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Effects of traditional practice of soil burning (*guie*) on soil physical properties at Sheno areas of North Shoa, Oromia Region, Ethiopia

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The study was conducted in the Kimbibit District, which is located at the North Shoa Zone of Oromia National Regional State, with the objective of investigating the effects of traditional practice of soil burning (guie) on physical properties of soils of the study area. Both disturbed and undisturbed 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 silt content, total porosity, percentage base saturation, all the other parameters considered in this study were significantly affected by soil burning. The burning reduced clay content (71.9, 78.4 and 75.8%), total porosity (20.3, 21.7 and 0.1%), water retained at FC (26.0, 58.4 and 33.8%) and PWP (19.7, 55.5 and 25.0%) and available water holding capacity (42.9, 67.1 and 57.1%), of the bottom, middle and top of the heap, respectively. Burning increased sand content (31.0, 38.0 and 34.5%), bulk density (19.7, 30.3 and 9.2%), particle density (7.7, 16.3 and 9.5%), water repellency (84.0, 149.4 and 95.1), 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 physical fertility as compared to unburned soils. Therefore, strategies to feed the expanding population in the study areas will have to seek a sustainable solution that better address integrated soil management.

Key words: Guie, heap, Kimbibit district, soil burning.

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

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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 (Mulongey and Merck, 1993). 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 (Berhanu, 1985). 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. 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 (Berhanu, 1985) years. 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 (Assefa, 1978).

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 soil physical quality of soil. These variations of soil physical 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 physical properties are not well studied. Therefore, this study was initiated to investigate the effects of traditional practice of soil burning (*Guie*) on soil physical properties.

MATERIALS AND METHODS

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 (Figure 1). Geographically, the District extends from 90°12'-9°32' N latitude and 39°04'-33°0' E longitudes (Figure 1) at an altitude ranging from 1950 to 2918 m 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 are 12.9 and 19.9°C, respectively (Data from Kimbibit District of Agricultural Office).

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 (Personal Communication and Data from Kimbibit District of Agricultural Office).

Site selection and soil sampling

The assessment of the effects of traditional soil burning, *Guie*, on soil physical 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 (Golelcha, Garechatu, Tuka Abdola**)**, 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) while undisturbed soil samples were collected using core sampler from the same depth for unburned soil. For burned soil, both disturbed and undisturbed soil samples were collected by manually forcing auger and core sampled 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 (the bottom of the heap), 20-40 (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 the 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.

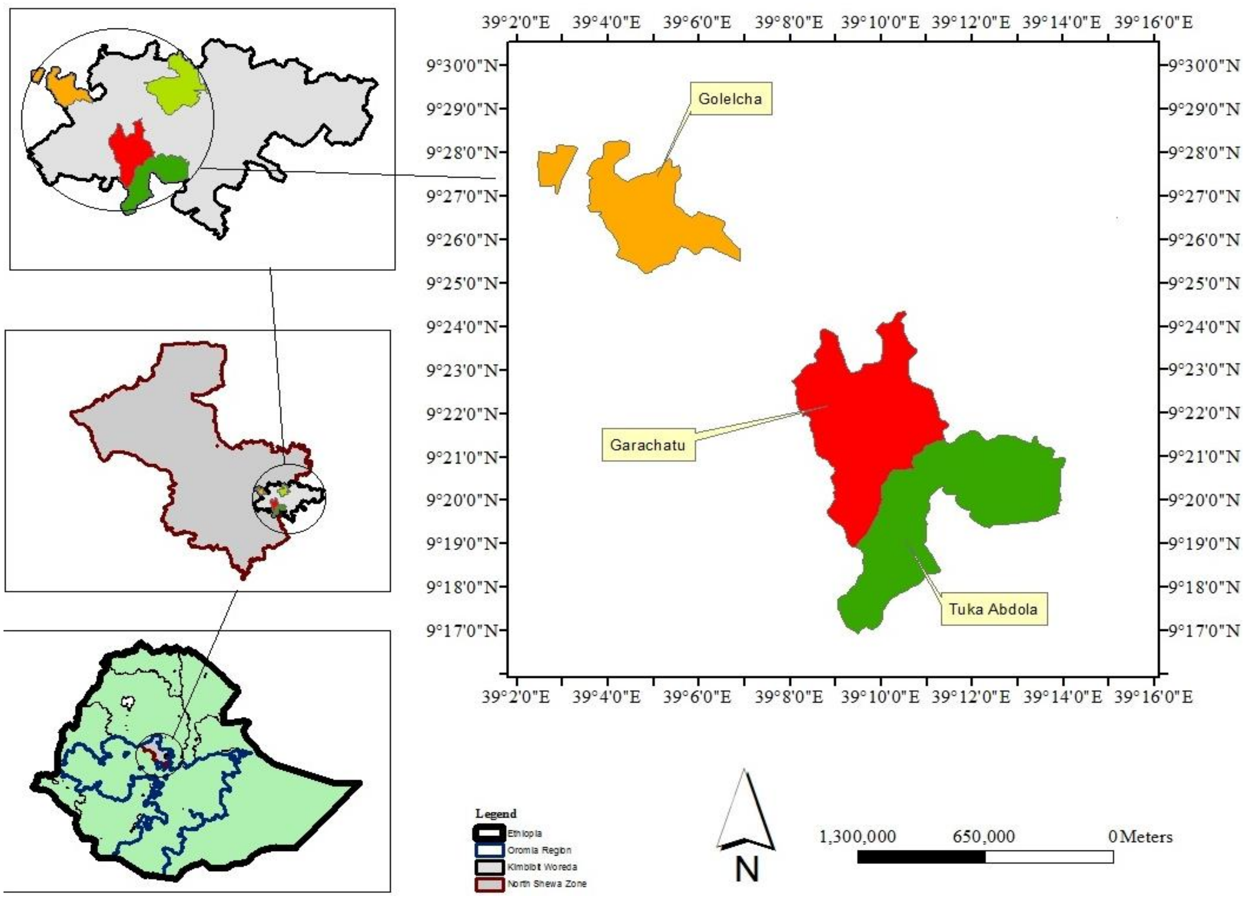

Figure 1. Map of study areas.

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 physical 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.

Soil sample preparation and laboratory analysis

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. The disturbed samples prepared in this way were used for laboratory analysis of particle size distribution (sand, silt and clay), particle density and water repellency. Undisturbed soil samples were used for the determination of soil bulk density and water retention capacity at field capacity and permanent wilting point.

Laboratory analysis of soil physical properties

Soil colors were determined with the help of the Munsell soil color chart. Soil particle size distribution was determined by the Boycouos hydrometer method (Bouyoucos, 1962) after destroying OM using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexameta phosphate. Soil bulk density (BD) was measured from undisturbed soil samples which were weighed at field moisture and after oven drying the pre-weighed soil core samples to constant weight (105°C) as per the procedure described by Black (1965). Particle density (PD) was determined by the pycnometer method (Devis and Freitans, 1984). Total porosity was estimated from the bulk and particle densities.

The soil-water holding capacity (WHC) values were measured at -1/3 bars for field capacity (FC) and -15 bars for permanent wilting point (PWP) using the pressure plate apparatus (Hillel, 1980). Soil water repellency can only be measured at the point scale, and this was done by measuring the water drop penetration time (WDPT). In this test, one or more drops of water were placed on the soil surface and the time required for the water to penetrate the soil was recorded (Letey, 1969).

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 (SAS, 2004). Mean separation was carried out using least significant difference (LSD). Pearson's simple correlation coefficient was executed to reveal the magnitudes and directions of relationship between different soil properties.

Table 1. Patterns of soil color (dry soil) as affected by soil burning and position in the heap.

Treatment	Golelcha	Garechatu	Tuka Abdola
Control	Weak red (7.5YR 4/2)	Weak red (7.5YR 4/2)	Dark red (10YR 3/6)
Bottom	Dark reddish gray (10YR 3/1)	Pale red (2.5YR 6/2)	Light red (7.5YR 4/3)
Middle	Light red (2.5YR 6/8)	Light red (10YR 6/6)	Light red (2.5YR 6/6)
Top	Black (5Y 2.5/5)	Black (5Y 2.5/5)	Black (5Y 2.5/5)

Table 2. Changes in texture of the soils studied.

Treatment	Golelcha	Garechatu	Tuka Abdola
Control	SL (56, 28 and 16)	SL (60, 26 and 14)	SL (58, 26 and 16)
Bottom of heap	LS (77, 19 and 4)	SL (71, 24 and 5)	LS (80, 16 and 4)
Middle of heap	LS (81, 16 and 3)	SL (73, 23 and 4)	LS (86, 11 and 3)
Top of heap	LS (81, 15 and 4)	SL (71, 25 and 4)	LS (82, 15 and 3)

Figures in parenthesis are percentage of sand, silt and clay, respectively; LS= loamy sand; SL= sandy loam.

RESULTS AND DISCUSSION

Soil color

The color of the soil samples studied were found to belong to 4 hue groups, namely 5Y (3 samples), 7.5YR (3 samples), 10YR (3 samples) and 2.5 YR (3 samples) (Table 1). The values in the soil of Tuka Abdola were 3 in the control, 4 in the bottom, 6 in the middle and 2.5 in the top of the heap. The soils from the Garechatu site had the values of 4 in the control, 6 in the bottom, 6 in the middle and 2.5 in the top of the heap. Golelcha site had soil color values of 4 in the control, 3 in the bottom, 6 in the middle and 2.5 in the top of the heap (Table 1).

Generally, increase in temperature had different influences on the chroma and values of the soil. Red color values are formed with constant depletion of soil organic matter (OM) which may be due to increase in oxidation level and other chemical changes. These results were in agreement with Ulery and Graham (1993) and Certini (2005) who stated that the redder hue which appears in the burned soils is apparently because of transformation of Fe-oxides and complete removal of OM. The redder colors on the middle of the heaps were the indication of occurrence of higher fire intensity in that position of the heap while the black color of the top of the heap is due to charred organic matter and total organic matter is not combusted. Color of the burned soil can be used as an indicator of fire severity.

Soil texture

The highest average sand content (80.00%) was observed at the middle of the burned heap and the lowest (58.00%) was recorded in the unburned soil or the control. The average clay fraction of the unburned soil, the burned soil at the bottom, middle and top of the heap were 15.30, 4.30, 3.30 and 3.70%, respectively (Table 2). Sand contents were increased by 31.0, 38.0 and 34.5% on the bottom, middle and top of the burned heap, respectively as compared to the control. On the contrary, soil burning reduced clay contents by 71.9, 78.4 and 75.8% in the bottom, middle and top of the heap, respectively, as compared to the control treatment.

The observed variation in soil separates may be related to the exposure of the soils to high temperatures resulting in the fusion of clay and silt particles into sand-sized particles. Thus, soil burning increases the coarser particles by decreasing the contents of finer particles. Similar results were reported by Oguntunde et al. (2004) that in severely burnt soils, the decrease in clay fraction and corresponding increase in sand content were observed.

Despite the fact that texture is an inherent soil property, soil burning contributed to the changes in particle size distribution. The textural class of the soils from Golelcha and Tuka Abdola changed from sandy loam to loamy sand as a result of soil burning while the textural class of the soil from the Garechatu site remained sandy loam both before and after the soil burning treatment (Table 2). In this study, sand was negatively but significantly ($r = -0.93^{**}$) correlated with clay (Table 4).

Soil bulk and particle densities

With exception to silt contents, the results of the analysis of variance (Table 5) showed that all soil physical properties studied were significantly ($P \leq 0.05$) affected by soil burning.

The highest (1.85 g cm^{-3}) and lowest contents (1.42 g

Table 3. Mean values of soil physical properties and relative change (%) due to soil burning.

Soil properties	Control	Bottom of heap	Middle of heap	Top of heap
Sand (%)	58.00[b]	76.00[a] (31.0)	80.00[a] (38.0)	78.00[a] (34.5)
Silt (%)	26.70	19.70 (-26.2)	16.70 (-37.5)	18.30 (-31.5)
Clay (%)	15.30[a]	4.30[b] (-71.9)	3.30[b] (-78.4)	3.70[b] (-75.8)
BD (g cm^{-3})	1.42[c]	1.70[ab] (19.7)	1.85[a] (30.3)	1.55[bc] (9.2)
PD (g cm^{-3})	2.21[c]	2.38[b] (7.7)	2.57[a] (16.3)	2.42[b] (9.5)
TP (%)	35.79	28.53 (-20.3)	28.03 (-21.7)	35.78 (-0.1)
FC (%)	25.67[a]	19.00[b] (-26.0)	10.67[c] (-58.4)	17.00[b] (-33.8)
PWP (%)	18.67[a]	15.00[b] (-19.7)	8.30[c] (-55.5)	14.00[b] (-25.0)
AWHC (%)	7.00[a]	4.00[b] (-42.9)	2.30[b] (-67.1)	3.00[b] (-57.1)
WR (Second)	27.00[c]	49.67[b] (84.0)	67.33[a] (149.4)	52.67[b] (95.1)

*Means with in a row followed by the same letter (s) are not significantly different from each other at $P \leq 0.05$; Figures in the parenthesis are relative change (%) due to soil burning; BD = bulk density; PD = particle density; TP = total porosity; FC = field capacity; PWP = permanent wilting point; AWHC = available water holding capacity; WR = water repellency.

Table 4. Pearson's correlation coefficient (r) among soil physical properties.

Soil properties	Sand	Clay	BD	PD	TP	AWHC	WR
Sand	1						
Clay	-0.93**	1					
BD	0.71**	-0.69*	1				
PD	0.71*	-0.65*	0.96**	1			
TP	-0.63*	0.69*	-0.88**	-0.72**	1		
AWHC	-0.71**	0.88**	-0.69*	-0.67*	0.62*	1	
WR	0.69*	-0.71**	0.92**	0.89**	-0.78**	-0.80**	1

* and ** = Significant at $P \leq 0.01$ and < 0.05, respectively; ns = Not significant; BD = bulk density; PD = particle density; TP = total porosity; AWHC = available water holding capacity; WR = water repellency.

cm^{-3}) soil bulk density were recorded in the middle of the burned heap and the unburned soil, respectively (Table 3). Due to soil burning, the increase in soil bulk density by 19.7, 30.3 and 9.2% in the bottom, middle and top of the heap was observed, respectively, as compared to the control or unburned soil. Firstly, the increase in the bulk density of the soil may be attributed to the combustion of soil OM leading to deterioration of soil structure. The binding agents such as humic substances are deeply affected by fire temperature and, in connection with clays, promoting important changes in soil structure which is in agreement with the findings of Choromanska and DeLuca (2002) who reported that as a result of the loss of OM in heated soils, soil structure was destroyed which led to increase in the bulk density of the soil.

Secondly, the other reason for the increase in the soil bulk density is the decreases in the soil porosity. The increase in the sand and decrease in the clay fractions due to soil burning might have contributed to the increase in soil bulk density on the burned soil samples. As indicated in Table 4, correlation analysis showed a positive and significant (r = 0.71**) relation between bulk density and sand content while a negative and significant (r = -0.69*) relation was obtained between bulk density and clay content.

The average values of soil particle density of the unburned soil, the burned soil at the bottom, middle and top of the heap were 2.21, 2.38, 2.57 and 2.42 g cm^{-3}, respectively (Table 3). The results of this study revealed an increment of soil particle density by 7.7, 16.3 and 9.5% due to soil burning in the bottom, middle and top of the heap, respectively, as compared to the control. These higher particle density values in the middle of the burned heap could be because of the decrease in OM and expected iron oxide transformation in the burned soil.

The other reason for the higher values of particle density obtained in the middle of the burned heap might be due to the presence of heavy mineral Mn in the middle of the burned heap as indicated by the higher Mn contents which is in agreement with past reports by Hillel (1980) and Wakene (2001).

Total porosity

The average values of total porosity of the unburned soil,

Table 5. Results of analysis of variance for soil physical properties.

Soil properties	Treatment MS (3)	Error MS (8)	LSD (0.05)	CV	SE
Sand (%)	308.00**	26.25	9.65	7.0	5.07
Silt (%)	58.00^{ns}	21.83	ns	22.9	2.20
Clay (%)	100.67**	0.58	1.44	11.5	2.89
BD (g cm^{-3})	0.39**	0.02	0.28	13.2	0.18
PD (g cm^{-3})	0.38**	0.03	0.31	8.7	0.18
TP (%)	190.71*	36.29	11.34	14.7	4.00
FC (%)	114.53**	3.42	3.50	10.2	3.09
PWP (%)	54.89**	2.17	2.77	10.5	2.15
AWHC (%)	12.75**	0.83	1.72	22.4	1.04
WR (Second)	833.88**	38.75	11.72	12.7	8.34

*, ** = Significant at P ≤ 0.05 and P ≤ 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; SE = standard error; BD = bulk density; PD = particle density; TP =total porosity; FC = field capacity; PWP = permanent wilting point; AWHC = available water holding capacity; WR = water repellency.

the burned soil at the bottom, middle and top of the heap were 35.79, 28.53, 28.03 and 35.78%, respectively, which reveals a reduction of total porosity by 20.3, 21.7 and 0.1% in the bottom, middle and top of the heap, respectively, as compared to the control or unburned soil (Table 3).

Firstly, the increase in sand content and the decrease in clay content are also likely to decrease the total porosity by decreasing the amounts of soil micropores. Sandy soil has larger pore (macropore) but small total porosity while clay has smaller pores (micropores) but higher total porosity which is in agreement with the findings of Landon (1991) who stated that the fine textured soils especially those without a stable granular structure may have a dominance of micropores, thus allowing relatively slow gas and water movement, despite the relative large volume of total pore space. Correlation analysis (Table 4) showed a positive and significant (r = 0.69*) relationship between total porosity and clay with a negative and significant (r = -0.63*) relationship between total porosity and sand contents.

Secondly, the reduction in soil OM content which acts as binding agent of soil particles leading to stable aggregate formation is heavily affected by fire temperature during the process of soil burning leading to decrease in soil total porosity.

Soil water holding capacity

The mean AWHC contents decreased considerably from 7.00% on the unburned soil to the values of 4.00, 2.30 and 3.00% on the bottom, middle and top of the burned heap, respectively which reveals a reduction by about 42.9, 67.1 and 57.1% in the bottom, middle and top of the heap of the burned soil, respectively, as compared to the control.

The variation in water contents both at FC and PWP may be due to differences in their particle size distribution (sand, silt and clay fractions). The increases in sand sized particles and corresponding decreases in the clay sized particles after soil burning have led to the lower water contents at both FC and PWP which in turn reduced the soil AWHC. Similar results were reported by Emerson (1995) that increases in clay content increases the soil water holding capacity both at the FC and PWP. Similarly, the results obtained from the correlation analysis also indicated that AWHC has a positive and significant (r = 0.88**) relationship with clay content, whereas sand fraction has a negative, however, significant (r = -0.71**) relationship with AWHC (Table 4).

The reduction of soil water retention after soil burning may also be due to the reduction in the total OM of the soils which is burnt off during burning. This may be attributed to the fact that OM improves water retention through its positive effects on aggregate formation and stability leading to a well-structured soil of relatively low bulk density as a result of increased total soil porosity. Similar results were reported by Assunta et al. (2004) that most OM within the soil contains 50-90% water.

Moreover, the increase in soil bulk density is also another reason for the decrease in soil AWHC because bulk density is the measure of soil porosity which is the indicator of soil water content which is in agreement with the findings of Barauah and Barthakulh (1997) who concluded that soil bulk density is an indicator of soil aeration status and soil water content. In harmony with this, the analysis of the Pearson’s correlation coefficient (Table 4) also revealed that AWHC was negatively and significantly (r = -0.69*) related with soil bulk density. In general, the observed changes in the AWHC, FC and PWP in the present study indicate that the water retention properties of the soils in the study area have been disturbed significantly by soil burning.

Water repellency

The mean values of soil water repellency increased considerably from 27.00 (second) on the unburned soil to the values of 49.67, 67.33 and 52.67 (second) in the bottom, middle and top of the heap, respectively due to soil burning which reveals an increment of about 84.0, 149.4 and 95.1% in the bottom, middle and top of the heap, respectively, as compared to the control or unburned soil (Table 3).

The highest value of soil water repellency in the middle of the burned heap could be due to the highest fire intensity expected and the highest sand content (80.00%) observed at the middle of the heap which is supported by the findings of Huffman et al. (2001) who concluded that soil water repellency is strengthened with increasing burn severity and sand content. Accordingly, the results of correlation analysis also revealed that water repellency is significantly ($r = 0.69^*$) and positively related with sand content (Table 4).

Conclusion

The results from this study showed that as compared to normal or unburned soil, burning reduced available water holding capacity (42.9, 67.1 and 57.1%) and total porosity (20.3, 21.7 and 0.1%) in the bottom, middle and top of the heap, respectively. On the other hand, soil burning increased water repellency (84.0, 149.4 and 95.1%), bulk density (19.7, 30.3 and 9.2%) and particle density (7.7, 16.3 and 9.5%) in the bottom, middle and top of the heap, respectively, as compared to the unburned soil. The soil attributes due to soil burning showed an overall change towards the direction of the loss of its physical fertility as compared to unburned soils.

These variations of soil physical 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. The huge emission of carbon dioxide, that is, greenhouse gas during soil burning is also a problem of global warming.

Conflict of Interests

The authors have not declared any conflict of interests.

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