

ORION
SCHOLAR JOURNALS



(RESEARCH ARTICLE)



A field and laboratory study for effect of heat on some chemical properties of soils of Northeastern of Libya

Eldiabani Gibrel Salah ^{1,*}, Hale William H.G ² and Heron Carl P ²

¹ Department of Chemistry, Faculty of Art and Science, University of Darna, Darna.

² Department of Archaeological and Forensic Sciences, University of Bradford, Bradford, UK.

International Journal of Scientific Research Updates, 2022, 04(01), 286–302

Publication history: Received on 05 July 2022; revised on 16 August 2022; accepted on 20 August 2022

Article DOI: <https://doi.org/10.53430/ijrsru.2022.4.1.0136>

Abstract

Libya is one of semi-arid regions in the world except in a small area called (Aljabal Alakhdar) forests. It is the only wet area in Libya. This region exposing to encroachments such as burning parts of it to convert trees to charcoal trees and other purposes. The aim of this study is to evaluate the effects of heat on chemical properties of soil of Aljabal Alakhdar. The chemical properties of soil following heat in two geographic areas were determined in one coastal (old burned) and one mountain site (recently burned). The properties studied were:

soil moisture content, soil particle size, soil electrical conductivity (EC), soil pH and soluble Na, K, Ca and Mg, a soluble Cl, HCO₃ and SO₄.

The results showed except for the soil particle size, heat has a clear effect on the soils in the two studied areas. It is particularly interesting to note that many of the results when assessed by ANOVA, showed these properties were affected by heat and very few of the data sets proved to be showing no or low significance due to the effect of heat. This is still true at the coastal site even though the burned area there affected by heat several years ago. However, the affected parameters showed a recovery towards unburned levels with time, being less strongly different in the coastal site than in the mountain site.

Many of these effects are pronounced in the upper soil layer, reflecting the rapid decline in temperatures with soil depth.

Keywords: Soil heating; Soil water content; Soil particle size; EC; pH; Soluble cations and anions

1 Introduction

High soil temperatures may cause nutrient loss from the soil. Redistribution or losses of organic compounds and nutrients within the soil often change the physical properties of the soil [1]. Many studies, for example [2] and [3] have reported changes in chemical properties of soils in relation to heat effects.

Soil moisture in burned areas reflect consequent changes in vegetation or soil properties such as reduced infiltration by surface sealing [4] or by water repellence [5] which can lower soil moisture levels. However, [6] found that soil moisture can also increase after a fire, as interception and transpiration are negligible, and they reported that on some post-fire sites both conditions can occur simultaneously.

* Corresponding author: Eldiabani GS

Department of Chemistry, Faculty of Art and Science, University of Darna, Darna.

The textures of severely burned soils usually become coarser (from decreased clay content) as a result of the melting and fusion of clay minerals. Heating the soil above 150°C will produce the aggregation of finer clay particles into larger silt and sand particles [7].

According to [8] particle size distribution remains unchanged until 300-400°C but above this temperature range silt and clay aggregates and the sand fraction of soils increases.

Because soil temperature decreases with increasing soil depth, the magnitude of pH increases is higher in the top soil than in deeper layers [9]. Increases in soil pH following fire have been widely reported [10,11,12 and 13] and are primarily due to an increase in base elements contained in the ash residue and a decrease in organic materials. Pritchett and Fisher [14] have shown that the magnitude and duration of pH change is dependent on the amount and base content of the ash, the texture, and organic matter content of the soil. On the other hand, [15] noticed that the important implication of increased pH in the burned soil is encouragement of increased nitrogen fixation, whereas [16] found that consistent increases in exchangeable Ca²⁺ and pH in all horizons is a result of heat.

In general, after exposure to moderate temperature soil (EC) may increase significantly after releasing of soluble salts resulting from combustion of the organic matter [17]. However, [18] concluded that EC may also decrease in soils exposed to temperatures about 500°C due to demolition of the clay minerals, the formation of oxides and the formation of coarse particles.

Moreover, the effect of high air temperature and high rates of evaporation from the soil surface will be to cause an increase in salts concentration in the surface layers of the profiles [19]. Tomkins *et al* [20] found in their research in a Eucalypt forest in Australia that the mean soil solution of Ca⁺⁺ and Mg⁺⁺ ions increased more than 10 fold after fire, but the relative predominance of these cations was not affected by burning. On the other hand, they also noticed that mono-valent ion concentrations (K⁺ and Na⁺) were at or below pre-burn levels.

2 Methodology

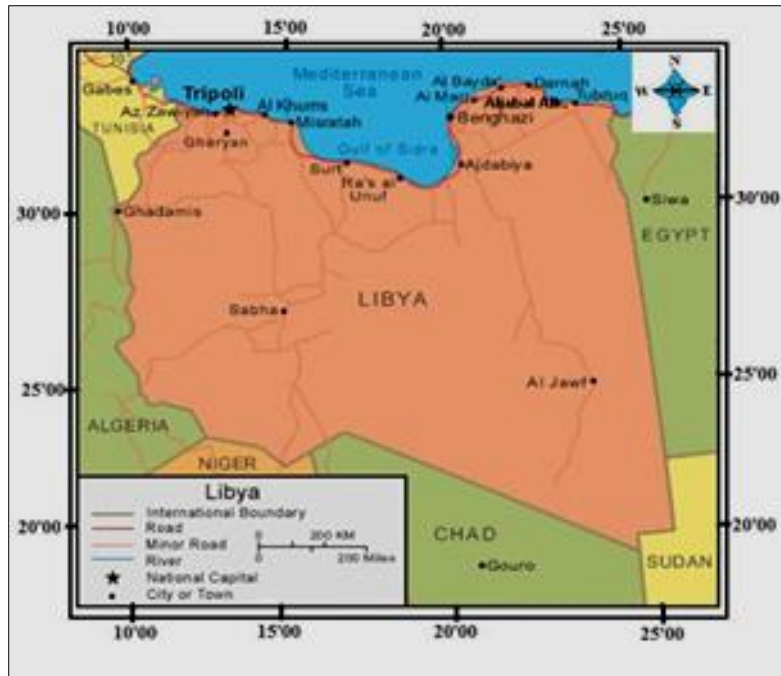
2.1 Study area, site selection and sample collection

This study conducted in the Aljabal Alakhdar (Green Mountain) region, Libya (Figure1). The climate in the study area is semi-arid, being hot and dry in the summer, warm and wet in the winter. Most of the precipitation falls during the period from October to April at an annual rate of between 275-660 mm. The annual minimum and maximum temperatures are approximately 10 and 35° C, annually [21].

Two sites have been used in this study. The first one (old burned site) is in area called Ras Alhelal subsequently; this site will be referred to as the coastal site. It is located between the longitudes 22° 12' 030" and 22° 13' 120", and the latitude 32° 52' 390" and 32° 53' 132" at an altitude of 83 m above sea level, approximately 1.5 km away from the seashore (Figure 2). According to (USDA, 2001) the soils in the area are classified as Lithic Haploxeralf.

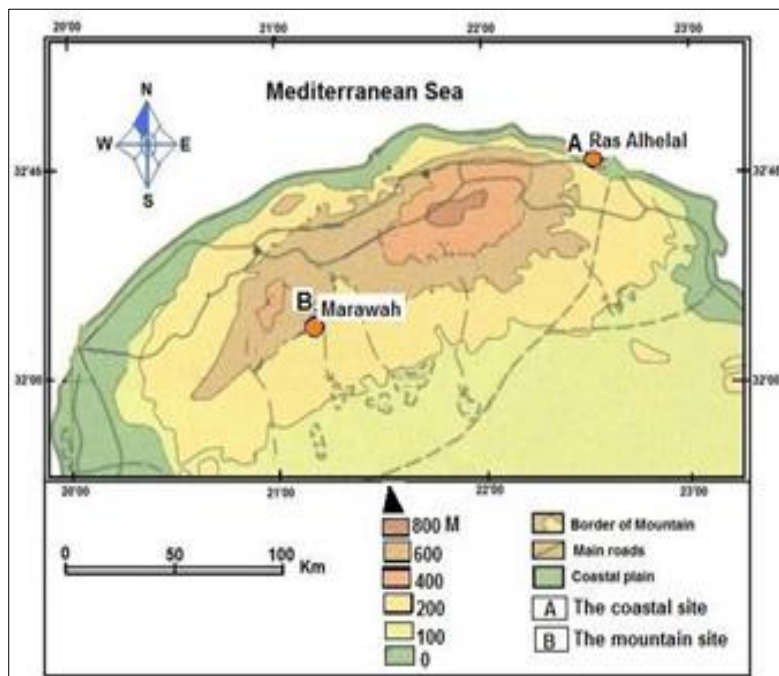
The second site (recent burned site) is located in an area called Marawah, approximately 150 km South-West of the first site. Throughout the rest of this study it will be referred to as the mountain site. It is located between longitude 21° 24' 021" and 21° 25' 299" and latitude 32° 29' 038" and 32° 29' 464" , at an altitude of 540 m above sea level, and about 2 km east of Marawah village (Figure 2). The soils in this site are classified as Typic Haploanthrepts [22].

These sites occur in the same region (Aljabal Alakhdar) and in convergent climatic conditions, however they lie in different geographical units (coastal and mountainous) and have a different vegetation density and were chosen so that the potential impacts of fire on their soils could be assessed based on exposure to fire at different periods of time, and therefore by comparing the results obtained it may be possibly to identify whether these soils are capable of regaining their preburn status over time.



(Source: Libyan National Atlas, 1980)

Figure 1 Map of Libya



(Source: Libyan National Atlas, 1980)

Figure 2 Map showing the distance between the locations of the two study sites (coastal (A) and mountain (B))

2.2 Soil sample collection

At each of the two sites sampled (coastal and mountain), two areas (burned and unburned) were studied. According to the soil profile description in the two sites, which were consistent in their soil characterizations for burned and unburned areas, the soil samples from the coastal site in the burned and unburned soils were collected from following horizons that were identified in the field, i.e. from the centre of the following layers: 0-15, 15-35, and 35-60 cm depth. Samples from the second site (mountain) in the burned and unburned soils were taken from the centre of the horizons:

0-15, 15-45, and 45-70cm depth. The sampling protocol followed for both sites, both burned and unburned soils, was as shown in [23]. This means (3 depths × 9 replicates × 2 areas), and the total number of samples for both sites was 108.

2.3 Method of soil analysis

2.3.1 Soil moisture content

After collection in 24 hours, a sub-sample from each sample was taken and used to establish the water content. This determination was made using the method of loss of weight which is shown in [24].

2.3.2 Soil particle size

Has been determined using the pipette-sedimentation method as described in [24].

2.3.3 Soil electrical conductivity (EC)

Estimated directly after soil-water extracts collection following the procedure specified by Carter [25].

2.3.4 Soil pH

The soil pH was recorded directly after the end of the electro-conductivity measurements using the procedure described in [26].

2.3.5 Soluble cations

Soluble sodium and potassium

Soil extracts of Na & K were estimated using a spectrophotometer (model; Corning, 410), as described in Allen (1989).

Soluble calcium and magnesium

Soluble Ca & Mg were estimated using the method showed by Vogel's textbook [27]. This involved a titration of a specific volume of soil-water extract with Ethylenediaminetetraacetic salt solution (EDTA) (0.02N) in the presence of murexide (Ammonium purpurate) indicator for calcium and EBT (Erichrome Black-T) indicator for magnesium.

2.3.6 Soluble anions

Soluble carbonate and bicarbonate

Those were estimated by titration of a specific volume of soil-water extract using sulphuric acid (0.01N) in the presence of phenolphthalein as the indicator for carbonates, and methyl orange indicator for bicarbonates, as described in [24].

Soluble chlorine

Soluble Cl has been estimated using the same soil-water extract which was used for estimation of carbonate and bicarbonate as shown in [24].

Soluble sulphate

The soluble sulphate was estimated using the precipitation method as described in [28].

2.4 Statistical analysis

A 3-factor analysis of variance test with replications was undertaken in order to statistically verify the results of this study. The factors used related to sample values obtained from the site (coastal and mountain), the soil type (burned and unburned) and the depth (0-15, 0-35, 35-60 cm for the coastal site and 0-15, 15-45, 45-70 cm for the mountain site). MINITAB Release 17 Statistical Software has been used for Windows on CD-ROM, 2016 edition for all data analysis, both statistical and graphical.

3 Results and discussion

3.1 Soil particle size

Results from the particle size analyses for both the coastal site and the mountain site and from all soil horizons are fall into the category of a (silt loam) according to Soil Classification American System as described in USDA (2001).

Field observations of the soil profiles of both study sites indicated that these profiles were characterized by a granular structure in the surface layers and sub- angular soil structures in the sub-surface layer horizons. The results (Table 1) show that there is a relatively low clay content (particles of $< 2\mu\text{m}$ in diameter), compared to the contents of silt and sand, in both study sites and burned and unburned areas, but especially in the mountain site. This is may be attributed to the reduced quantity of vegetation in the mountain site which may have affected the erosion of soil and therefore the selective movement of the clay particles, leaving the large particles of sand and silt in situ. This also reflects on the quantity of clay within the studied soil profiles, where the quantities of clay were accumulated in the middle depth. These results reinforced by the ANOVA results which indicate that the differences were highly significant ($p < 0.001$) between the study sites in the clay, silt and sand contents, however the differences were highly significant between different depths in clay content (Table I). The silt fraction (particles $2\mu\text{m} - 50\mu\text{m}$ in diameter) forms the highest percentage of the three particle size fractions, and there are considerable amounts of sand particles ($50 - 2000\mu\text{m}$ in diameter) in the soil profiles. Thus, all the soils in both study sites, irrespective of burning or depth fell into the category of a silt loam texture (USDA, 2001). The fires were presumably induced not enough to change the soil fractions and therefore the type of texture. ANOVA results strengthened that when indicate that there were no significant differences ($p > 0.05$) between the burned and unburned depths in the soil fractions sizes in the two studied sites.

Table 1 Results of soil particle size analysis in the two study sites (coastal and mountain), for both burned and unburned areas at three depths. Each value represents the average of 9 replicates

Site	Soil depth (cm)	Sample Area	Percentage of soil particles within each size fraction		
			clay	silt	sand
Coastal***	0-15	Burned	^a 21.0 ^a	^a 52.0 ^a	^a 27.0 ^a
		Unburned	^a 21.3 ^a	^a 51.4 ^a	^a 27.3 ^a
	15-35	Burned	23. 7 ^b	51.7 ^a	24.6 ^b
		Unburned	24.2 ^b	51.2 ^a	25.0 ^b
	35-60	Burned	24.0 ^b	51.0 ^a	25.0 ^c
		Unburned	22.4 ^c	51.0 ^a	26.6 ^c
Mountain***	0-15	Burned	^a 8.4 ^a	^a 62.6 ^a	^a 29.4 ^a
		Unburned	^a 8.2 ^a	^a 61.8 ^a	^a 30.0 ^a
	15-45	Burned	13.2 ^b	61.3 ^a	^a 25.5 ^a
		Unburned	13.5 ^b	61.0 ^a	^a 25.5 ^a
	45-70	Burned	12.4 ^c	61.0 ^a	26.6 ^c
		Unburned	12.0 ^c	60.0 ^a	28.0 ^c

*** Symbols means the differences were highly significant ($p < 0.001$) between the two sites in each of the soil particle size analysis results. The letters who are on the upper left side of the values represent the statistical analysis results between the three studied depths in the two sites of the study area, while those who are on the upper right side of the values represent the statistical analysis results between the burned and unburned depths. Across each column, values followed by a different letter are significantly different ($p < 0.001$) while those followed by a same letter are not significantly different ($p > 0.05$).

3.2 Soil moisture content

The results of soil moisture content show that the studied soils had a low water content, between about 1 and 5% (Table 2). This may be because the period in which the samples were collected (in August) is the period where the air temperature is at its highest (about 30 and 35°C at the coastal and mountain sites, respectively), thus increasing the evaporation rates from the soil. The data obtained from this study also indicate that there is a strong link between the

percentage of moisture in the soils and the soil’s clay content (Figure 3). This relationship was present at both study sites and for both the burned and unburned areas. The soil moisture present increased with depth at the four study areas so, the results also show highly significant differences ($p < 0.001$) between the mean values of the water content at different depths, being lower in the top layer. This is may be consistent with the pattern of increase in the proportion of clay particles with depth (Figure 4), as greater percentage clay concentration will lead to increased water retention, thus provide an opportunity to provide the humidity needed for the growth of vegetation. Thus, due to the proportion of clay being higher in the coastal site which increases the capacity of the soil to retain water, results also indicated that water content is lower in the mountain site samples compared to the samples from the coastal site. This difference between sites was significant at the $p < 0.001$ level (Table 2). However, the proportion of moisture in the coastal site at all depths appears to have been sufficient to meet the needs of evaporation and transpiration, since it was observed during the collection of samples that there was a notable recovery of the vegetation at this site after burning.

Table 2 Results of clay (%) and soil moisture content (%) in the both study sites for both burned and unburned areas at three depths. Each reading represents the average of 9 replicates

Site	Sample type	Sample depth (cm)	Clay particle size (%)	Soil moisture Content (%)
Coastal***	Burned	00-15	a 21.0 ^a	^a 2.42 ^a
		15-35	23.7 ^b	^b 3.50
		35-60	24.0 ^b	^c 3.39
	Unburned	00-15	^a 21.3 ^a	^a 4.33 ^b
		15-35	24.2 ^b	^b 4.83
		35-60	22.4 ^c	^c 4.82
Mountain***	Burned	00-15	^a 8.4 ^a	^a 1.05 ^a
		15-45	13.2 ^b	^b 2.34
		45-70	12.4 ^c	^c 2.30
	Unburned	00-15	^a 8.2 ^a	^a 1.85 ^a
		15-45	13.5 ^b	^b 2.55
		45-70	12.0 ^c	^c 2.23

***Symbol means the differences were highly significant ($p < 0.001$) between the two study sites in each of the clay particle size analysis and soil moisture content estimation results. The litters who are on the upper left side of the values represent the statistical analysis results between the three studied depths in the two sites of the study area, while those who are on the upper right side of the values represent the statistical analysis results between the burned and unburned depths. Across each column, values followed by a different letter are significantly different ($p < 0.05$) while those followed by a same letter are not significantly different.

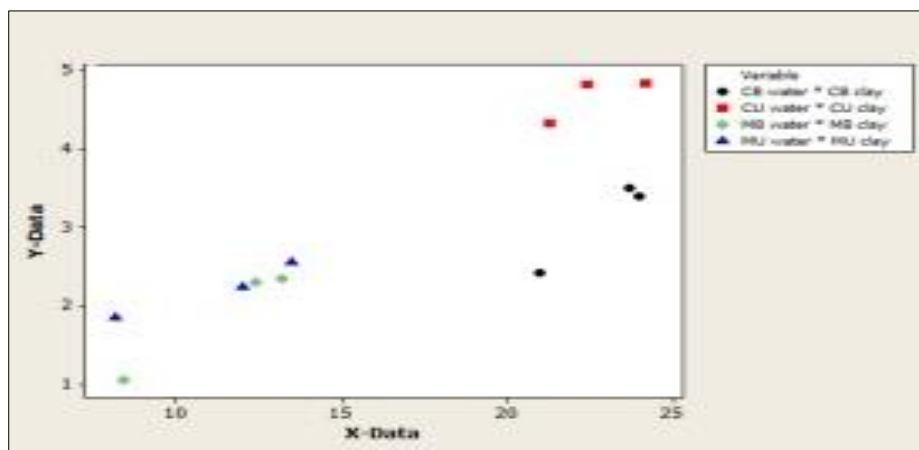


Figure 3 Scatter plot of the relationship between soil moisture content (Y-Data) and soil clay content (X-Data) using mean data for all depths and burned and unburned area, from coastal and mountain sites, the different symbols indicate the four areas sampled (CB is burned coastal, CU is unburned coastal, MB is burned mountain and MU is unburned mountain)

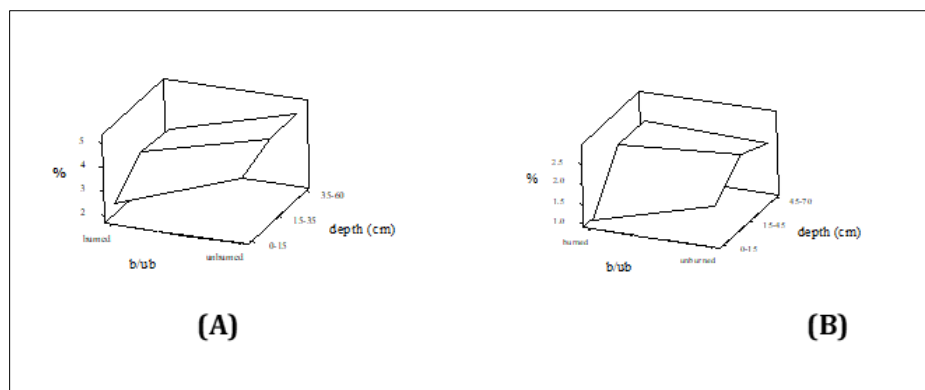


Figure 4 Surface plot showing the variation in the percentage of the moisture content at three depths in burned (b) and unburned (ub) soils from (A) the coastal site and (B) the mountain site

3.3 Soil electrical conductivity (EC)

It is obvious from (Table 3) that the electrical conductivity (EC) of soil-water extracts range from the lowest value at the unburned coastal site (15-35 cm in depth), to the highest one at the burned mountain site (depth of 0-15 cm).

This may be due to the period when the samples were collected (in August) when the annual air temperature was at its highest (about 30 and 35°C at the coastal and mountain sites, respectively). This will have resulted in an increase in the evaporation rates from soils.

Table 3 Mean values of soil EC and pH. Each reading represents the average of 9 replicates.

Site	Sample type	Sample depth (Cm)	EC mS cm ⁻¹ at 25°C	pH
Coastal**	Burned	0-15	a1.42 ^a	a7.09 ^a
		15-35	b1.16	b7.04 ^b
		35-60	a 1.32	c7.27 ^c
	Unburned	0-15	a1.35 ^a	7.06 ^d
		15-35	b1.05	7.11 ^e
		35-60	a1.20	7.20 ^f
Mountain***	Burned	0-15	a2.22 ^a	7.57 ^g
		15-45	b1.56	7.16 ^h
		45-70	b1.72	7.26 ⁱ
	Unburned	0-15	a1.84 ^a	7.10 ^j
		15-45	b1.59	7.14 ^k
		45-70	b1.64	7.20 ^l

***Symbol means the differences were highly significant ($p < 0.001$) between the two study sites in each of the EC and pH results. The litters who are on the upper left side of the values represent the statistical analysis results between the three studied depths in the two sites of the study area, while those who are on the upper right side of the values represent the statistical analysis results between the burned and unburned depths. Across each column, values followed by a different letter are significantly different ($p < 0.00$) while those followed by a same letter are not significantly different ($p > 0.05$).

However, the results show that the EC values for the mountain site in the uppermost soil layer are higher than the values in the coastal site at the same depth. This is likely to be because the fires have a role in lowering the moisture content, which will increase the values of soil EC at this depth. Three-factor ANOVA statistical analysis results (Table 3) reinforced this conclusion when it indicated to the differences in EC values were highly significant ($p < 0.001$) between the two study sites, also these results indicated to no significant difference ($p > 0.05$) between burned and unburned areas in the two study sites. The results also show that the EC values decrease to their lowest values in the middle depth at both study sites, whether burned or unburned (Figure 5). This may be attributed to an increase in moisture content

with depth (Figure 3). This may be accompanied by an increase in the solubility of salts, which would lead to a decrease in salt concentrations and thus lower soil EC. This probably refers to the homogeneity of the soil profiles, in terms of ease of passage of the soil solution within it, and perhaps that the effect of heat from the high air temperature during the sampling period lowered the moisture content and increased the EC values at the surface of the soil and was more important than the effect of fire. Besides the individual factor effects of site and depth on soil EC, however, none of the interaction effects were significant.

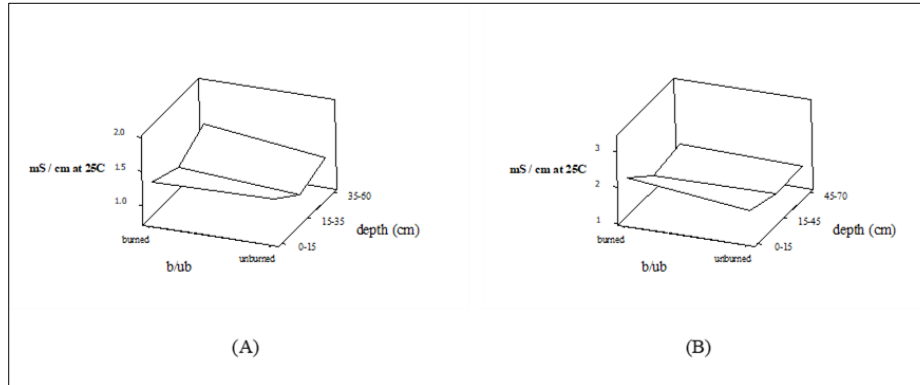


Figure 5 Surface plot showing the variation in EC (mS cm^{-1} at 25°C) at three depths in burned (b) and unburned (ub) areas from (A) the coastal site and (B) the mountain site

On the other hand, it should be noted that statistical analysis showed that there is an inverse relationship between the values of electrical conductivity of soil samples and moisture content values of those samples. This means that the increase in moisture values with depth has been accompanied by a decrease in the values of electrical conductivity (Table 4 and Figure 6). This is a clear indication that the rates of rainfall on the study area were enough to cause leaching of an important proportion of salts in the root zone. It is clear from Figure 5 that this effect is most pronounced in the coastal site, the results of which lie to the lower right of the diagram.

Table 4 The distribution patterns of moisture content (%) and electrical conductivity (EC) (mS cm^{-1} at 25°C) of soils of the two study areas at both sites at three depths. Each reading represents the average of 9 replicates.

Site of study	Type of sample	Depth of sample (cm)	Moisture (%)	EC (mS cm^{-1} at 25°C)
Coastal	Burned	00-15	2.42	1.42
		15-35	3.50	1.16
		35-60	3.39	1.32
	Unburned	00-15	4.33	1.35
		15-35	4.83	1.05
		35-60	4.82	1.20
Mountain	Burned	00-15	1.05	2.22
		15-45	2.34	1.56
		45-70	2.30	1.72
	Unburned	00-15	1.85	1.84
		15-45	2.55	1.59
		45-70	2.23	1.64

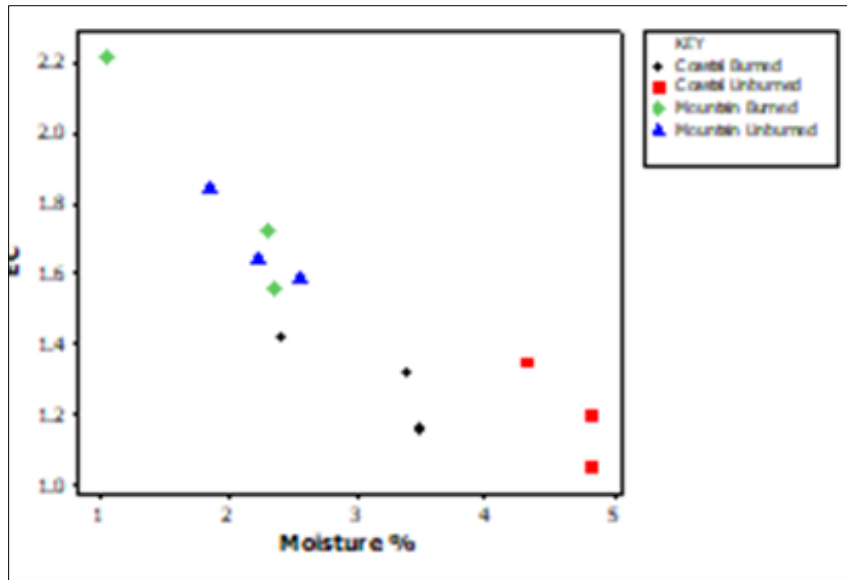


Figure 6 Scatter plot of the relationship between EC (mS cm^{-1} at 25°C) and soil water content (soil moisture) using mean data for all depths and burned and unburned areas, from coastal and mountain sites, the different symbols indicate the four areas sampled.

3.4 Soil pH

The pH values of all soil samples are characterized as slightly alkaline (Table 3). Slightly higher values were recorded in almost all cases in the burned areas at both study sites compared with the same depth in the unburned areas, with one exception (Figure 7). The increase in the pH in the surface layer due to burning was much greater in the mountain site (0.47 units) than it was in the coastal site (0.03 units). The two sites are statistically highly significantly different ($p < 0.001$) from each other (Table 3), with higher values in the mountain site. There was also a very significant effect of burning ($p < 0.001$).

The results also show a strongly significant ($p < 0.001$) effect of depth (Table 3), with the greatest values at the lowest depth except for the upper layer of the burned mountain site (Figure 7).

The increase in pH values in the uppermost layer in the burned mountain site may be attributed primarily to an increase in the percentage of basic cations in the ash residues, due to the consumption of organic matter by the oxidation processes during the fire and thus a lack of organic acids.

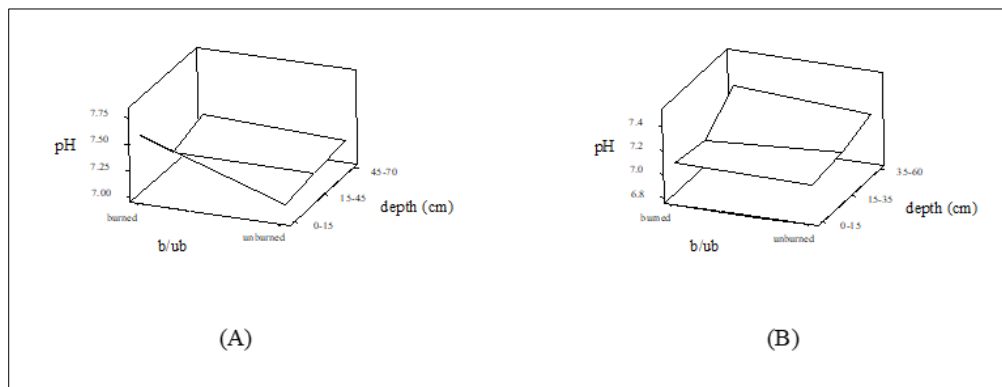


Figure 7 Surface plot showing the variation in pH at three depths in burned (b) and unburned (ub) areas from (A) the coastal site and (B) the mountain site

The fact that there is a large increase in pH in the upper layer only of the more recently – burned mountain site explains why there are significant ($p = 0.001$) interaction effects between all pairs of factors and also the interaction of all three factors. This may be an indication of the impact of fire on the uppermost layer of soil shortly after a burn, since these

soil samples were collected less than one month after the fire. It is worth noting that, in the burned part of the coastal site, the soil pH has returned to about pre-fire levels. The up-take of basic elements by regenerating vegetation and leaching of ash under conditions of rainfall have probably resulted in a drop of pH after fire at this site.

3.5 Soil soluble ions

3.5.1 Soluble cations

Soluble sodium (Na⁺)

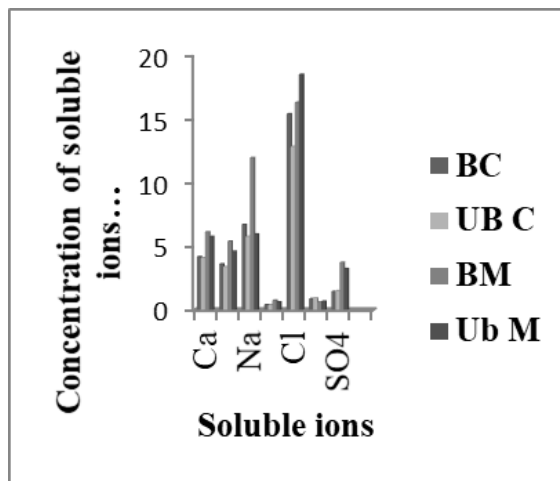


Figure 8 Histogram showing the concentration of soluble ions in soil samples at 0-15 cm depth from the four study areas. (C = coastal; M = mountain; B = burned & Ub = unburned)

Table 5 Results of soil soluble cations and anions in the two study sites (coastal and mountain), for both burned and unburned areas at three depths. Each value represents the average of 9 replicates

Site	Sample Type	Sample Depth (cm)	Soluble cations (meq. L ⁻¹)				Soluble anions (meq. L ⁻¹)		
			Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻
Coastal**	Burned	0-15	^a 6.71 ^a	^a 0.42 ^a	^a 4.18 ^a	^a 3.62 ^a	^b 15.39 ^a	^a 0.89 ^a	^b 1.46 ^a
		15-35	^b 4.96 ^b	^b 0.27 ^b	^b 3.84 ^b	^b 2.71 ^b	10.60 ^c	^b 0.60 ^a	1.20 ^c
		35-60	^c 6.30 ^c	^c 0.38 ^c	^c 4.09 ^c	^c 3.36 ^c	11.40	^c 0.87 ^a	1.38
	Unburned	0-15	^d 5.77 ^d	0.40	^d 4.0 ^d	3.40	12.82	^d 0.93	1.52
		15-35	^e 3.53 ^e	0.23	3.33	2.60	9.38	0.54	1.18
		35-60	^f 4.72 ^f	0.28	4.04	2.89	10.91	0.67	1.41
Mountain***	Burned	0-15	^g 11.95 ^g	0.77	^g 6.13 ^g	5.40	18.48	0.62	3.74
		15-45	^h 7.12 ^h	0.48	4.24	4.36	12.49	0.33	2.82
		45-70	ⁱ 7.43 ⁱ	0.51	5.53	4.69	12.00	0.58	3.41
	Unburned	0-15	^j 5.96 ^j	^j 0.64 ^j	5.77	4.60	16.29	0.69 ^a	3.25
		15-45	^k 4.11 ^k	^k 0.38 ^k	3.33	^k 3.27 ^k	10.52	0.32 ^a	2.67
		45-70	^l 5.47 ^l	^l 0.46 ^l	^l 4.62 ^l	^l 4.42 ^l	^z 15.84 ^y	^l 0.35 ^a	^z 3.13 ^y

***Symbol means the differences were highly significant ($p < 0.001$) between the two study sites in each of soluble cations and anions results. The letters who are on the upper left side of the values represent the statistical analysis results between the three studied depths in the two sites of the study area, while those who are on the upper right side of the values represent the statistical analysis results between the burned and unburned depths. Across each column, values followed by a different letter are significantly different ($p < 0.00$) while those followed by a same letter are not significantly different ($p > 0.05$).

The dissolved sodium cations in the water extracts of soil samples form a considerable percentage of the concentration of the total cations in the study area sites in both burned and unburned areas (Table 5). The results show that the concentration of soluble sodium is higher compared with the concentration of the other cations at all depths, and second only to chlorine of all the ions studied, this is attributed to the high air temperature during the sampling period, the processes of evaporation that occurred in the soil have led to an accumulation of sodium salts in the uppermost layer of the soil profile in both study sites (Figure 8, 9 and 10).

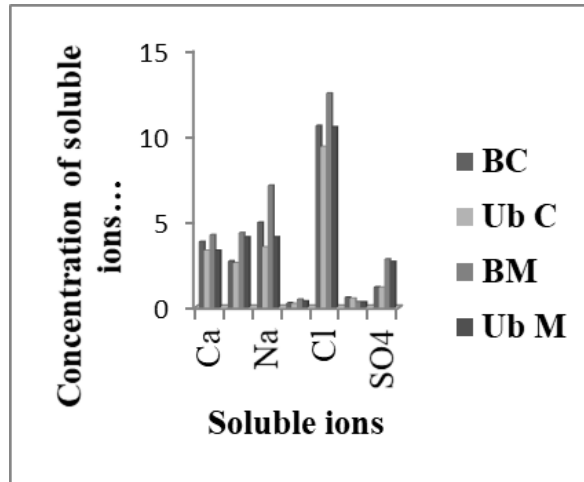


Figure 9 Histogram showing the concentration of soluble ions in soil samples at 15-45 cm depth from the four study areas. (C = coastal; M = mountain; B = burned & Ub = unburned)

Moreover, fire in the mountain site may have contributed to the increase of sodium concentration in the uppermost layer at that site, because the increased soil temperature would lower the moisture content and increase the concentration of dissolved ions. The average sodium concentration in the uppermost layer of the burned area was nearly twice its average concentration at the same depth in the unburned area (Table 5).

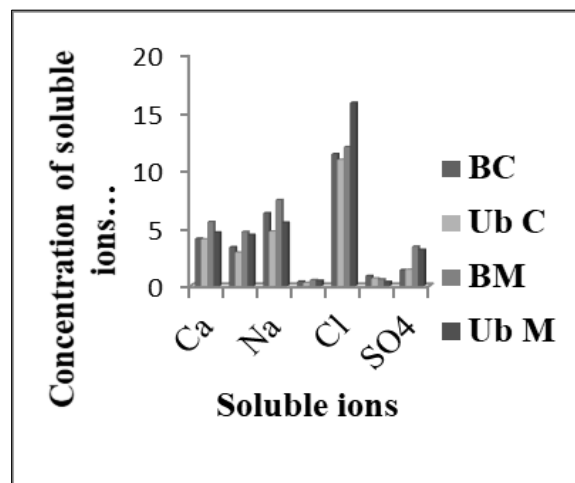


Figure 10 Histogram showing the concentration of soluble ions in soil samples at 45-70 cm depth from the four study areas. (C = coastal; M = mountain; B = burned & Ub = unburned)

The results of the statistical analysis by three-factor ANOVA (Table 5) show highly significant differences ($p < 0.001$) in the average concentration of dissolved sodium between the two study sites, between burned and unburned areas and between the depths in the studied soils. This significant difference between depths appears partly due to the effects of air temperature and burning on the upper layer, but also the high solubility and limited quantities of sodium salts, which may provide an opportunity for leaching down the soil profile during the rainy season, resulting in a greater concentration at the lowest depth than at the middle one (Figure 11 especially). It is worth mentioning that due to the marked effect of burning on the uppermost layers of the sampled soils particularly in the mountain site, as well as the different response to depth in the two sites, all the interaction terms are also highly significant ($p < 0.00$).

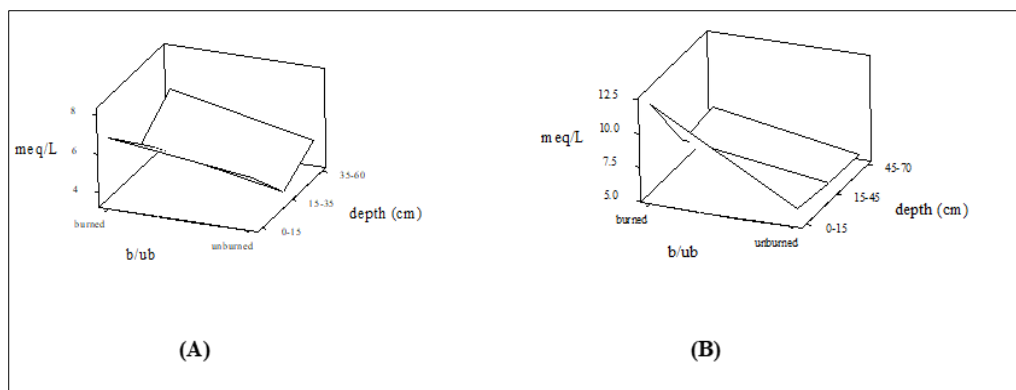


Figure 11 Surface plot showing the variation in soluble sodium content (meq. L^{-1}) at three depths in burned (b) and unburned (ub) areas from (A) the coastal site and (B) the mountain site

Soluble potassium (K^+)

The result of the chemical analysis of the soil-water extracts (Table 5) show that the dissolved potassium represents a very small percentage of the total concentration of the dissolved cations in all samples. This may be due to its limited quantity in precipitation and non-supply to the soil from the parent material (limestone). It is obvious also from the results that its concentrations decreased from the upper to the middle depth but then increased again in the all four study areas. There is a clear effect of burning, since the highest average concentrations of dissolved potassium were found in the uppermost soil layer of the burned areas of both study sites (Figure 12). The behaviour of potassium is thus similar to sodium in the mountain site, but showed a similar if not so pronounced effect in the coastal site, which the sodium did not. However, the results also indicate that the average soluble potassium values were higher in the mountain site compared with the coastal. All three of the main factors are then highly significant ($p < 0.001$) in the three-factor ANOVA statistical analysis (Table 5). There is also a highly significant ($p < 0.001$) effect of all the interaction terms, because of the increase in dissolved potassium especially in the topmost layer of the burned mountain site (Table 5).

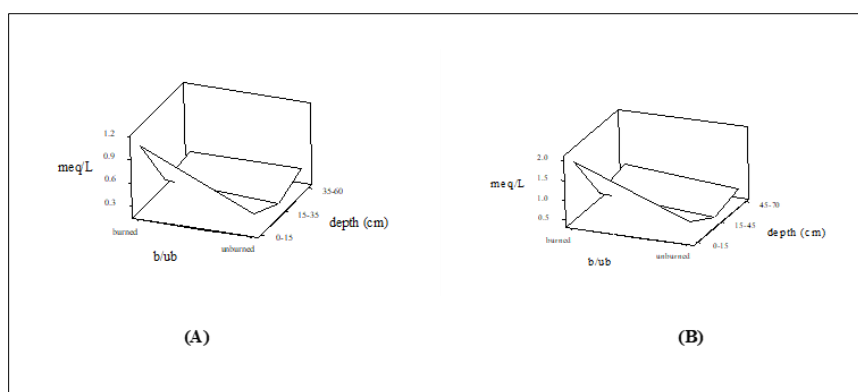


Figure 12 Surface plot showing the variation in soluble potassium content (meq. L^{-1}) at three depths in burned (b) and unburned (ub) areas from (A) the coastal site and (B) the mountain site.

Soluble calcium (Ca^{++})

The results of chemical analysis for soluble calcium concentration (Table 5) showed essentially the same patterns as for sodium and potassium. Higher concentrations were found at the mountain site compared with the coastal site (Table 5); concentrations were at their lowest in the middle depth layer of the soil; and there was some indication of greater values in the burned areas, though this difference was more slight with potassium (Figure 13).

These results are reinforced by the three-factor ANOVA statistical analysis results for the soluble calcium values (Table 5) which show that there were highly significant differences ($p < 0.001$) for all three of the factors separately. However, due to the presence of higher concentrations of the soluble calcium in the uppermost soil layers of the burned areas, the three-factor ANOVA results (Table 5) also indicated that there was a highly significant difference ($p = 0.001$) in the interaction between the impact of fire and soil depth. There was also a very highly significant ($p < 0.001$) interaction between soil depth and site, due to the more pronounced difference in the calcium values between the middle soil layer

and the others in the mountain site than was the case in the coastal site (Figure 7). Other interactions were not significant (Table 5), as the response to burning was similar in the two sites.

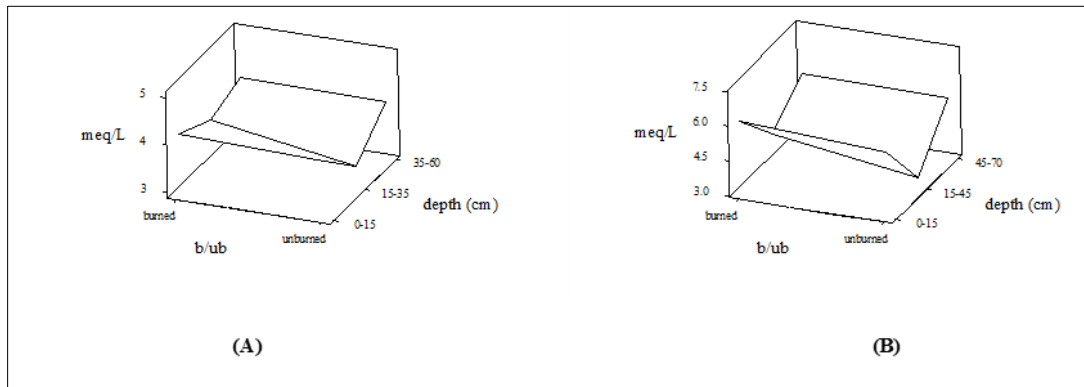


Figure 13 Surface plot showing the variation in soluble calcium content (meq. L^{-1}) at three depths in burned (b) and unburned (ub) areas from (A) the coastal site and (B) the mountain site

Soluble magnesium (Mg^{++})

The results of the chemical analysis of the soil-water extracts (Table 5) indicate that the patterns of the concentration of soluble magnesium was similar to the pattern shown by sodium and calcium. Namely, on average, the highest concentrations of soluble magnesium were found in the uppermost layer of all the soil profiles; the average concentrations at the mountain site were higher than in the coastal site (Table 5); and the burned area values were higher than the unburned ones, especially in the mountain site (Figure 14). When these results analyzed by three-factor ANOVA (Table 5), the differences were highly significant ($p < 0.001$) for all three factors separately. There were also less strong but significant differences ($p < 0.05$) in the interaction terms between burning and site and between burning, depths and site. Both of these interactions appear related to the greater magnesium concentration found in the upper layer of the burned mountain site.

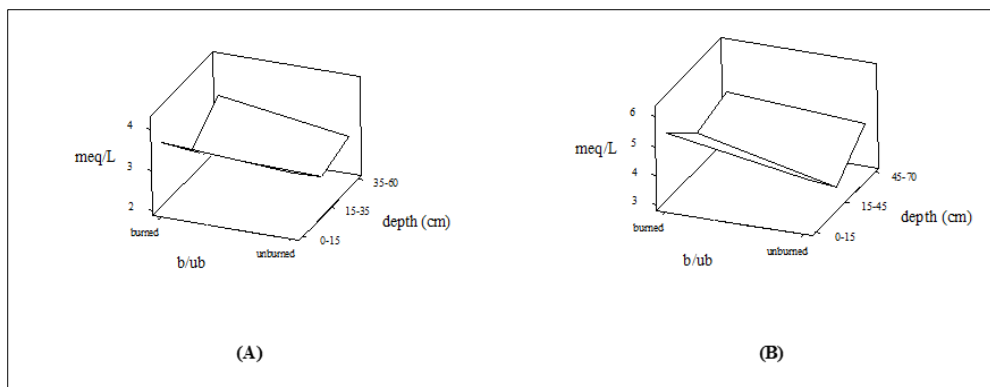


Figure 14 Surface plot showing the variation in soluble magnesium content (meq. L^{-1}) at three depths in burned (b) and unburned (ub) areas from (A) the coastal site and (B) the mountain site.

3.5.2 Soluble anions

Soluble chlorine (Cl^-)

Table 5 shows that the soluble chlorine anion was the prevalent ion in the soil-water extracts of the soil at both study sites, whether the area was burned or unburned. The prevalence of this ion is probably associated with the high solubility of its salts and being an anion, the chance of it being expelled from the surface of the soil particles is high. The result of this is that most of the surfaces of clay particles on which ions exchanged carry negative charges [29]. The data also indicate the soluble chlorine extracted from the soil samples taken from the mountain site was higher than in those samples taken from the coastal site (Table 5). Thus, the two sites are statistically significantly different ($p < 0.001$) from each other (Table 5). It might expected that fire would play a role in increasing the evaporation rates and thus increasing the concentration of chlorine salts in soil solution in the topmost soil layer. There is no significant effect of burning on

its own (Table 5), but there are significant interaction terms between burning and depth ($p < 0.001$) and between all three factors combined ($p < 0.05$).

The highest concentration of soluble chlorine found in the uppermost layers of the soil profiles in the burned areas, particularly in the mountain site (Figure 15). This may partly be attributed to the increase effect of air temperature and evaporation rates on the upper soil layer, which also shows the properties of chlorine salts in terms of high solubility and its rising up the soil profile due to capillary action and increased concentration in the uppermost layers during the summer period, as well as the effect of burning in having similar effects.

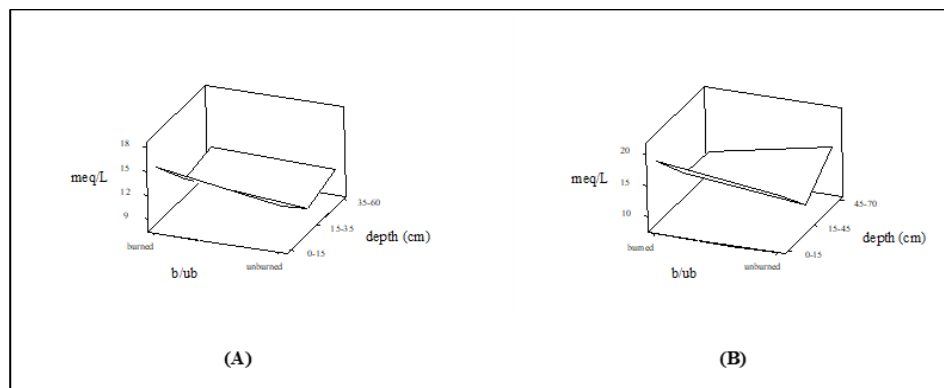


Figure 15 Surface plot showing the variation in soluble chlorine content (meq. L^{-1}) at three depths in burned (b) and unburned (ub) areas from (A) the coastal site and (B) the mountain site

Soluble bicarbonate (HCO_3^-)

The concentration of the soluble bicarbonate anion was low in all soil-water extracts from all areas and depths (Table 5). This may be due to its low content in precipitation, and no precipitation will have been occurring in the study period (in August). Results indicate that the highest average concentrations found in the uppermost layers in both study sites and both burned and unburned areas (Figure 16).

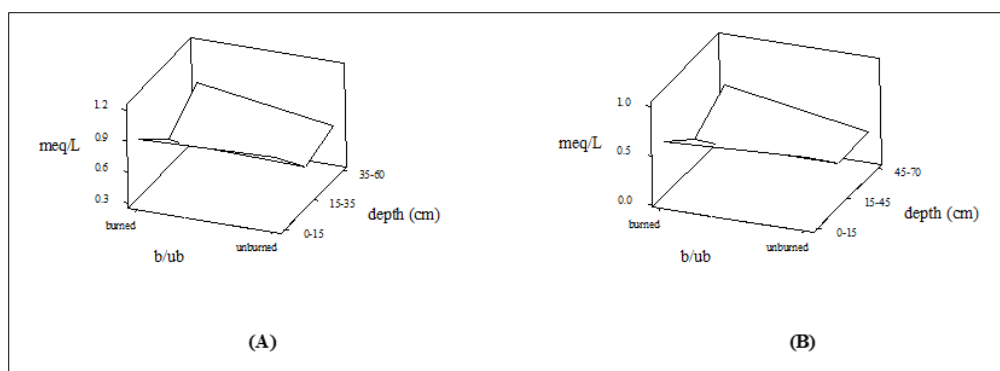


Figure 16 Surface plot showing the variation in soluble bicarbonate content (meq. L^{-1}) at three depths in burned (b) and unburned (ub) areas from (A) the coastal site and (B) the mountain site

The ANOVA results (Table 5) indicate that there were highly significant differences ($p < 0.001$) in the soluble concentration of this anion between the different depths in the four studied areas. When the bicarbonate chemical analysis results were analyzed by three-factor ANOVA (Table 5), the differences between burned and unburned areas in the two study sites were not significant ($p > 0.05$) which indicates that there was not an independent effect of fire on its own on the soluble content of this anion; nevertheless, there was a modestly significant difference ($p < 0.05$) when considering the interaction between the effect of burning and the soil depth. This interaction would appear to be because of slightly lower bicarbonate values in the upper layer of burned soils compared to unburned ones, but slightly higher values in the lower soil layer in the burned compared to unburned areas. Although the results (Table 5) show that the mean values of the soluble bicarbonate concentration do not vary much within each site, higher values were recorded in the coastal site compared with the mountain site, probably due to the fact that the amount of rainfall at the coastal site is higher than in the mountain site and thereby this will increase the solubility of this anion. There is a highly

significant difference ($p < 0.001$) in these concentrations between the studied sites when statistically analyzed (Table 5). However, the statistical analysis results also show that there are no significant differences ($p > 0.05$) in the soluble bicarbonate content in relation to any other of the interaction terms.

Soluble sulphate (SO_4^{2-})

From Table 5 and Figure 17, it can be seen that the pattern of distribution of the soluble sulphate anion within the soil profiles of the study sites was similar to the chlorine anion. Its average concentrations were higher in the mountain site than in the coastal site; the concentration in the middle depth was lower than in either of the others in the soil profiles; and burning seems to increase this parameter in the upper layer of the more recently burned site in the mountain. All three of the main factors are therefore highly significant ($p < 0.001$) in the ANOVA (Table 5).

It should be noted that all the interaction terms are also highly significant ($p < 0.001$), probably due to the marked effect of burning on the top layer, but only in the mountain site.

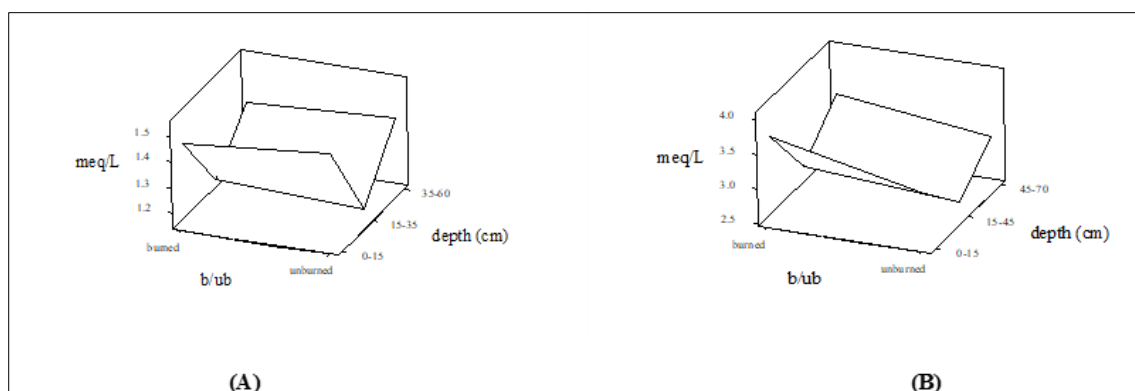


Figure 17 Surface plot showing the variation in soluble sulphate content (meq. L^{-1}) at three depths in burned (b) and unburned (ub) areas from (A) the coastal site and (B) the mountain site

4 Conclusion

This study was conducted in Aljabal alakhdar (Green Mountain) which lies in the N.E of Libya. It is the only naturally well-vegetated region in Libya. The risk of fires, mainly as a consequence of people removing fire wood, or sometimes converting forested areas to agricultural use, which may affect the soil chemical and physical properties. Data obtained from this study indicate that except soil particle size, heat has effects on the studied properties and the observed changes were mostly limited to the surface layer of soil (0-15cm depth). It is hoped that the output from this research will be used to develop recommendations that will help to conserve these forests and make people aware of the dangers of fire to this ecosystem, in terms of their potential effect on soil physical and chemical properties.

Compliance with ethical standards

Acknowledgments

We acknowledge the help of Libyan ministry of high education and scientific research and all my friends in university of Darna.

Disclosure of conflict of interest

The authors have no conflicts of interest to disclose.

References

- [1] Wells, C. G., J. Campbell, J., and DeBano, L.F. Effects of fire on soil: a state-of-knowledge review. US Department of Agriculture, Forest service, 1979: Washington, DC., USA, 34pp.

- [2] Dyrness, C. T., and Youngberg, C. T. The effects of logging and slash burning on soil structure. *Soil Science Society of American Journal*, 1957; 21: 444-447. (1957).
- [3] Kovacic, D. A., Swift, D.M., Ellis, J.E., and Hakonson, T.E. Immediate effects of prescribed burning on mineral soil nitrogen in ponderosa pine of New Mexico, *Soil Science*, 1986 ; 141: 71-76.
- [4] Ahlgren, I. F., and Ahlgren, C. E. Ecological effects of forest fires. *Botanical Review*, 1960; 26: 483 – 533.
- [5] DeBano, L. F. Water repellent soils: a state-of-the-art. General Technical Report USDA Forest Service, 1981; PSW - 46: 21.
- [6] Rowe, P. B. and Colman, E. A. Disposition of rainfall in two mountain areas of California. Agricultural Research Service, U.S. Department of Agriculture, 1951; USDA, 84pp.
- [7] Giovannini, G., Lucchasi, S., and Giachetti, M. Effect of heating on some physical and chemical parameters related to soil aggregation and erodibility. 1988; *Soil Science* 146: 255-261.
- [8] Nishita, H. and Hang, R. M. Some physical and chemical characteristics of heated soil, 1972; *Soil Science* 113: 422-430.
- [9] Humphreys, F. R., and Craig, F. G. Effects of fire and soil chemical, structural and hydrological properties.. In: *fire and the Australian biota*. Australian Academy of Science Press, 1980; (Eds AM Gill, RH Groves and IR Noble), Canberra, pp. 177-200.
- [10] Wells, C. G. Effects of prescribed burning on soil chemical properties and nutrients availability. Prescribed burning symposium proceedings. United States Department of Agriculture, forest surface, Southeastern forest Experiment station, 1971; Asheville, USA.
- [11] DeRonde C. Impact of prescribed fire on soil properties-comparison with wildfire effect. In: *Fire in ecosystem dynamics. Mediterranean and Northern perspective*, 1990; J.G. Goldammer and M. J. Jenkins (eds), SPB Academic Publishing. The Hague; pp127-136.
- [12] Diaz-Fierros F., Benito, E., and Gurrero, J. Solute loss and soil erosion in burnt soil Galicia (Northernwest of Spain). *Fire in ecosystem dynamics. Mediterranean and Northern perspective*, 1990; J. G. Goldammer and M. J. Jenkins (eds), SPB Academic Publishing, The Hague, 103-116.
- [13] Kutiel P., Naveh Z., and Kutiel, H. The effect of a wildfire on soil nutrients and vegetation in an Aleppo pine forest on mount carmel, Palestine. *Fire in ecosystem dynamics. Mediterranean and Northern perspective*, 1990; G. Goldammer and M. J. Jenkins (eds), SPB Academic Publishing. The Hague, pp 85-94.
- [14] Pritchette, W., and Fisher, R.R. Properties and management of forest soil. 2nd edition 1987; John Wiley and Sons, New York, USA.
- [15] St. John, T. V. and Rundel, P. W. The role of fire as a mineralizing agent in a Sierran coniferous forest, 1976; *Ecologia* 25: 35 - 45.
- [16] Murphy, J. D., Johnson, D.W., Miller, W.W., Walker, R.F., Carrol, E.F., and Blank, R. R. Wildfire effects on soil nutrients and leaching in a Tahoe basin watershed, Nevada. *Journal of Environmental Quality*. 2006; 35: 479-489.
- [17] DeBano, L. F. and Conard, C. E. The effect of fire on nutrients in a chapparal ecosystem. 1978; *Ecology* 59: 489 - 497.
- [18] T Terefe, I Mariscal-Sancho, F Peregrina, R Espejo. Influence of heating on various properties of six Mediterranean soils A laboratory study. *Geoderma*, 2008; 143(3-4) pp 273-80.
- [19] Duguay B., Rovira P., Gomez, R. Land - use history and fire effects on soil fertility in eastern of Spain. *Soil Science European Journa*. 2007; 58: 83 - 91.
- [20] Tomkins, I. B., Kellas, J.D., Tolhurst, K.G. and Oswin, D.A. Effects of fire intensity on soil chemistry in a eucalypt forest. *Australian Journal of Soil Research*. 1991; 29: 25-47.
- [21] The meteorological Service Centre. Periodic routine report. 2022; Shahat, Libya.
- [22] USDA (Soil Survey Staff). *Soil Taxonomy, A Basic System of Soil classification for Making and Interpreting Soil Surveys*. Natural Resources Conservation Service, 2001; Agriculture Hand book (436). Washington, D. C., USA.
- [23] Hemingway, R.L. Soil-sampling errors and advisory analyses. *Journal of Agricultural Science*. 1955; 46: 1-8.
- [24] Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E., and Clark, F. E. *Methods of Soil analysis, part (1) and part (2)*. American Society of Agronomy. 1965; Inc., publisher Madison, Wisconsin, USA.

- [25] Carter M.R., Gregorich E.G, Soil Sampling and Methods of Analysis. Canadian Society of Soil Science.1993; Lewis Publishers, Charlottetown, Canada.
- [26] Allen, S. E. Chemical analysis of ecological materials. Blackwell Scientific, 1989; Oxford, UK.
- [27] Vogel, I.A. Textbook of Quantitative Chemical Analysis. 5th edition 1989; Longman Scientific& Technical, UK.
- [28] Jackson, M. L. Soil chemical analysis. Verlag: Prentice Hall, Inc., Englewood Cliffs, NJ. 1958; Englewood Cliffs, New Jersey, USA.
- [29] Bohn H.L., Brian L., M., George A. O'Connor. Soil Chemistry. 3rd edition 2001; John Wiley and Sons, New York, USA.