14.7 ^{0}C, average rainfall is 619.7 mm (Anonymous, 2004).

Akman and Ekim (1988) reported that previously determined species have kept their existence in the National Park, however due to the destructions from fire and grazing and following re-forestion, their expansion showed increase and decrease or form changes. They, based on these findings, determined *Pinus brutia, Olea europae* var. *oleaster, Quercus coccifera, Arbutus andrachne, Phillyrea latifolia and Cistus creticus* as six of the most important species in the national park flora.

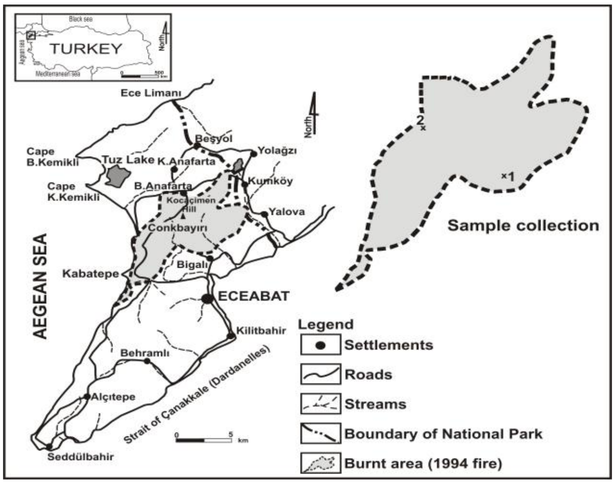


Figure 1. Location of the study area (1. Bigalı Village 2. Conkbayırı)

Soil samples for this study were taken from two points as the representative of the fire in 1994 (Güvensen et al. 2007). They were taken from 0-5 cm depth in August, 2007 after plant species were removed by hand as much as possible.

2.2. Laboratory Analyses

Samples dried under laboratory conditions were sieved through 2 mm sieve. 150 g soil was placed in every porcelain containers. The containers were kept in a muffle furnace for 1 hour at temperatures of 100, 200, 300, 400 and 500 °C. Control group was kept at room temperature (25 °C). Trials were with 3 replicates with 6 different temperature applications (control, 100, 200, 300, 400 and 500 °C) on the two different soil samples taken from the Bigalı and Conkbayırı regions. Following analyses were performed on the samples after cooling.

Soil colors were determined with a Munsell soil color chart; particle size distribution by the pipette method using sodium hexamethaphosphate as a dispersing agent, with silt and clay fractions being determined after sieving to remove sand particles (Gee and Bauder, 1986). Soil aggregate stability was assayed by wet sieving (Kemper and Rosenau, 1986). Soil pH and electrical conductivity (EC) were determined potentiometrically in a 1:2.5 ratio in H_2O (McLean 1982; Rhoades 1982b). Total carbonate content was measured volumetrically (calcimeter) after treating with HCl (Nelson 1982). Available P was determined by 0.5 M Na- bicarbonate extraction at a nearly constant pH of 8.5 (Olsen and Sommers 1982). Cation exchange capacity (CEC) using the method of Rhoades (1982a) for arid land soils; after extraction with ammonium acetate, exchangeable K^+ and Na^+ were determined by flame photometry and Ca^{2+} and Mg^{2+} by EDTA titrimetry (Thomas 1982). Total C and total N concentrations were determined in duplicate by dry combustion on a Vario Max CN elemental analyser (Elemental Vario El). All samples were free of carbonate so that the total C concentration equals the organic carbon (OC) concentration. Loss on ignition was determined by the protocol reported by Nelson and Sommers (1996). XRD patterns of the soils were assessed using CuK_α rays and Ni filtres in a powder diffractometer of Philips PW 1730 (Whitting, 1965).

2.3. Statistical Analysis

One way analysis of variance was performed with Minitab (Windows version 13.0) statistical software on the data obtained in the study. Important differences in the mean values were tested with Duncan’s multiple range test.

3. RESULTS AND DISCUSSION

3.1. Soil Texture

Clear differences were seen in the particle size distribution of the soils with soil heat treatment. Sand content of Conkbayırı control group with 742.10 g kg^{-1} increased to 953.90 g kg^{-1} at 500 °C, while clay content decreased from 56.20 g kg^{-1} to 8.40 g kg^{-1}. Initial sand content (598.60 g kg^{-1}) of the control group from Bigalı decreased to 891.30 g kg^{-1} at 500 °C. In the mean time, clay content decreased from 66.10 g kg^{-1} to 19.70 g kg^{-1} (Table 1). Silt contents of both the soils taken from Conkbayırı and Bigalı decreased as the temperature went up (Table 1). Crystal structure of clay colloids disappear at 400 °C and higher temperatures. Possible reason for clay particles to turn into sand-size particles might be the calcination of iron and aluminosilicate (Sertsu and Sanchez 1978; Giovannini et al. 1988; Terefe et al. 2008). Ulery and Graham (1993) obtained similar results from their field experiments.

3.2. Aggregate Stability

Aggregate stability increased as the temperature of the soils raised (Table 1). The reason for that is the alteration of iron and aluminium oxides and changes in the structure of clay minerals (Giovannini et al. 1988; Marcos et al. 2007; Terefe et al. 2008). Heat treatment at different temperatures did not change clay content (p=0.318) while sand content (p=0.000), sand content (p=0.000) and aggregate stability (p=0.002) significantly differed.

3.3. Soil Reaction (pH)

Samples of unheated and the ones heated at 100 °C showed very little changes in the soil pH. However, pH decreased in the soils heated at 200 °C (Table 1). This might be due to the decreased effects of oxidation of certain elements, exposure of new surfaces, dehydration of colloids and buffer action and due to the increase in organic acid compounds arising from microbial processes (Altınbaş, 1982). On the other hand, increase in pH at higher temperatures (400 °C) was caused by formation of metal oxides (Giovannini et al. 1990). Decrease in pH at 500 °C might be because of diminishing buffer reaction (Terefe et al. 2008).

3.4. Electrical Conductivity (EC)

Electrical conductivity of soils reaching maximum at 300 °C is the results of soluble ion maximization at these temperatures (Altınbaş, 1982; Terefe et al. 2008). Decrease in EC as the temperature goes up is an outcome of collapse in clay minerals, formation base oxides and increase in sand-size particles (Terefe et al. 2008).

3.5. Lime ($CaCO_3$)

It is seen in Table 1 that lime content decreased constantly as the temperature inclined, except for Conkbayırı soils at 100 and 200 °C. Loss of carbonates as CO_2 form is the reason and similar situtation was reported also by Altınbaş (1982).

3.6. Organic C and Total N

Under laboratory conditions, organic C content, initially 44.90 g kg^{-1} in the Conkbayırı soils and 39.10 g kg^{-1} in the Bigalı soils showed a decrease as the temperature was higher, except for those at 100 and 200 °C in Conkbayırı. Oxidation of organic matter at elevating temperatures keeps increasing depending on oxidation level. However at lower temperatures, oxidation slowing down or disappearing minimized loss of organic matter. Basically oxidation process of organic matter starts extensively at 300 °C. Organic matter components and adsorption forms on the surface of clay minerals have an effect on oxidation process (Altınbaş 1982).

Total N in Conkbayırı soil increased up to 200 °C, and later decreased. Initial total N content (2.20 g kg^{-1}) in Bigalı soil became 2.60 and 2.50 g kg^{-1} at 100 and 200 °C, respectively. It was 3.20 g kg^{-1} at 300 °C and at upper temperatures it tended to decrease (Table 1). The reason for decrease is that total nitrogen becomes a component of organic matter, turning to gas depending on oxidation process (Altınbaş, 1982; Giovannini and Lucchesi 1997).

3.7. Exchangeable Cations and Cation Exchange Capacity

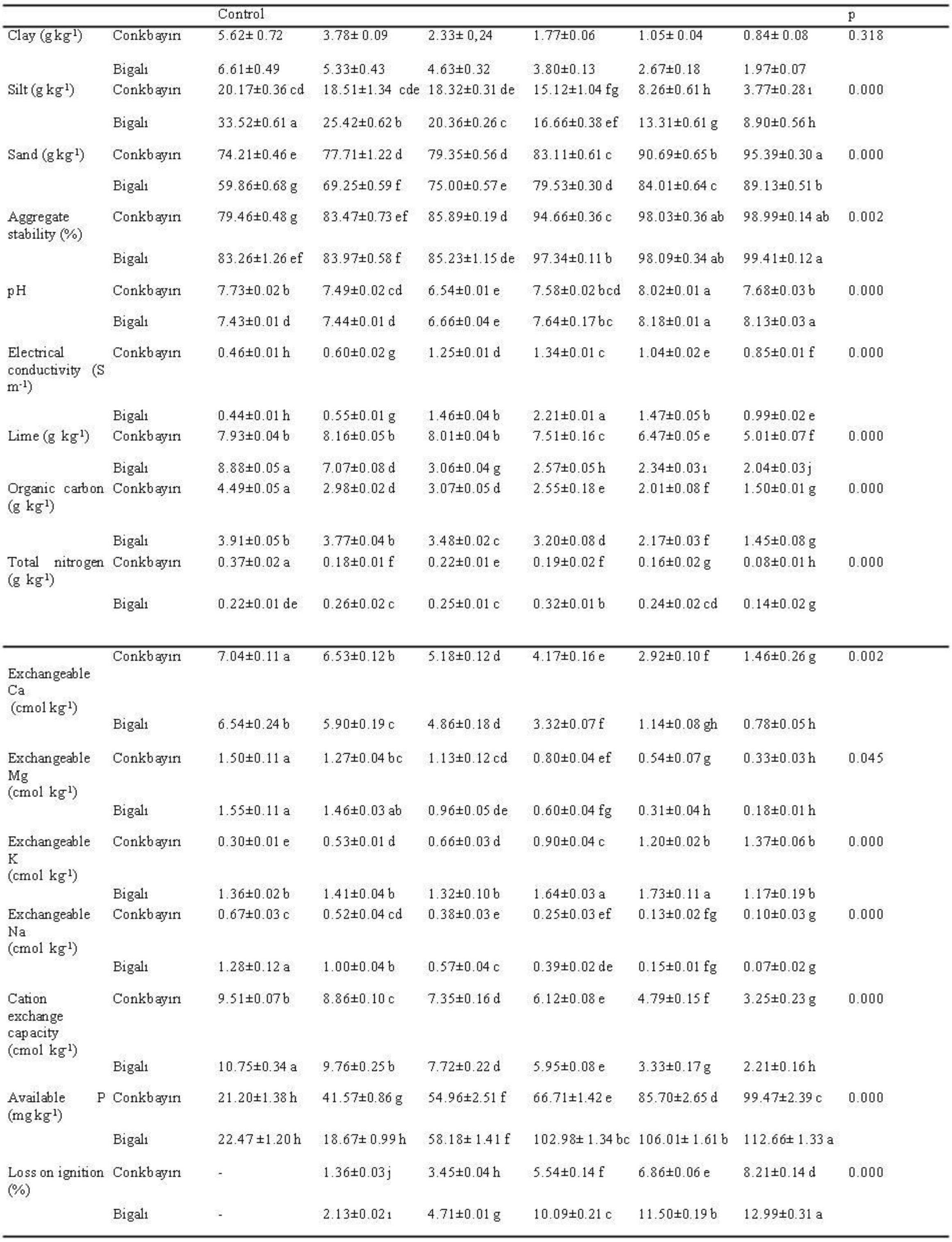
Exchangeable Ca steadily decreased in the soils with rising temperature. Extractability of Ca was diminished due to aggregation of the thin particles. Exchangeable Mg also showed similar change with exchangeable Ca with the temperature (Table 1) (Giovannini et al. 1990). The reasons might be that soil samples did not form soluble MgO and those small ions such as Mg was forced into octahedral structure of clay minerals during dehydration (Sertsu and Sanchez 1978). Exchangeable K showed an increase due to fusion in the soils as the temperature rose (Table 1) (Giovannini et al. 1990; Marcos et al. 2007). Increasing temperature caused a decrease in exchangeable Na in the soils (Table 1). This is because aggregation of the sand-size particles leading to less extractability from water (Giovannini et al. 1990; Marcos et al. 2007). Cation exchange capacity diminished with increasing temperature (Table 1). Structural change in clay minerals, combustion of organic matter and turning of clay particles to sand-size particles (Giovannini et al. 1990; Marcos et al. 2007).

3.8. Available Phosphorus and Loss on Ignition

Increasing temperature caused an increase in available P because of the mineralization of organic matter (Sertsu and Sanchez 1978; Giovannini et al. 1990; Marcos et al. 2006). Temperature causes an increase in the weight loss in soils (Sertsu and Sanchez 1978; Giovannini and Lusschei 1997; Marcos et al. 2006). Loss on ignition at 100 °C was 1.36 and 2.13 % in the Conkbayırı and Bigalı soils, respectively and it reached to 8.21 % and 12.99 % at 500 °C (Table 1).

Statistically important differences were observed with heating for some chemical property of the soils, such as pH (p=0.000), EC (p=0.000), lime (p=0.000), organic carbon (p=0.000), total N (p=0.000), exchangeable Ca (p=0.002), Mg (p=0.045), K (p=0.000), Na (p=0.000), CEC (p=0.000), available P (p=0.000) and loss on ignition (p=0.000).

Table 1. Effect of heating on some of soil properties (Mean±Standart error)*



		Control						p
Clay (g kg^{-1})	Conkbayırı	5.62± 0.72	3.78± 0.09	2.33± 0,24	1.77±0.06	1.05± 0.04	0.84± 0.08	0.318
	Bigalı	6.61±0.49	5.33±0.43	4.63±0.32	3.80±0.13	2.67±0.18	1.97±0.07	
Silt (g kg^{-1})	Conkbayırı	20.17±0.36 cd	18.51±1.34 cde	18.32±0.31 de	15.12±1.04 fg	8.26±0.61 h	3.77±0.28 ı	0.000
	Bigalı	33.52±0.61 a	25.42±0.62 b	20.36±0.26 c	16.66±0.38 ef	13.31±0.61 g	8.90±0.56 h	
Sand (g kg^{-1})	Conkbayırı	74.21±0.46 e	77.71±1.22 d	79.35±0.56 d	83.11±0.61 c	90.69±0.65 b	95.39±0.30 a	0.000
	Bigalı	59.86±0.68 g	69.25±0.59 f	75.00±0.57 e	79.53±0.30 d	84.01±0.64 c	89.13±0.51 b	
Aggregate stability (%)	Conkbayırı	79.46±0.48 g	83.47±0.73 ef	85.89±0.19 d	94.66±0.36 c	98.03±0.36 ab	98.99±0.14 ab	0.002
	Bigalı	83.26±1.26 ef	83.97±0.58 f	85.23±1.15 de	97.34±0.11 b	98.09±0.34 ab	99.41±0.12 a	
pH	Conkbayırı	7.73±0.02 b	7.49±0.02 cd	6.54±0.01 e	7.58±0.02 bcd	8.02±0.01 a	7.68±0.03 b	0.000
	Bigalı	7.43±0.01 d	7.44±0.01 d	6.66±0.04 e	7.64±0.17 bc	8.18±0.01 a	8.13±0.03 a	
Electrical conductivity (S m^{-1})	Conkbayırı	0.46±0.01 h	0.60±0.02 g	1.25±0.01 d	1.34±0.01 c	1.04±0.02 e	0.85±0.01 f	0.000
	Bigalı	0.44±0.01 h	0.55±0.01 g	1.46±0.04 b	2.21±0.01 a	1.47±0.05 b	0.99±0.02 e	
Lime (g kg^{-1})	Conkbayırı	7.93±0.04 b	8.16±0.05 b	8.01±0.04 b	7.51±0.16 c	6.47±0.05 e	5.01±0.07 f	0.000
	Bigalı	8.88±0.05 a	7.07±0.08 d	3.06±0.04 g	2.57±0.05 h	2.34±0.03 ı	2.04±0.03 j	
Organic carbon (g kg^{-1})	Conkbayırı	4.49±0.05 a	2.98±0.02 d	3.07±0.05 d	2.55±0.18 e	2.01±0.08 f	1.50±0.01 g	0.000
	Bigalı	3.91±0.05 b	3.77±0.04 b	3.48±0.02 c	3.20±0.08 d	2.17±0.03 f	1.45±0.08 g	
Total nitrogen (g kg^{-1})	Conkbayırı	0.37±0.02 a	0.18±0.01 f	0.22±0.01 e	0.19±0.02 f	0.16±0.02 g	0.08±0.01 h	0.000
	Bigalı	0.22±0.01 de	0.26±0.02 c	0.25±0.01 c	0.32±0.01 b	0.24±0.02 cd	0.14±0.02 g	
Exchangeable Ca (cmol kg^{-1})	Conkbayırı	7.04±0.11 a	6.53±0.12 b	5.18±0.12 d	4.17±0.16 e	2.92±0.10 f	1.46±0.26 g	0.002
	Bigalı	6.54±0.24 b	5.90±0.19 c	4.86±0.18 d	3.32±0.07 f	1.14±0.08 gh	0.78±0.05 h	
Exchangeable Mg (cmol kg^{-1})	Conkbayırı	1.50±0.11 a	1.27±0.04 bc	1.13±0.12 cd	0.80±0.04 ef	0.54±0.07 g	0.33±0.03 h	0.045
	Bigalı	1.55±0.11 a	1.46±0.03 ab	0.96±0.05 de	0.60±0.04 fg	0.31±0.04 h	0.18±0.01 h	
Exchangeable K (cmol kg^{-1})	Conkbayırı	0.30±0.01 e	0.53±0.01 d	0.66±0.03 d	0.90±0.04 c	1.20±0.02 b	1.37±0.06 b	0.000
	Bigalı	1.36±0.02 b	1.41±0.04 b	1.32±0.10 b	1.64±0.03 a	1.73±0.11 a	1.17±0.19 b	
Exchangeable Na (cmol kg^{-1})	Conkbayırı	0.67±0.03 c	0.52±0.04 cd	0.38±0.03 e	0.25±0.03 ef	0.13±0.02 fg	0.10±0.03 g	0.000
	Bigalı	1.28±0.12 a	1.00±0.04 b	0.57±0.04 c	0.39±0.02 de	0.15±0.01 fg	0.07±0.02 g	
Cation exchange capacity (cmol kg^{-1})	Conkbayırı	9.51±0.07 b	8.86±0.10 c	7.35±0.16 d	6.12±0.08 e	4.79±0.15 f	3.25±0.23 g	0.000
	Bigalı	10.75±0.34 a	9.76±0.25 b	7.72±0.22 d	5.95±0.08 e	3.33±0.17 g	2.21±0.16 h	
Available P (mg kg^{-1})	Conkbayırı	21.20±1.38 h	41.57±0.86 g	54.96±2.51 f	66.71±1.42 e	85.70±2.65 d	99.47±2.39 c	0.000
	Bigalı	22.47 ±1.20 h	18.67± 0.99 h	58.18± 1.41 f	102.98± 1.34 bc	106.01± 1.61 b	112.66± 1.33 a	
Loss on ignition (%)	Conkbayırı	-	1.36±0.03 j	3.45±0.04 h	5.54±0.14 f	6.86±0.06 e	8.21±0.14 d	0.000
	Bigalı	-	2.13±0.02 ı	4.71±0.01 g	10.09±0.21 c	11.50±0.19 b	12.99±0.31 a	

*V alues shown with different letters are significantly different at 5% level

3.9. Soil Color

Hue values of the soils from Conkbayırı and Bigalı remain unchanged except for Bigalı soil heated at 500 ºC (Table 2). Value in the Conkbayırı soil was 5 at the control, 100 and 200 ºC, 2 at 400 ºC and 3 at 500 ºC temperatures. Bigalı soils had the value of 4 at the control and 100 ºC and 5, 3, 2 and 2.5 at 200-500 ºC, respectively (Table 2). Temperature increase had different influences on chroma values of the soil. Red color values are formed with constant depletion of organic matter, increase in oxidation level and other chemical changes. Intensive MnO_2 at increasing temperatures causes black color. Dark soils with limited organic matter could contain ferrous and manganese compounds, elementel C and hematite (Altınbaş, 1982; Ulery and Graham 1993).

Table 2. Colors of the soil samples

	Dry soil	
Heating level (ºC)	Conkbayırı	Bigalı
Control	10 YR 5/3 (brown)	10 YR 4/3 (brown)
100	10 YR 5/4 (yellowish brown)	10 YR 4/4 (dark yellowish brown)
200	10 YR 5/6 (yellowish brown)	10 YR 5/4 (yellowish brown)
300	10 YR 3/2 (very dark grayish brown)	10 YR 3/1 (very dark gray)
400	10 YR 2/2 (very dark brown)	10 YR 2/1 (black)
500	10 YR 3/3 (dark brown	2.5 Y 2.5/1 (black)

3.10. Soil Mineralogy

Quartz in the Conkbayırı soil depleted with heating. Calcite, quartz- calcite and plagioclase increased. Smectite content increased at 100 °C and decreased at the other temperatures compared to the control (Figure 2).

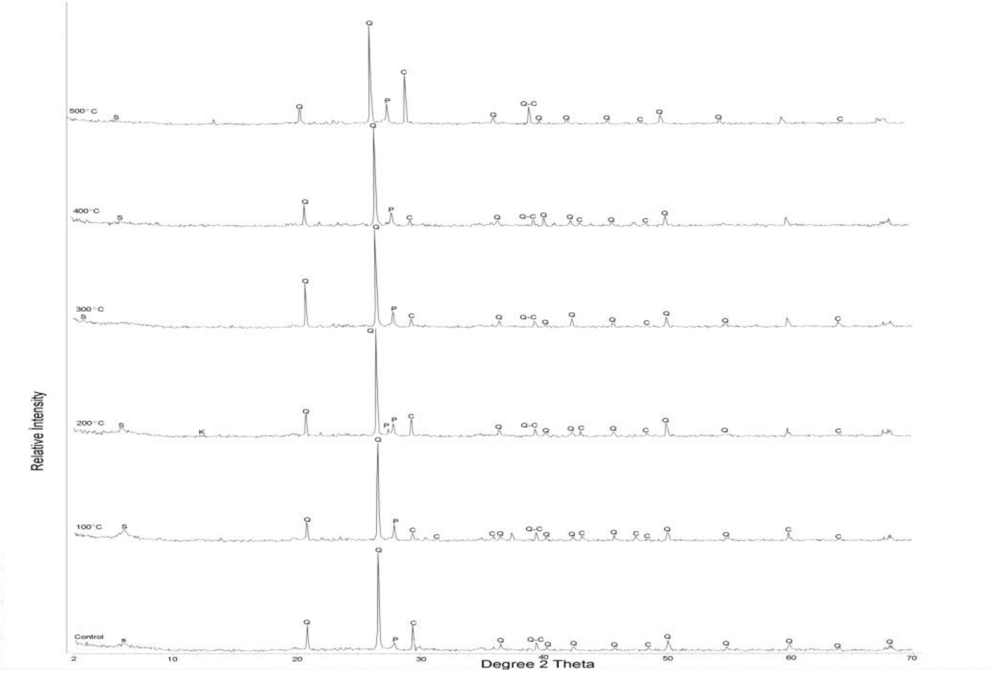


Figure 2. X- ray diffraction of the Conkbayırı soil. Q: Quartz, C: Calcite, Q-C: Quartz- Calcite, P: Plagioclase, S: Smectite

In the Bigalı soils, quartz and quartz-calcite showed an increase with heating. Calcite displayed undulations. Plagioclase decreased compared to the control. Smectite decreased with heating, except for at 100 °C. Kaolinite exhibited a similar pattern with the control at 300 °C while increasing at other temperatures (Figure 3). Decrease in smectite, a 2:1 type clay mineral, with heating except for 100 °C in both the Conkbayırı and Bigalı soils is consistent with decrease in cation exchange capacity. It was reported that smectite partially collapses and kaolinite and calcite weathering at temperatures higher than 600 °C (Ulery et al. 1996; Ketterings et al. 2000).

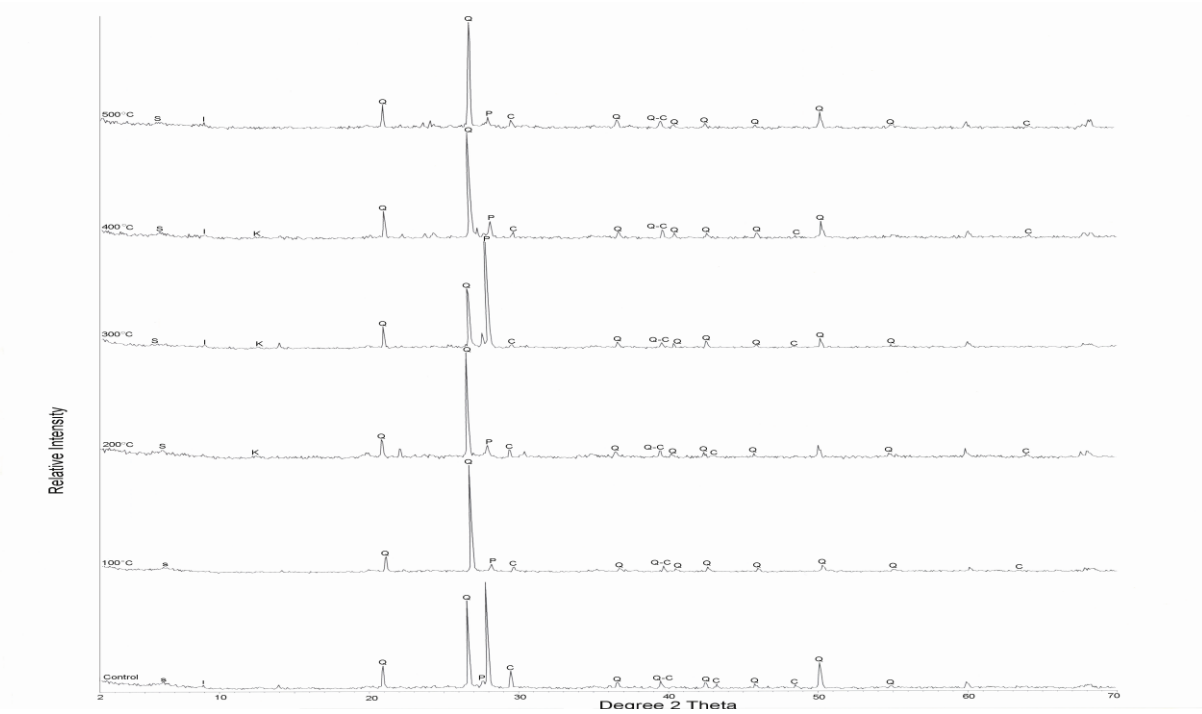


Figure 3. X- ray diffraction of the Bigalı soil. Q: Quartz, C: Calcite, Q-C: Quartz- Calcite, P: Plagioclase, S: Smectite, I: Illite, K: Kaolinite

CONCLUSIONS

Heating soils at different temperatures results in significant effects on physical, and chemical aspects of the soils. It spesifically changes elementel contents in the soil compounds. As the temperature increased, clay, silt, organic carbon, exchangeable Ca, Mg, Na and cation exchange capacity of the soils decreased; sand, aggregate stability and loss on ignition increased. There also increases and decreases in pH, electrical conductivity, lime, total N, exchangeable K, and available phosphorus. Soil color was observed to darken with increasing temperature. There is need in X-ray diffraction, differential thermal analysis, and scanning electron miscroscope for detailed explanation of soil mineralogy.

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