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# Effects of Traditional Practice of Soil Burning (*Guie*) on Soil Chemical Properties at Sheno Areas of North Shoa, Oromia Region, Ethiopia

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**Abstract:** The study was conducted at the Kimbibit District, which is located in the North Shoa Zone of Oromia National Regional State, with the objective of investigating the effects of traditional practice of soil burning (guie) on soil chemical properties of soils of the study area. Disturbed soil samples were collected from farmers' burned fields and normal fields in three peasant associations. The burned soils samples were collected from the bottom, middle and top of the heap. Soil parameters were analyzed using standard procedures and the results were subjected to analysis of variance (ANOVA). Mean separation was done using the least significant difference (LSD). Except percentage base saturation and available Cu, all the other parameters considered in this study were significantly affected by soil burning. The burning reduced organic carbon (73.7, 85.3 and 75.1%), total N (52.6, 68.4 and 26.3%), CEC (30.8, 44.8 and 37.2%), exchangeable Na (0.9, 14.2 and 13.3%), exchangeable Ca (27.9, 49.6 and 35.3%), exchangeable Mg (16.7, 26.7 and 20.0%) and available Fe (13.4, 26.2 and 35.3%) on the bottom, middle and top of the heap, respectively. Burning increased soil pH (5.6, 15.2 and 8.1%), available phosphorous (955.6, 1219.4 and 986.1%), exchangeable K (165.7, 328.6 and 165.7%), available Zinc (239.4, 284.8 and 219.6%) and Mn (6.5, 13.3 and 9.0%) on the bottom, middle and top of the heap, respectively. The soil attributes due to soil burning showed an overall change towards the direction of the loss of its chemical fertility compared to unburned soils.

**Keywords:** Guie, Heap, Kimbibit District, Soil Burning

## 1. Introduction

Soil fertility maintenance is a major concern in tropical Africa, particularly with the rapid population increase, which has occurred in the past few decades. In traditional farming systems, farmers use bush fallow, plant residues, household refuse, animal manures and other organic nutrient sources to maintain soil fertility and soil organic matter (OM). Although this reliance on biological nutrient sources for soil fertility regeneration is adequate with low cropping intensity, it becomes unsustainable with more intensive cropping unless fertilizers are applied [1]. Without maintaining soil fertility, one cannot talk about increment of agricultural production in feeding the alarmingly increasing population. Therefore, to get optimum, sustained-long lasting and self-sufficient crop production, soil fertility has to be maintained.

The vast majority of soils around Kimbibit District are burned annually for cropping of virgin and fallowed land. This specialized form of shifting cultivation is practiced in almost all peasant associations in the District. Traditionally, farmers in the area sow crops to mature on residual moisture, fallow the land in the main rainy season, and burn, or "*Guie*" the soil [2]. Land that is plowed early for late planting of crops is exposed to soil erosion due to high and intense rainfall, hence diminishing soil fertility. Therefore, to maintain soil fertility and productivity, the use of other alternative option of soil fertility replenishment is indispensable [3].

This indigenous technical knowledge (ITK) is used mainly for production of barley (local variety), which is a major food crop. The traditional method of growing barley involves opening virgin and fallowed land by digging slabs of soil. The slabs are spread in order to dry the grass. After drying, they are stacked upside down in conical shapes in various spots of the field and burned. The burning is not rapid and is similar to the method used for charcoal production. The burned brown soil is then spread on the dug area, mixed to make a fine seedbed and barley is planted (broadcast). According to farmers, high yields and quality of barley are obtained by using this indigenous technical knowledge. After one season of barley growth, the land is abandoned for at least more than 4 years [2]. The practice of soil burning before planting crops is not unique to Ethiopia. The same practice is done in Kenya and locally known as "Belset ab Tindinyek".

Soil burning can have a marked effect on the OM stock because almost all OM is consumed during burning which affects long term crop productivity and soil fertility. Since burning removes OM and their colloids fractions, and since such materials furnish most of the microbiological activities and the base exchange capacity of the soils thereby providing ample storage for plant food, the removal of such essential particles and their colloids decrease the fertility of the soils [4]. Carbon and nitrogen are the main constituents of SOM with stocks varying, depending on land use and management practices [5].

This exacerbates soil quality decline due to soil burning leading to soil degradation which may ultimately lead to complete loss of land values. The consumed soil OM during soil burning affects chemical quality of soil. These variations of soil chemical properties due to soil burning indicate the risk to the sustainable crop production in the area. However, in the study areas the effects of soil burning (*Guie*) on soil chemical properties are not well studied. Therefore, this study was initiated to investigate the effects of traditional practice of soil burning on selected soil chemical properties.

# 2. Materials and Methods

### *2.1. Location and Description of the Study Area*

Geographically, Sheno is located in the Oromia Regional State, Central highlands of Ethiopia at distance of 78 km north of the national capital, Addis Ababa. Geographically, the District extends from $9^0$12'-$9^0$32' N latitude and $39^0$04'-$33^0$0' E longitudes at an altitude ranging from 1950 to 2918 meters above sea level (masl).

The agro ecology is highlands *(Baddaa)* with flat topography. Soils of the district are moderately fertile black, red and brown clay soils.

Sheno areas are characterized by bimodal rainfall pattern with erratic distribution. There are four main seasons: the long rainy season *Genna* (June to August), the short rains *Arfassa* (March to May), harvesting period *Birra* (September to November) and dry season *Bona* (December to February). The mean (1996-2007) annual rainfall is 1366.7 mm. The annual mean minimum and mean maximum temperatures at the study area for the periods from 1996 to 2007 (Appendix Table 3) are 12.9 and 19.9°C, respectively (Kimbibit District of Agricultural Office, 2008).

### *2.2. Vegetation and Land Use*

Except very few and scattered bushes, grasses and small trees, the natural vegetation has been cleared for expansion of agricultural land. Only patches of artificially planted Eucalyptus tree species are found on the peripheral sides of the farm lands. Much of the land is used for crop production and a few parts as pasture (grazing) lands. The main category of livelihood is mixed farming focusing on crop and livestock production. Crop production is entirely rain fed. The livelihood zone is best known for barley, wild oats, wheat, horse beans, linseed and lentils. Barley, wild oats, wheat and horse beans are the main crops grown for home consumption. The main crops sold are wheat, linseed, lentils and horse beans. Cattle, sheep and equines are the main types of livestock (Kimbibit District of Agricultural Office, 2008).

### *2.3. Site Selection and Soil Sampling*

The assessment of the effects of traditional soil burning, *Guie*, on soil chemical properties was conducted under laboratory conditions. From the whole of Sheno District, three representative peasant associations (PAs) farm lands known for practicing *Guie* for barley and other crops production and that are relatively similar in their agroecology and soil type were selected through reconnaissance survey and discussion with development agents and the Office of Agriculture of the District.

From the selected PAs, one representative farm was selected and disturbed soil samples were collected from burned heaps and unburned fields that are adjacent to each other. The disturbed samples were collected using auger from the plow layer (0-20 cm). For burned soil disturbed soil samples were collected by manually forcing auger into the soil. Soil samples were collected from the bottom, middle and top of the heaps.

The height of most of the heaps was 60 cm during soil sampling. Accordingly, soil samples were collected from 0-20 cm (the bottom of the heap), 20-40 cm (middle of the heap) and 40-60 cm (top of the heap). The major criteria used for selection of the height for the bottom, middle and top of the heap were colors transition from the bottom to middle, middle to top and the expected difference in the soil properties. In case of the height variation for the heaps, colors transition were used as major sampling criteria from the bottom, middle and top of the heap.

The sub-samples collected from different points of each field at different points of the field and heaps were composited to make one composite sample per field. One composite soil sample was then prepared from the fifteen sub samples for each treatments (Control, the bottom, middle and top of the heap). In this way, a total of 12 composite samples were collected from the three PAs (replications) and analyzed for their chemical properties to see the effects of soil burning under farmers' practice. The composite soil samples were labeled and transported to the laboratory in plastic bags for further processing and analysis at Haramaya University laboratory.

### *2.4. Soil Sample Preparation and Laboratory Analysis*

#### *2.4.1. Soil Sample Preparation*

The disturbed samples collected from the field were air-dried and crushed to pass through a 2 mm sieve for analysis of all properties of interest except total N and OC. For these two parameters, the samples were ground further to pass through a 0.5 mm sieve. The disturbed samples prepared in this way were used for laboratory analysis of soil pH, OC, total N, available P, exchangeable bases (Na, K,Mg and Ca), CEC and available micronutrients (Fe, Mn, Zn and Cu).

#### *2.4.2. Laboratory Analysis of Soil Chemical Properties*

Soil pH was determined in a 1:2.5 soil to water ratio using pH meter [6]. OC of the soils was determined following the wet digestion method as described by [7]. Total N of the soil was determined through digestion, distillation and titration procedure of the Kjeldahl method as described by [8]. Available P was determined using the Olsen extraction method [9]. The exchangeable bases (Na, K, Mg and Ca) in the soil were determined from the leachate of a 1 M ammonium acetate ($NH_4OAc$) solution (pH 7) used as an extractant. Exchangeable K and Na were read using flame photometer [10], whereas Ca and Mg were measured by atomic absorption spectrometry.

Cation exchange capacity (CEC) was measured after leaching the ammonium acetate extracted soil samples with 10% sodium chloride solution. The amount of ammonium ion in the percolate was determined by the Kjeldahl procedure and reported as CEC [11]. The percent base saturation (PBS) of the soil samples was calculated from sum of the basic exchangeable cations (Na, K, Mg and Ca) as the percentage of the CEC. Available Fe, Mn, Zn and Cu were extracted from the soil samples with diethylene triamine pentaacetic acid (DTPA) as described by [12]. The micronutrients extracted were measured by atomic absorption spectrometry.

### *2.5. Methods of Data Analysis*

Soil data generated through laboratory analysis were subjected to analysis of variance (ANOVA) using the general linear model procedure of the statistical analysis system [13]. Mean separation was carried out using least significant difference (LSD). Pearson's simple correlation coefficient was executed to reveal the directions of relationship between different soil properties.

## 3. Results and Discussion

*Effects of Soil Burning on Soil Chemical Properties*

### *3.1. Soil Reaction (pH)*

The highest (6.13) and lowest (5.32) pH were recorded on the middle of the burned heap and unburned soil (Table 1), respectively. Soil burning increased the pH by 5.6, 15.2 and 8.1% on the bottom, middle and top of the heap, respectively, as compared to the control. The highest value of pH obtained on the middle of the burned heap could be due to greater accumulation of ashes at middle during combustion of OM.

The other reason for the increase in the pH after soil burning is the increase in percentage base saturation (PBS). The increase in the PBS is due to the significant increase in exchangeable K with the corresponding decrease in the CEC. The results of correlation analysis between PBS and pH (Table 2) revealed a positive and significant (r = 0.81**) relationship.

The ratings of soil pH suggested by [14] for Ethiopian soils are < 5 as very strongly acidic, 5.1 to 5.5 as strongly acidic, 5.6 to 6.0 as moderately acidic, 6.1 to 6.5 as slightly acidic, 6.6 to 7.3 as neutral, 7.4 to 7.8 as slightly alkaline, 7.9 to 8.4 as moderately alkaline, 8.5 to 9.0 as strongly alkaline and > 9 as very strongly alkaline pH status. Based on these ratings, the pH values of the burned soil on the bottom and middle of the heap qualified for moderately acidic soil while the top of the heap qualified for slightly acidic soil reaction. The unburned soils of the study area on the contrary qualified for strongly acidic soil condition (Table 1).

Aluminum toxicity is expected in the study area. [15] reported that excess concentration of $Al^{3+}$ is observed at pH below 5.5. The results of this study indicated that the pH of the soils in the study area is below 5.5 indicating that the basic cations had been leached from the exchange site being replaced by $Al^{3+}$ ions present in the soil solution in high concentration. The unburned soils of the study area are very strongly leached as indicated by the very low (11.13%) percent base saturation (Table 1). Therefore, the concentration of exchangeable $Al^{3+}$ is expected to be high and Al toxicity is expected in the soils of the study area.

### *3.2. Soil Organic Carbon*

The highest (2.93%) and lowest (0.43%) values of OC were recorded on the unburned soil and the middle of the burned heap, respectively (Table 1). Soil burning decreased soil OC by 73.7, 85.3 and 75.1%, on the bottom, middle and top of the burned heap, respectively, as compared to the control. The decrease in the soil OC after soil burning is due to high rate of oxidation of OM at the highest temperature. The lowest OC content of the soil at the middle of the burned heap is due to the highest temperature and highest oxidation of OM expected at the middle of the heap leading to a high loss of OC from the soil. [16] have also reported a significant reduction in the OC content of soils exposed to severe fire. In addition, significant C losses are reported in soils heated under laboratory conditions [17].

The ratings of soil OC suggested by [18] for Ethiopian soils are OC < 0.5% as very low, 0.5 to 1.5% as low, 1.5 to 3% as medium and > 3% as high, respectively. Based on these ratings, the OC values of the soil on the bottom and top of the burned heap qualified for low OC while the soil on the middle of the burned heap qualified for very low OC. On the contrary, the unburned soils of the study area qualified for medium OC soil condition (Table 1). In general, as OM is the main supplier of soil N, S and P, a decline in the soil OM content of the soils due to soil burning is likely to affect the soil productivity.

### *3.3. Total Nitrogen*

The highest (0.38%) and lowest (0.12%) total N contents were recorded on the unburned soil and on the middle of the burned heap, respectively (Table 1). The burned soil on the bottom, middle and top of the heap have lost 52.6, 68.4 and

26.3%, of their total N contents respectively, compared to the control.

The decrease in the total N is due to volatilization of N in different forms during OM combustion. These results were confirmed by the findings of [19] who observed up to 80% loss of N due to soil burning.

Organic matter is the main source for total N which is lost during soil burning. Depending on fire severity, OM is oxidized during soil burning which leads to the decrease in soil OM content. In this study, OC was positively and significantly (r = 0.77**) correlated with total N (Table 2).

As per ratings of total N suggested by [20]; total N > 0.25% is high, 0.12 to 0.25% is medium, 0.05 to 0.12% is low and < 0.05% is very low N. Based on these ratings, the total N contents (Table 1) of the burned soil on the bottom and top of the heap qualified for medium total soil N while burned soils on the middle of the heap qualified for low total soil N. The unburned soils of the study area qualified for medium total soil N condition.

### *3.4. Available Phosphorus*

The highest (47.50 mg $kg^{-1}$) and lowest (3.60 mg $kg^{-1}$) values of available P were recorded on the middle of the heap and unburned soil, respectively (Table 1). The results of this study showed that burning of the soil increased available P by 955.6, 1219.4 and 986.1% on the bottom, middle and top of the burned heap, respectively, as compared to the control treatment. This is apparent because burning converts soil OM in to ash increasing all the metallic nutrients contained in to the soil in plant available forms and enhancing mineralization of organic forms of nutrients including P. As indicated in Table 2, correlation analysis revealed a negative, but significant (r = - 0.95**) relationship between OC and available P.

Moreover, the increase in soil pH after soil burning has contributed to the increase in the available P. The increase in the soil pH after soil burning would have lowered Al and Fe concentrations in the soil which interfere with P availability if present in higher amounts. In harmony with this, the analysis of Pearson's correlation coefficient (Table 2) also revealed a positive and significant (r = 0.81**) relationship between available P and pH and a negative, but significant (r = - 0.76**) relationship between available P and Fe.

According to [20] available soil P of < 5 mg $kg^{-1}$ is rated as low, 5-15 mg $kg^{-1}$ as medium and > 15 mg $kg^{-1}$ as high, respectively. Based on these ratings, the values of the available P (Table 1) of the burned soils at the bottom, middle and top of the heap qualified for high available soil P while the unburned soils qualified for low available soil P condition. The low contents of available P observed in the soils of the study area were in agreement with the results of [21] who concluded that the majority of Ethiopian soils are low in available P due to continuous mining by crop harvest under low or no input farming practices and high P fixation capacities of the soils especially those of the humid highlands of the country.

***Table 1.*** *Mean values of soil chemical properties and (relative changes, %) due to soil burning.*

| Soil properties | Control | Bottom | Middle | Top |
|---|---|---|---|---|
| pH ($H_2O$) | 5.32b | 5.62b (5.6) | 6.13a (15.2) | 5.75ab (8.1) |
| OC (%) | 2.93a | 0.77b (-73.7) | 0.43b (-85.3) | 0.73b (-75.1) |
| Total N (%) | 0.38a | 0.18bc (-52.6) | 0.12c (-68.4) | 0.28ab (-26.3) |
| AvP (mg $kg^{-1}$) | 3.60b | 38.00a (955.6) | 47.50a (1219.4) | 39.10a (986.1) |
| Na ($cmol_{(+)}$ $kg^{-1}$) | 1.13a | 1.12a (-0.9) | 0.97b (-14.2) | 0.98b (-13.3) |
| K ($cmol_{(+)}$ $kg^{-1}$) | 0.35c | 0.93b (165.7) | 1.50a (328.6) | 0.93b (165.7) |
| Mg ($cmol_{(+)}$ $kg^{-1}$) | 0.30a | 0.25b (-16.7) | 0.22b (-26.7) | 0.24b (-20.0) |
| Ca ($cmol_{(+)}$ $kg^{-1}$) | 2.58a | 1.86b (-27.9) | 1.30b (-49.6) | 1.67b (-35.3) |
| CEC ($cmol_{(+)}$ $kg^{-1}$) | 39.30a | 27.20b (-30.8) | 21.70b (-44.8) | 24.70b (-37.2) |
| PBS (%) | 11.13 | 16.37 (47.1) | 18.90 (69.8) | 15.87 (42.6) |
| Fe (mg $kg^{-1}$) | 53.90a | 46.67b (-13.4) | 39.77c (-26.2) | 34.90c (-35.3) |
| Mn (mg $kg^{-1}$) | 78.57c | 83.67b (6.5) | 89.00a (13.3) | 85.67ab (9.0) |
| Zn (mg $kg^{-1}$) | 7.77b | 26.37a (239.4) | 29.90a (284.8) | 24.83a (219.6) |
| Cu (mg $kg^{-1}$) | 11.30 | 10.87 (-3.8) | 10.90 (-3.5) | 10.70 (-5.3) |

*Means followed by the same letter in the same row are not significantly different from each other at $P \leq 0.05$; Figures in parenthesis are relative change (%) due to soil burning; OC = Organic carbon; AvP = Available phosphorous; CEC = Cation exchange capacity; PBS = Percentage base saturation

### *3.5. Exchangeable Sodium and Potassium*

The average values of exchangeable Na was highest (1.13 $cmol_{(+)}$ $kg^{-1}$) on the unburned soil and lowest (0.97 $cmol_{(+)}$ $kg^{-1}$) at the middle of the burned heap (Table 1). The mean exchangeable Na contents decreased considerably from 1.13 $cmol_{(+)}$ $kg^{-1}$ in normal or unburned soil to 1.12, 0.97 and 0.98 $cmol_{(+)}$ $kg^{-1}$ on the bottom, middle and top of the burned soil, respectively, which reveals a reduction by about 0.9, 14.2 and 13.3% on the bottom, middle and top of the burned heap, respectively, as compared to its amount in the control treatment. The results of this study were supported by the findings of [22,23] who concluded that the decrease exchangeable Na in the burned soils could be due to the aggregation of soil into the sand-size particles leading to less extractability from water.

The highest (1.50 $cmol_{(+)}$ $kg^{-1}$) and lowest (0.35 $cmol_{(+)}$ $kg^{-1}$) mean values of exchangeable K were recorded on the middle of the heap and the unburned soil, respectively (Table 1). The results of this study showed that there is an increment of exchangeable K by 165.7, 328.6 and 165.7%, respectively on the bottom, middle and top of the heap, respectively, due soil burning.

The highest content of exchangeable K observed on the middle of the heap was related with the highest pH values of the middle of the burned heap and was in agreement with study results reported by [24] that high K was recorded under high pH tropical soils.

***Table 2.*** *Pearson's correlation coefficient (r) among selected soil chemical properties.*

| Soil properties | pH | OC | TN | AvP | CEC | PBS | Fe | Mn |
|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | |
| OC OC | -0.70* | 1 | | | | | | |
| TN | -0.80** | 0.77** | 1 | | | | | |
| AvP | 0.81** | -0.95** | -0.85** | 1 | | | | |
| CEC | -0.81** | 0.77** | -0.82** | 0.87** | 1 | | | |
| PBS | 0.81** | -0.67* | -0.87* | 0.78** | -0.96** | 1 | | |
| Fe | -0.63* | 0.77** | 0.38ns | -0.76** | 0.69* | -0.52ns | 1 | |
| Mn | 0.66* | -0.84** | -0.58* | 0.75** | -0.58* | 0.51ns | -0.78** | 1 |

* and ** = Significant at $P \leq 0.01$ and $< 0.05$, respectively; ns = Not significant; OC = Organic carbon; TN = Total nitrogen; AvP = Available phosphorus; CEC = Cation exchange capacity; PBS = Percentage base saturation

### 3.6. Exchangeable Magnesium and Calcium

The average values of exchangeable Mg of the unburned soil, the burned soil at the bottom, middle and top of the burned heap were 0.30, 0.25, 0.22 and 0.24 $cmol_{(+)}\ kg^{-1}$, respectively, which reveals a reduction of exchangeable Mg by 16.7, 26.7 and 20.0% on the bottom, middle and top of the heap, respectively, as compared to the control or unburned soil (Table 1). The mean values of soil exchangeable Ca decreased considerably from 2.58 $cmol_{(+)}\ kg^{-1}$ on the unburned soil to the values of 1.86, 1.30 and 1.67 $cmol_{(+)}\ kg^{-1}$ on the bottom, middle and top of the burned heap, respectively, which reveals a reduction by about 27.9, 49.6 and 35.3% compared to its amount in the control treatment.

Exchangeable Ca contents of the soil steadily decreased by soil burning which is in agreement with the findings of [22] who concluded that extractability of Ca was diminished due to aggregation of the thin particles during soil burning. Exchangeable Mg contents also showed the similar change with exchangeable Ca with soil burning. Similarly, the results obtained by [16] reported that the decrease in exchangeable Mg contents after soil burning is because the soil samples did not form soluble MgO and those small ions such as Mg were forced into octahedral structure of clay minerals during dehydration.

Following the ratings of exchangeable Mg and Ca of < 0.3 and 2 ($cmol_{(+)}\ kg^{-1}$) as very low, 0.3 to 1 and 2 to 5 ($cmol_{(+)}\ kg^{-1}$) as low, 1 to 3 and 5 to 10 ($cmol_{(+)}\ kg^{-1}$) as medium, 3 to 8 and 10 to 20 ($cmol_{(+)}\ kg^{-1}$) as high and > 8 and 20 ($cmol_{(+)}\ kg^{-1}$) as very high exchangeable Mg and Ca, respectively, as indicated by [25], the burned soil on the bottom, middle and top of the burned heap qualified for very low exchangeable Mg and Ca soil, whereas the unburned soils qualified for low contents of the exchangeable Mg and Ca soil condition (Table 1).

### 3.7. Cation Exchange Capacity

The highest (39.30 $cmol_{(+)}\ kg^{-1}$) and lowest (21.70 $cmol_{(+)}\ kg^{-1}$) mean values of CEC were observed on the unburned soil and the middle of the burned heap, respectively. Soil burning has resulted in loss of 30.8, 44.8 and 37.2% CEC on the bottom, middle and top of the heap, respectively, as compared to the control treatment (Table 1).

The decrease in both clay and organic matter content as a result of soil burning could have led to the decrease in the soil cation exchange capacity. Similar results were reported by [26] that the CEC of a soil is strongly affected by the amount and type of clay, and amount of OM present in the soil. Moreover, an important role soil organic matter plays in soil (CEC) and retention of ions was also reported by [27]. In harmony with this, the analysis of Pearson's correlation coefficient (Table 2) also revealed a positive and significant (r = 0.77** and r = 0.76**) relationship of CEC with OC and clay, respectively.

Following CEC values of the soil suggested by [20]; CEC of < 5 $cmol_{(+)}\ kg^{-1}$ is very low, 5 to 15 $cmol_{(+)}\ kg^{-1}$ is low, 15 to 25 $cmol_{(+)}\ kg^{-1}$ is medium, 25 to 40 $cmol_{(+)}\ kg^{-1}$ is high and > 40 $cmol_{(+)}\ kg^{-1}$ is very high CEC. The CEC values of the burned soils on the bottom of the heap qualified for high CEC, whereas the middle and top of the heap qualified for medium soil CEC condition. Moreover, the unburned soils of the study area qualified for high soil CEC condition (Table 1).

However, numerically the highest mean (18.90%) values of PBS were recorded on the middle of the burned heap and lowest mean (11.13%) values on the control or unburned treatment. The reason for the highest PBS at the middle of the burned heap could be due to the highest (328.6%) increment in exchangeable K with the corresponding reduction in amounts (44.8%) of CEC (Table 1). Similarly, the results of correlation analysis revealed that PBS was negatively but significantly (r = - 0.96**) correlated with CEC (Table 2).

As per the ratings of PBS as a criterion of leaching suggested by [28] which are 70 to 100 is very weakly leached, 50 to 70 is weakly leached, 30 to 50 is moderately leached, 15 to 30 is strongly leached and 0 to 15 is very strongly leached. Accordingly, the PBS values of the unburned soils qualified for very strongly leached soil condition. On the other hand, the PBS values of burned soils on the bottom, middle and top of the qualified for strongly leached soil condition (Table 1).

***Table 3.*** *Results of analysis of variance for soil chemical properties.*

| Soil properties | MS (3) | | Error MS (8) | LSD (0.05) |
|---|---|---|---|---|
| pH ($H_20$) | 0.34* | 0.07 | 0.49 | 4.5 |
| OC (%) | 4.00** | 0.04 | 0.37 | 16.1 |
| Total N (%) | 0.04** | 0.003 | 0.11 | 24.7 |
| AvP (mg $kg^{-1}$) | 1127.63** | 39.75 | 11.89 | 19.7 |
| Na ($cmol_{(+)}$ $kg^{-1}$) | 0.02* | 0.01 | 0.14 | 7.0 |
| K ($cmol_{(+)}$ $kg^{-1}$) | 0.66** | 0.04 | 0.36 | 20.8 |
| Mg ($cmol_{(+)}$ $Kg^{-1}$) | 0.004** | 0.0003 | 0.03 | 6.8 |
| Ca ($cmol_{(+)}$ $kg^{-1}$) | 0.86** | 0.10 | 0.60 | 16.9 |
| CEC ($cmol_{(+)}$ $kg^{-1}$) | 178.17* | 36.93 | 11.44 | 21.5 |
| PBS (%) | $31.50^{ns}$ | 10.56 | ns | 20.8 |
| Fe (mg $kg^{-1}$) | 206.38** | 9.74 | 5.88 | 7.1 |
| Mn (mg $kg^{-1}$) | 57.21** | 4.36 | 3.93 | 2.5 |
| Zn (mg $kg^{-1}$) | 292.42** | 11.38 | 6.35 | 15.2 |
| Cu (mg $kg^{-1}$) | $0.19^{ns}$ | 5.09 | ns | 20.0 |

*, ** = Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively; (8 and 3) = Treatment and error degree of freedom, respectively; CV = Coefficient of variation; LSD = Least significant difference; ns = Not significant; MS = Mean square; OC = Organic carbon; AvP = Available phosphorous; CEC = Cation exchange capacity; PBS = Percentage base saturation

### *3.8. Soil Micronutrients*

The highest (53.90 mg $kg^{-1}$) and lowest (34.90 mg $kg^{-1}$) contents of available Fe were recorded on the unburned and top of the burned heap, respectively (Table 1). Generally, a burning has caused a reduction of 13.4, 26.2 and 35.3% of the available Fe on the bottom, middle and top of the burned heap, respectively, compared to the control or unburned soil. The highest and lowest available Mn (89.00 and 78.57 mg $kg^{-1}$) and Zn (29.90 and 7.77 mg $kg^{-1}$) were recorded on the middle of the burned heap and the unburned soil, respectively. Soil burning increased available Mn and Zn by 6.5, 13.3 and 9.0%; and by 239.4, 284.8 and 219.6 on the bottom, middle and top of the heap, respectively, compared to the control. The increase in available Mn and Zn is also due to highest nutrient release attributed to the highest oxidation of soil OM due to burning. These results were supported by the findings of [29] who concluded that after burning available Zn and Mn were increased, available Fe was decreased while burning had no effect on available Cu. The highest available Mn and Zn could also be due to the acidity of the soil as these micronutrients are more available and soluble under acidic condition.

Iron toxicity would be expected in the soils of the study area. The rating of soil available Fe suggested by [30] indicates that available Fe at > 20 to > 40 mg $kg^{-1}$ falls in the toxicity level. Based on this rating, the available Fe content of the unburned soil of the study area qualified for toxic soil condition. Similarly, based on the rating of available Mn suggested by [12] which categories > 48 mg $kg^{-1}$ in the toxicity level, the available Mn of the unburned soil of the qualified for toxic soil condition (Table 1). Thus, soil burning has caused an increment into the already toxic level of Mn in the soils of the study area.

## 4. Conclusions

The results of this study indicated significant changes in the quality attributes of the soils in the study area following soil burning. The soil attributes due to soil burning showed an overall change towards the direction of the loss of its fertility compared to unburned soils. This exacerbates soil quality decline due to soil burning leading to soil degradation which may ultimately lead to complete loss of land values.

Burning increases the availability of most plant nutrients. High concentrations of available plant nutrients immediately following fire may negate the advantage of fertilizing for at least 1 year after burning. However, it negatively affects soil chemical quality and the overall soil health.

These variations of soil chemical properties due to soil burning indicate the risk to the sustainable crop production in the study area. Therefore, strategies to feed the expanding population in the study areas will have to seek a sustainable solution that better addresses integrated soil management. In addition, improvement in the management of the soil resources for sustainable agricultural use would be one of the most useful strategies.

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