



(RESEARCH ARTICLE)



## Influence of the temperature on soil's exchangeable cations and cation exchange capacity, Derna district, Libya: A field and Laboratory study

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### Abstract

This study conducted in Aljabal alakhdar (Green Mountain), Derna, Libya. It is the only wet region in Libya. Like other Mediterranean forests, it is exposed to the risk of fires. To assist in this, two different geographical units from the region (coastal and mountain), which been burned at different times; to identify whether these soils are regaining their pre-burn status over time.

The studied properties were: the soil clay content, the soil organic matter (O M), the soil exchangeable cations and soil cation exchange capacity (CEC). It is obvious from the results that there is a relatively low clay content, compared to the contents of silt and sand, in both study sites and their burned and unburned areas. Soils of both study sites characterized by low organic matter content.

The results indicated that, the basic exchangeable cations ranking was:  $Ca^{++} > Mg^{++} > Na^{+} > K^{+}$ , in both study sites, for burned and unburned areas and at all depths. The rank order of these four cations did not change with depth in the four study areas except that sometimes-exchangeable potassium was more abundant than exchangeable sodium. The exchangeable calcium and magnesium account for about 80% of the CEC results so, the patterns of behaviour of the soil CEC are similar to the patterns of behaviour of these two elements.

**Keywords:** Burned and unburned soil; Soil clay content; Soil OM; Exchangeable cations; CEC

### 1. Introduction

Libya, in the Mediterranean region, has soils that are considered to be arid except in a small area called Aljabal Alakhdar (Green mountain), which is the geographic area covered by this essay. Like other forests in the Mediterranean, it has suffered extreme degradation. This is mainly due to people removing firewood, or sometimes converting forested areas to agricultural use, as well as fires, which may alter several soil chemical and physical properties [1], [2]. However, [3] indicate that exactly how fire affects the physical and chemical properties of soil depend on the amount of material consumed during burning, the magnitude and duration of soil heating, the frequency of fire, and the post-fire environment such as climate. Many authors, for example [4] and [5] studied the alteration of soil texture under intense fires (>400°C). They particles, making the soil texture more coarse and erodible. In some cases, increasing the coarseness of clay can makes soils more permeable to air and water [1]

According to [6] and [7] 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.

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The decrease in organic matter content after a fire depends on the temperature levels reached during burning. Roger *et al.* [8] found that due to fire the amount of organic matter and mineral nutrients in the soil can alter. While [9] found the organic matter content in the top 8cm of mineral soil to be only 0.6% on extremely burned compared to 3.8% in unburned soils. In addition, [10] observed that the changes in chemical properties following a fire are primarily related to changes in the quantity and quality of the organic matter on the soil surface, this indicates that burning can lead to a rapid loss of nutrients from the system as a result of volatilization, leaching, run off, and/or ash convection. Numerous authors have stated that the extent of soil organic matter decomposition varies according to the intensity of fires. For example, [11] reported that distillation of volatiles and loss of organic carbon in soils starts at temperatures between 100 and 200°C: above this the charring process starts. Between 130 and 190°C lignins and hemicellulose begin to degrade [1]). On the other hand, [12] found that temperatures over 300°C exert structural changes, mainly decarboxylations, and an increase in the proportion of aromatic structures.

Cation exchange capacity (CEC) is the sum of the exchangeable cations found on organic and inorganic soil colloids. Total CEC can be decreased by burning, and may remain low for at least one year after a fire, because organic matter, which provides a large reactive surface area, is consumed [13] and [14]. Grove *et al.* [15] noticed that though there was a pulse of base cations after a single burn, as burn frequency increases the magnitude of the pulse declined. They explained that this effect arises because of an initial large release of the base cations reservoir in standing biomass and organic materials, followed by a steady loss of cations from the soil as they are leached away. They concluded that further burning does not replenish the soil base cations pool because the standing biomass and organic matter pools have previously been exhausted by burning. Also, [16] noted that fire caused an increase of exchangeable  $K^+$  at a burnt site, but not  $Na^+$ ,  $Ca^{+2}$ , or  $Mg^{+2}$ . By contrast, [17] observed that the pumping up of nutrients by vegetation from the deeper horizon to the surface by the more established vegetation probably accounted for higher concentrations of exchangeable  $Na^+$ ,  $Ca^{+2}$ , and  $Mg^{+2}$  in an old burnt site.

Although, [18] found that potassium appears to decrease in concentration with time after a fire, [19] reported significantly higher levels of exchangeable potassium in burned forests for a period of 21 months following a wildfire. In contrast, [20] found in their study that there were no consistent or significant effects on potassium content in soil after fire.

This study will be investigating the effects of fires on studied chemical properties of soils from one particular country in the Mediterranean, Libya, and will hopefully provide information that will contribute to an understanding of the deterioration of the forests in the selected region. To assist in this, two different geographical units from the region, which been burned at different times, will be sampled to broaden the range of conditions which will be investigated.

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## 2. Material and methods

### 2.1. Study Area, Site Selection, and Soil Sample Collection

This study was conducted in the Aljabal Alakhdar (Green Mountain) region. 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].

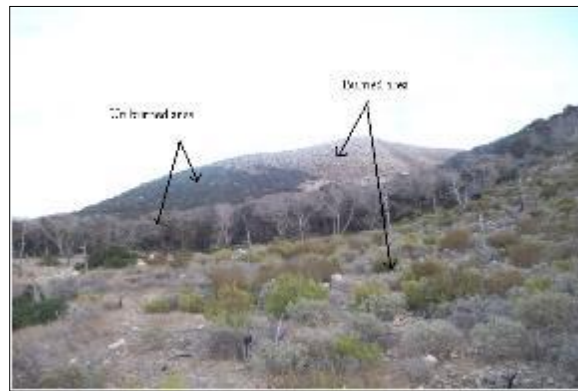
The first site (old burnt site) that has been used in this study lies in the coastal region (Figure 1). It is in an area called Ras Alhelal; subsequently, this site will be referred to as the coastal site. It is located between the longitudes 22° 12' 030" and 22° 13' 120", and the latitude 32° 52' 390" and 32° 53' 132" at an altitude of 83 m above sea level, approximately 1.5 km away from the seashore.

Fires affected the forests of this region (Figure 2) destroying the vegetation in more than 22 hectares out of the total of about 120 hectares.

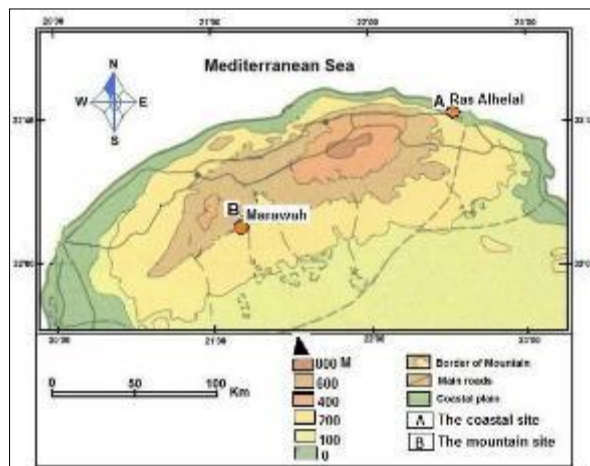
The second site (newly burnt site) used in this study is located in an area called Marawah, approximately 150 km South-West of the first site (Figure 3). Throughout the rest of this study, it will be referred to as the mountain site. It is located between the longitude 21° 24' 021" and 21° 25' 299" and the 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. The modern road runs between the burned and unburned areas (Figure 4). Fires swept through about 11 hectares of this site (Figure 5).



**Figure 1** View of the coastal site in the study area (Ras Alhelal). Note: (1) The dead trees, probably killed by fire; (2) the sparse regenerating vegetation; and (3) the very low level of humus in the soil. (Photo by the author)



**Figure 2** The effects of fire on the coastal site of the study area (Ras Alhelal). Note: The area in the ground was burned and had been recovering for eight years since the fire (Photo by the author)



**Figure 3** Map showing the distance between the locations of the two study sites (coastal and mountain). (Source: Libyan National Atlas, 1980)



**Figure 4** The mountain study site of the study near Marawah area looking from the burned area to the unburned woodland, which is on the far side of the road. (Photo by the author)



**Figure 5** Fire effects on the Marawah forests (the mountain site). Note: the effects on the soil surface and the Aleppo tree (*Pinus halepensis*) trunks. (Photo by the author)

According to [22]); the soils in the coastal site are classified as Lithic Haploxeralf , while in the mountain site are classified as Typic Haploanthrepts.

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

## 2.2. Soil samples 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 areas collected from following horizons that 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 areas 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 areas, was as shown in [23]. In the two sites (coastal and mountain) the protocol was involved collecting the samples from nine positions in the form of a zigzag line to cover the studied area as much as possible, in the circumstances of this article the distance between each point was about 18 meters in the coastal site and about 22 m in the mountain site. To avoid the mixture of the samples with each other, the third depth was collected first, then the second and finally the first depth. This means there were three soil samples at each of nine positions per area for burned and unburned area at each site (coastal and mountain). All samples at the four study areas collected by auger tool, which was marked at the required depths. A total of fifty four soil samples were therefore collected from each site (3 depths × 9 replicates × 2 areas), and the total number of samples for both sites was 108. These samples were manually broken down and air-dried for not less than 72 hours. The samples then disaggregated by mortar, passed through a 2mm sieve and placed in labeled sample plastic bags.

### 3. Methods of soil analysis

#### 3.1. Soil particle size analysis

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

#### 3.2. Soil organic matter

The soil organic matter was determined gravimetrically by using the loss on ignition method as described in [25].

#### 3.3. Exchangeable cations

##### 3.3.1. Exchangeable sodium and potassium

Were estimated using ammonium acetate ( $\text{NH}_4\text{C}_2\text{H}_3\text{O}_2$ ) (1N) as a displaced agent as shown [26].

##### 3.3.2. Exchangeable calcium and magnesium

Exchangeable Ca & Mg were estimated by titration using the soil-  $\text{NH}_4\text{C}_2\text{H}_3\text{O}_2$  extract with EDTA solution as described in [27].

##### 3.3.3. Cation exchange capacity (CEC)

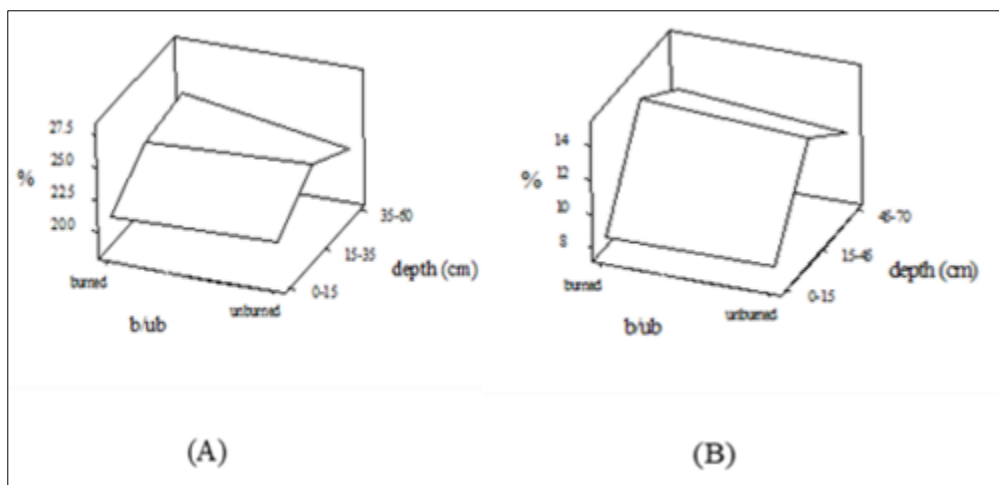
CEC was determined by summing the milliequivalents of the exchangeable cations (sodium, potassium, calcium and magnesium) in 100 g of oven-dry soil, as shown in [24].

#### 3.4. Statistical analysis

MINITAB Release 17 Statistical Software has been used for Windows on CD-ROM, 2016 edition for all data analysis, both statistical and graphical in order to statistically verify the results of this study. A three-factor analysis of variance test with replications was undertaken. 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, 15-35, 35-60 cm for the coastal site and 0-15, 15-45, 45-70 cm for the mountain site).

## 4. Results and Discussion

### 4.1. Soil clay content



**Figure 6** Surface plot showing the percentage of the particles consisting of the clay fraction at three depths in burned (b) and unburned (ub) areas from the coastal site (A) and mountain site (B)

It is obvious from Table 1 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 their burned and unburned areas but especially in the mountain site. When illustrated graphically, (for convenience), it can be seen from Figure 6 that there is a higher proportion of clay at

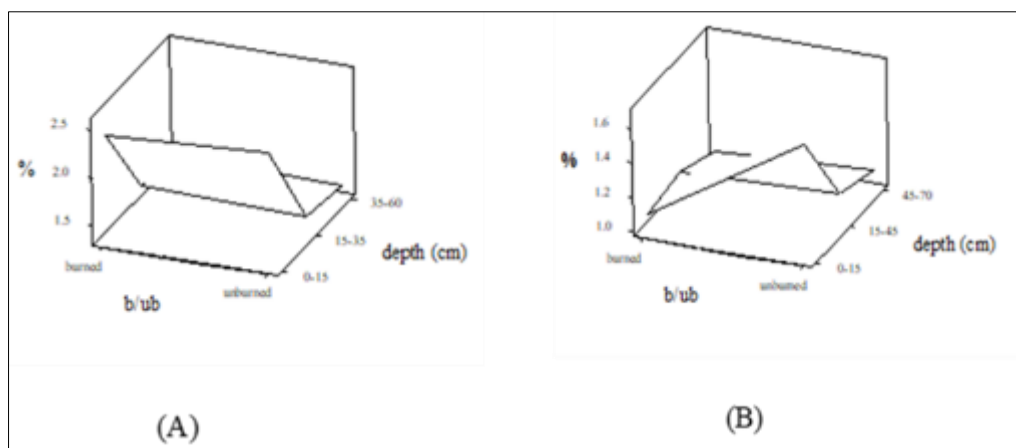
the coastal site than the mountain site and an increase in clay content of the soils with soil depth in all studied soil profiles. These results confirmed by the ANOVA results which indicated that the differences were highly significant ( $p < 0.001$ ) between the study sites in the clay, however the differences were highly significant between different depths in clay content (Table 1).

**Table 1** Results of soil particle 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			Organic matter % (O.M)
			clay	silt	sand	
Coastal***	0-15	burned	<sup>a</sup> 21.0 <sup>a</sup>	<sup>a</sup> 52.0 <sup>a</sup>	<sup>a</sup> 27.0 <sup>a</sup>	<sup>a</sup> 2.42 <sup>a</sup>
		unburned	<sup>a</sup> 21.3 <sup>a</sup>	<sup>a</sup> 51.4 <sup>a</sup>	<sup>a</sup> 27.3 <sup>a</sup>	<sup>a</sup> 2.53 <sup>a</sup>
	15-35	burned	23.7 <sup>b</sup>	51.7 <sup>a</sup>	24.6 <sup>b</sup>	1.51 <sup>b</sup>
		unburned	24.2 <sup>b</sup>	51.2 <sup>a</sup>	24.6 <sup>b</sup>	1.46 <sup>b</sup>
	35-60	burned	24.0 <sup>b</sup>	51.0 <sup>a</sup>	25 <sup>c</sup>	1.43 <sup>b</sup>
		unburned	22.4 <sup>c</sup>	51.0 <sup>a</sup>	26.6 <sup>c</sup>	1.40 <sup>c</sup>
Mountain***	0-15	burned	<sup>a</sup> 8.4 <sup>a</sup>	<sup>a</sup> 62.6 <sup>a</sup>	29.4 <sup>a</sup>	<sup>a</sup> 1.07 <sup>a</sup>
		unburned	<sup>a</sup> 8.2 <sup>a</sup>	<sup>a</sup> 61.8 <sup>a</sup>	30 <sup>a</sup>	<sup>a</sup> 1.65 <sup>a</sup>
	15-45	burned	13.2 <sup>b</sup>	61.3 <sup>a</sup>	25.5 <sup>a</sup>	1.12 <sup>b</sup>
		unburned	13.5 <sup>b</sup>	61.0 <sup>a</sup>	25.5 <sup>a</sup>	1.15 <sup>b</sup>
	45-70	burned	12.4 <sup>c</sup>	61.0 <sup>a</sup>	26.6 <sup>c</sup>	1.02 <sup>c</sup>
		unburned	12.0 <sup>c</sup>	60.0 <sup>a</sup>	28 <sup>c</sup>	1.08 <sup>c</sup>

\*\*\* Symbols means the differences were highly significant ( $p < 0.001$ ) between the two sites in each of the soil particle size analysis and organic matter results. The letters who are on the upper 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 ( $p > 0.05$ ).

#### 4.2. Soil organic matter



**Figure 7** Surface plot showing the variation in organic matter (%) at three depths in burned (b) and unburned (ub) soils from the coastal site (A) and mountain site (B)

Soils of both study sites characterized by low organic matter content (Table 1). In addition, the results indicate that the average percentage of the organic matter in all layers at the coastal site was higher than its average percentage in the equivalent layers at the mountain site. This may be due to the diversity of vegetation in the coastal site, as this site

included several species of trees, bushes, etc., while in the mountain site, the forest just one type of tree. The two sites are statistically significantly ( $p < 0.001$ ) from each other in the amount of organic matter percent (Table 1). Furthermore, the illustrated surface plot in Figure 7A show that the organic matter percentages decreased with depth in the coastal site and in the unburned mountain site; the low content of organic matter in the burned uppermost in the mountain site may emphasize the effect of heat on this layer (Figure 7B). Decreasing of organic matter with depth expected, due to the accumulation and degradation of plants residues in the top layers and the microbial activities of degradation of organic matter decrease with depth. Results of the ANOVA also indicated that there were highly significant differences ( $p < 0.001$ ) between the different depths.

### 4.3. Soil exchangeable cations

#### 4.3.1. Soil exchangeable calcium

The results (Table 2) indicate the basic exchangeable cations ranking was:  $Ca^{++} > Mg^{++} > Na^{+} > K^{+}$ , in both study sites, for both burned and unburned areas and at all depths. The rank order of these four cations did not change with depth in the four study areas except that sometimes exchangeable potassium was more abundant than exchangeable sodium. The calcium cation accounted for more than 50% of the exchange points and cation exchange capacity of soils of both study sites and at all depths. In a similar pattern to the clay ratio changes with depth (Tables 1 and 2), it may also be noted from the results that the exchangeable calcium average quantities had their maximum values in the middle depth in both study sites (Figure 8). There was a significantly greater ( $p < 0.001$ ) amount of exchangeable calcium in the coastal site (Table 2); a significant effect of depth ( $p < 0.001$ ) with higher values particularly in the middle depth layer (Figure 8); and a significant effect ( $p < 0.001$ ) of burning which increased the exchangeable calcium concentration (Figure 8), particularly in the mountain site. Because this effect of burning is mainly observed in the mountain site, there are also highly significant effects ( $p < 0.001$ ) for all the interaction terms (Table 2).

**Table 2** Mean values of exchangeable cations, CEC and Exchangeable Sodium Percentage in soils from the coastal and mountain sites for both burned and unburned areas at three depths. Each reading represents the average of 9 replicates

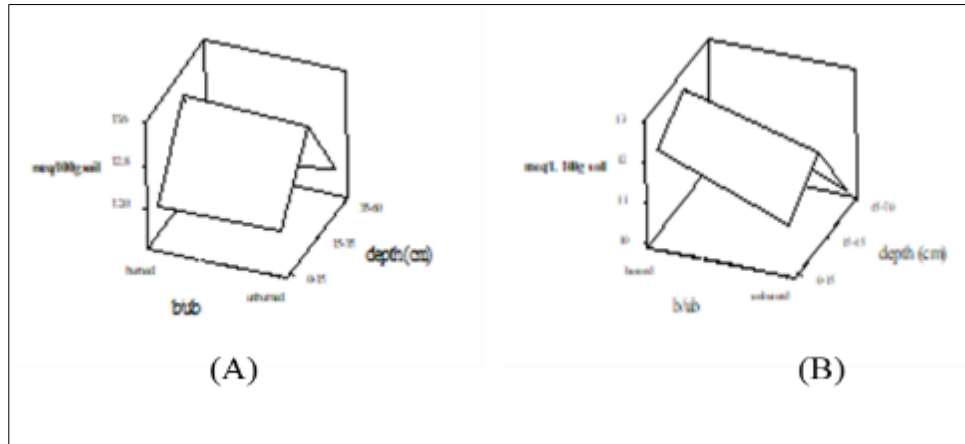
Site	Type of sample	Depth (cm)	Exchangeable cations (meq. 100g <sup>-1</sup> soil)				Cation Exchange Capacity (CEC) (meq.100g <sup>-1</sup> soil)	Exchangeable Sodium Percentage (ESP)* (%)
			Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>		
Coastal***	Burned	0-15	<sup>a</sup> 12.01 <sup>a</sup>	<sup>a</sup> 7.26 <sup>a</sup>	<sup>a</sup> 1.02 <sup>a</sup>	<sup>a</sup> 1.06 <sup>a</sup>	<sup>a</sup> 21.35 <sup>a</sup>	<sup>a</sup> 4.80 <sup>a</sup>
		15-35	13.41 <sup>b</sup>	8.92 <sup>b</sup>	0.91 <sup>b</sup>	0.31 <sup>b</sup>	23.55 <sup>b</sup>	3.86 <sup>b</sup>
		35-60	11.48 <sup>b</sup>	7.20 <sup>b</sup>	0.79 <sup>b</sup>	0.31 <sup>b</sup>	19.78 <sup>b</sup>	4.01 <sup>b</sup>
	Unburned	0-15	12.06 <sup>b</sup>	7.38 <sup>b</sup>	0.94 <sup>b</sup>	0.23 <sup>b</sup>	20.61 <sup>b</sup>	4.55 <sup>b</sup>
		15-35	13.32 <sup>c</sup>	8.62 <sup>c</sup>	0.51 <sup>c</sup>	0.38 <sup>c</sup>	22.83 <sup>c</sup>	2.24 <sup>c</sup>
		35-60	11.88 <sup>c</sup>	7.12 <sup>c</sup>	0.46 <sup>c</sup>	0.38 <sup>c</sup>	19.84 <sup>c</sup>	2.32 <sup>c</sup>
Mountain***	Burned	0-15	<sup>a</sup> 12.20 <sup>a</sup>	<sup>a</sup> 8.27 <sup>a</sup>	<sup>a</sup> 0.94 <sup>a</sup>	<sup>a</sup> 1.92 <sup>a</sup>	<sup>a</sup> 23.33 <sup>a</sup>	<sup>a</sup> 4.15 <sup>a</sup>
		15-45	<sup>a</sup> 13.04 <sup>a</sup>	<sup>a</sup> 8.97 <sup>a</sup>	<sup>a</sup> 0.91 <sup>a</sup>	<sup>a</sup> 0.83 <sup>a</sup>	<sup>a</sup> 23.75 <sup>a</sup>	<sup>a</sup> 3.90 <sup>a</sup>
		45-70	11.37 <sup>b</sup>	8.62 <sup>b</sup>	0.91 <sup>b</sup>	0.62 <sup>b</sup>	21.52 <sup>b</sup>	4.18 <sup>b</sup>
	Unburned	0-15	11.08 <sup>b</sup>	7.13 <sup>b</sup>	0.58 <sup>b</sup>	0.42 <sup>b</sup>	19.21 <sup>b</sup>	3.03 <sup>b</sup>
		15-45	11.96 <sup>c</sup>	8.66 <sup>c</sup>	0.52 <sup>c</sup>	0.85 <sup>c</sup>	21.99 <sup>c</sup>	2.40 <sup>c</sup>
		45-70	10.15 <sup>c</sup>	7.84 <sup>c</sup>	0.49 <sup>c</sup>	0.60 <sup>c</sup>	19.08 <sup>c</sup>	2.56 <sup>c</sup>

\*\*\*Symbols means the differences were highly significant ( $p < 0.001$ ) between the two sites in each of the soil particle size analysis and organic matter results. The letters who are on the upper 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 ( $p > 0.05$ ).

According to (U.S. Salinity Lab., 1954) ESP = Exchangeable Sodium Percentage\*

$$ESP = \frac{\text{Exchangeable sodium}}{\text{Cation Exchange Capacity}} \times 100$$

A sodic (alkali) soil has an ESP of more than 15 and an EC of less than 4 mS cm<sup>-1</sup> at 25°C.



**Figure 8** Surface plot showing the variation in exchangeable calcium content (meq. 100g<sup>-1</sup> soil) at three depths in burned (b) and unburned (ub) soils from the coastal site (A) and mountain site (B)

Although the differences in the absolute values of the exchangeable calcium quantities in the soils of the two study sites are fairly small, probably due to the prevailing parent material (limestone) being a main source of the soluble and exchangeable calcium, the ANOVA results show that there were highly significant differences ( $p < 0.001$ ) in the exchangeable calcium content between the studied sites, the coastal site having generally higher values.

The difference in the exchangeable calcium values at the uppermost layer between burned and unburned areas in the coastal site was very small. Probably this may be attributed to the coastal site being an old-burned site; also, the pumping of nutrients by regenerating vegetation (Figure 1) from the deeper horizons towards the surface probably accounts for increased concentrations of exchangeable calcium in the middle depths; and at the mountain site, the increased amount in the surface layer of the burned area was probably due to the accretion of ash from burning of surface organic matter.

Although the interaction terms are also highly significant, nevertheless it seems that the heat did not affect the ratio of this important cation compared to the total cation exchange capacity of the soils of the two study sites, and this may have helped to keep their physical properties such as good structure and suitable permeability for water and air.

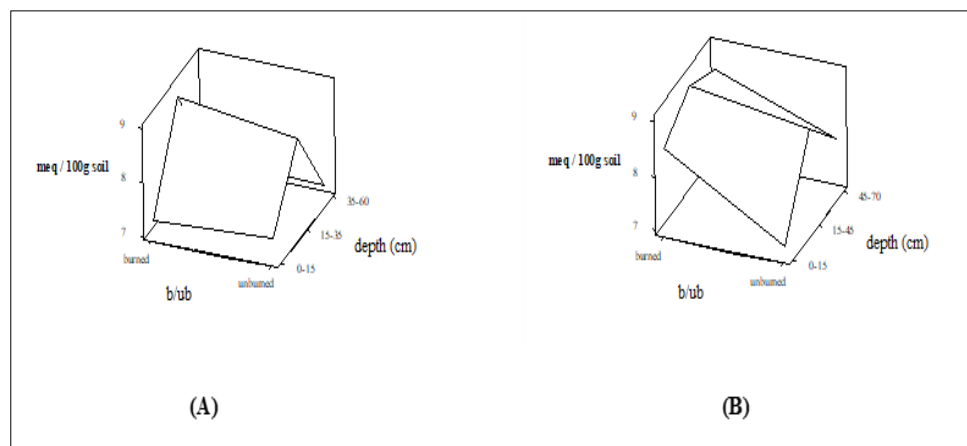
#### 4.3.2. Soil exchangeable magnesium

The magnesium cation has formed an important part of the exchange points and cation exchange capacity of soils of both study sites (Table 2). Results indicate that the proportion of the exchangeable magnesium overall reached a maximum of 30% of the total cation exchange capacity .

It may be seen that there is a similarity in the patterns of the results for exchangeable magnesium compared to these for exchangeable calcium. Quantities of the exchangeable magnesium were highest in the middle depth layers (Figures 9). The effect of burning was much more pronounced in the mountain site, especially in the topmost layer of the soil profile (Table 2). Therefore, as with exchangeable calcium, all three factors and all of their interaction terms were highly significant ( $p < 0.001$ ) (Table 2).

It should be noted that this parameter seems to be returning to its pre-burn levels in the coastal site which was burned 8 years ago (and which has begun regenerating the vegetation); therefore, the effects of heat on this parameter (and on calcium) are quite short-lived in the study area where limestone is the parent material.

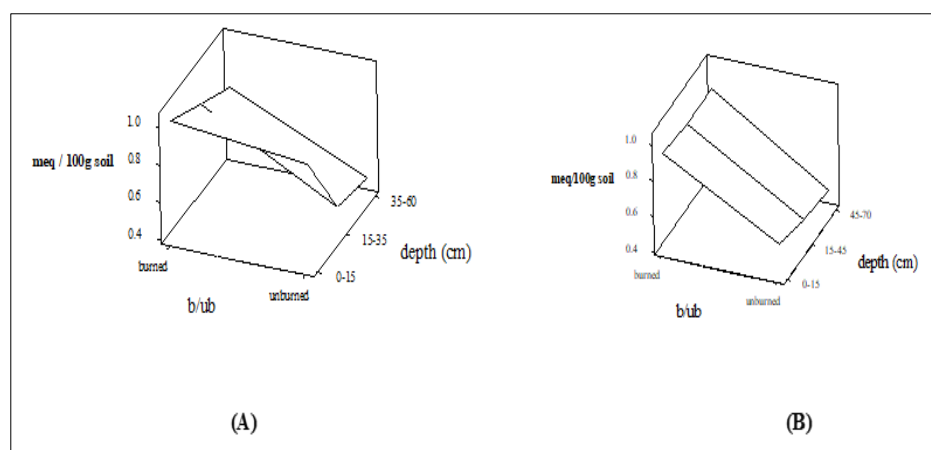




**Figure 9** Surface plot showing the variation in exchangeable magnesium content ( $\text{meq. } 100\text{g}^{-1}$  soil) at three depths in burned (b) and unburned (ub) soils from the coastal site (A) and mountain site (B)

#### 4.3.3. Soil exchangeable sodium

Despite the varying amount of the exchangeable sodium in soils of the different areas, it comprised a relatively small proportion of the exchangeable ions in the soil, with the mean exchangeable values not exceeding  $1.02 \text{ meq. } 100\text{g soil}^{-1}$  (found in the burned coastal site in the uppermost layer) (Table 2). Figure 10 shows there to be generally more exchangeable sodium in the burned areas. This is shown to be highly statistically significant ( $p < 0.001$ ) comparing the exchangeable sodium between the burned and unburned areas (Table 2). There is also a highly significant ( $p < 0.001$ ) effect of depth, with higher values in the uppermost layers (Figure 10), whether burned and unburned. There is also a significant difference ( $p < 0.001$ ) between the sites, with the coastal site tending to have relatively higher values (Table 2).



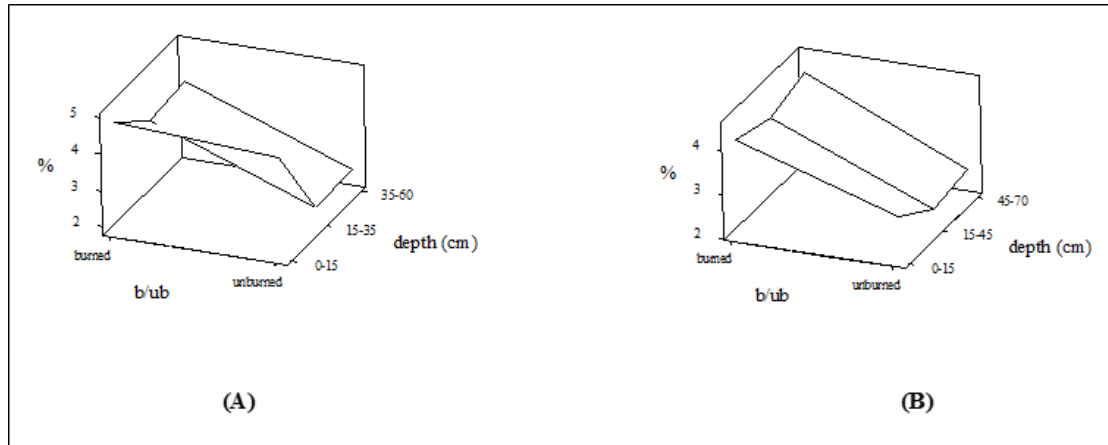
**Figure 10** Surface plot showing the variation in exchangeable sodium content ( $\text{meq. } 100\text{g}^{-1}$  soil) at three depths in burned (b) and unburned (ub) soils from the coastal site (A) and mountain (B)

It is obvious from the results that there is not always a clear trend in the content of the exchangeable sodium between the studied sites, with a relatively elevated content in the burned area at the coastal site than at other depths there. This may be due to the regeneration of the vegetation in the coastal site following the release of elements during the degradation of the plants residues (Figure 1).

The fact that the exchangeable sodium percentage (ESP) in soils of the study sites was less than 5% (Table 2) confirms that these soils would not be classified as sodic soils (U.S. Salinity Lab., 1954) and heat did not cause an increase in exchangeable sodium to the degree which causes its dominance on the adsorption complex. In addition, except in the mountain site burned area third depth, the results also show the exchangeable sodium percentage values decreased with depth (Table 2). This decrease of the exchangeable sodium percentage with depth, compared to an increase of the exchangeable calcium and magnesium especially in the middle depth layer in the four study areas (Table 2 ; Figure 11) may be due to the competition between exchangeable calcium and magnesium as a divalent cations, for exchangeable

sodium as mono-valent cation on exchanging points on surfaces of the soils particles, which may encourage the replacement of a part of the exchangeable sodium with exchangeable calcium or magnesium (Bohn et al, 1979) .

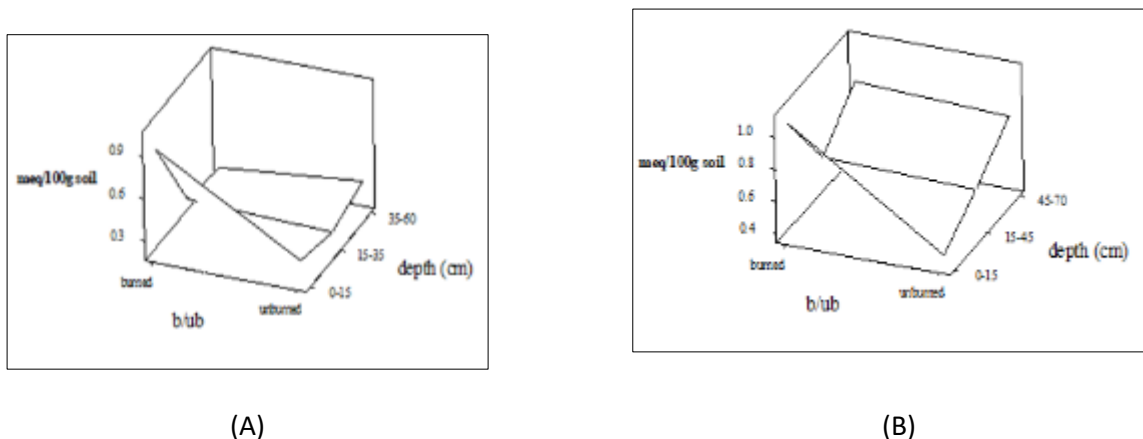
Due to the close relationship between the ESP values and sodium exchangeable concentration values in the soils of study sites, statistical analysis results of ESP values (Table 2) have agreed completely with those of the analysis of exchangeable sodium values (Table 2). Results indicate the differences between all three factors and their interactions terms were highly significant ( $p < 0.001$ ).



**Figure 11** Surface plot showing the variation in exchangeable sodium percentage (ESP) values at three depths in burned (b) and unburned (ub) soils from the coastal site (A) and mountain site (B)

#### 4.3.4. Soil exchangeable potassium

Exchangeable potassium represents a very limited ratio of the total exchangeable cations (Table 2). This is probably due to its absence in the parent material of the soils and almost all that there is being absorbed by plants. Like the other exchangeable cations, the results indicate that the highest quantities of the exchangeable potassium were in the uppermost layers in both study sites, were particularly high in the mountain site compared with the coastal site, and were markedly affected by heat in the top layer of the soil (Figure 12). Thus it was not surprising that the results of the ANOVA statistical analysis results (Table 5.18) show highly significant differences ( $p < 0.001$ ) between the two studied sites, and between the different depths ( $p < 0.001$ ) with the decrease of its concentration with depth probably being due to the continuous depletion by plant roots because it is one of the main nutrients. Furthermore, the ANOVA results also show highly significant differences ( $p < 0.001$ ) in the average exchangeable potassium concentration between burned and unburned areas, where heat appears to be cause an increase in this exchangeable cation .



**Figure 12** Surface plot showing the variation in exchangeable potassium content (meq. 100g-1 soil) at three depths in burned (b) and unburned (ub) soils from the coastal site (A) and mountain site (B)

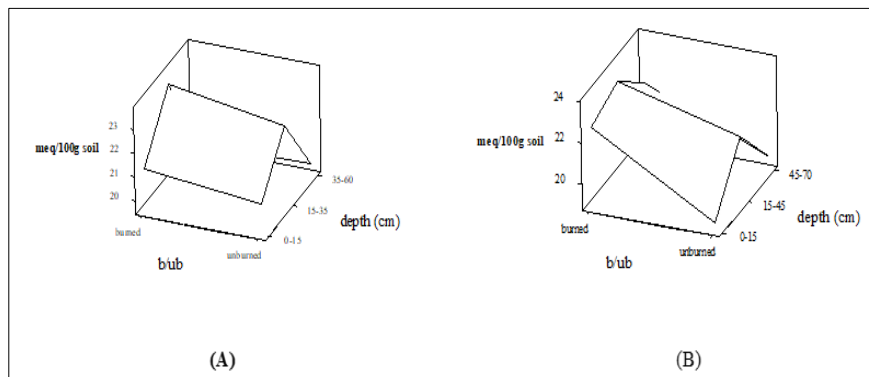
Besides the individual factor effect of heat on the exchangeable potassium content, however, all the interaction effects are also highly significant ( $p < 0.001$ ; Table 2). The soil exchangeable potassium is most increased in the burned mountain site in the top soil layer, which is a positive effect. It is known that potassium is a macro-nutrient element of

plants and its most important function is to increase the synthesis and transmission of carbohydrates, which promotes increased thickness of cell walls and the strength of plants stems (Foth, 1984), so its increased availability after burning will encourage plant regrowth.

#### 4.4. Soil cations exchange capacity (CEC)

The results in Table 2 indicate that the CEC of the study sites ranged from a mean of 19.08 in the unburned mountain site at a depth of 45-70 cm, to 23.55 meq. 100g soil<sup>-1</sup> in the burned coastal site at 15-35 cm depth. When the soil CEC results were analyzed by three-factor ANOVA (Table 2), the differences between burned and unburned areas in the two study sites were highly significant ( $p < 0.001$ ), with higher values in the burned areas which may relate to an increase of the exchangeable cations due to fire due to release of these cations from the litter and their being deposited on the mineral soil. Since the exchangeable calcium and magnesium account for about 80% of the CEC results (Table 2), the patterns of behaviour of the soil CEC are similar to the patterns of behaviour of these two elements. Results show the CEC values were greatest at the intermediate depths in the study sites (Figure 13). The ANOVA results indicate that there were highly significant differences ( $p < 0.001$ ) between the different depths. There is also a weaker but still significant ( $p < 0.05$ ) effect of site but more importantly there is a highly significant interaction ( $p < 0.001$ ) between all combinations of factors since, as can be seen in figures 13, the effects of heat and depth are different in the two sites. This is not surprising, as the behaviour of CEC is related to the behaviour of the exchangeable cations in the studied soils, especially exchangeable calcium and magnesium; however, the separate effect of site on the CEC is not as clear as it is with these two elements individually .

It can be concluded that, although there is a significant effect of fire on the CEC due to its impact in the consumption of the surface organic matter, this effect is reversible after a few years, as is demonstrated by the return of values to nearly unburned levels in the 8 year old coastal site.



**Figure 13** Surface plot showing the variation in CEC content (meq. 100g<sup>-1</sup> soil) at three depths in burned (b) and unburned (ub) soils from the coastal site (A) and mountain site (B)

## 5. Conclusion

The heat was not enough to change the studied soil fractions and therefore the type of texture, and the clay content was always the smallest fraction, especially in mountain sites, but increased with depth. Heat appeared to decrease soil organic matter of these soils as a result of the pyrolysis of organic materials. Exchangeable Ca<sup>++</sup> and Mg<sup>++</sup> formed a significant proportion of the total exchangeable cations, they account more than 80% of CEC in soils of four studied areas. The results showed that the heat may have contributed to the increase of exchangeable Ca<sup>++</sup> and Mg<sup>++</sup> by about 9% and 14%, respectively. Data obtained in this study confirmed that the heat did not lead to a change in the quantity of exchangeable Na<sup>+</sup> however, the results of this study have showed that although, exchangeable K<sup>+</sup> formed a very limited quantity of total exchangeable cations, heat caused an increase in the exchangeable quantity of this cation by about 57% in the mountain unburned area.

## Compliance with ethical standards

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*Disclosure of conflict of interest*

The authors have no conflicts of interest to disclose.

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