Impact of Biomass Burning on Selected Physicochemical Properties of Nitisol in Jimma Zone, Southwestern Ethiopia

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Burning of biomass for charcoal production and land preparation is common in Ethiopia. However, the analysis of the impacts of these practices on soil physical and chemical properties is seldom examined. Therefore to investigate the impact of biomass burning on soil properties, composite and core soil samples were collected at a depth of 0–20cm from cultivated land, a charcoal production site, and farmlands where crop residues are burned for land preparation. Burning of biomass significantly (P<0.01) decreased bulk density and clay percentage while the sand fraction was increased significantly (P<0.01). However, the differences in silt percentage and WHC were non-significant (P>0.05). Burning also increased pH, EC, available phosphorous, CEC (cation exchange capacity), and exchangeable bases significantly (P<0.01) as compared to cultivated land. Furthermore, charcoal production significantly (P<0.01) increased organic carbon and total nitrogen, but burning of crop residues for land preparation reduced them significantly (P<0.01). The formation of ash and charred biomass due to burning might improve most soil properties. But this causes environmental pollution and therefore it is useful to study the long term impact of biomass burning on soil properties. Moreover, it is important to consider a biochar strategy in order to enhance soil productivity.

Keywords: Biomass burning, charcoal site, crop residue burning, cultivated land.

INTRODUCTION

Biomass burning for charcoal making and the preparation of land for cultivation is common in Ethiopia. Crop residues left on the farmlands are burned in the field to recycle soil nutrients and to minimize crop residues interfere with tillage and seeding operations for the subsequent crop (Yisehak, 2009). The major reasons for deforestation in the country are cutting of trees and shrubs for fuel wood, charcoal, cultivating crops and construction materials (Teketay 2005). At present, the country is heavily dependant on traditional fuels consisting mainly of wood, crop residues, and animal waste (Wolde-Ghiorgis, 2002). Biomass accounts for 94.7% of total energy supply in the country (World Bank,

2001). Ethiopian Electric and Power Cooperation (EEPCO) (2000) also stated that the major indigenous sources of energy are woody biomass and crop residues. According to the Ethiopian Forestry Action Program (1994), fuel wood including charcoal contributes 66 and 62 percent, respectively, of the energy consumption in rural and urban areas.

Burning of biomass for charcoal production and conventional land preparation methods have a net negative impact on the soil organic carbon (C) as well as on the environment through the oxidation of carbon into carbon dioxide, an anthropogenic greenhouse gas (Parker et al., 2010; Makundi, 1998; Leenhouts, 1998). Burning of biomass also results in woody biomass stock depreciation (Stefan, 2009). Methane (CH_4), carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic carbon, and aerosols emitted as a result of the deliberate or accidental burning of natural vegetation constitute a

large component of the greenhouse gas emissions of many African countries (Scholes, 1995). In sub-Saharan Africa, biomass burning is the primary source of CO_2 emissions in the region (Vagen *et al.,* 2005). Moreover, burning of biomass fuels such as wood, animal dung, and crop residues, results in levels of exposure to inhalable carbonaceous particulate matter that are an order of magnitude above the health-based guidelines of the developed world (Ezzati and Kammen, 2001)**.**

Loss of plant nutrients, up to 80% of N (Raison, 1979), 25% of P, 21% of K (Ponnamperuma, 1984), and 4-60% of S (Lefroy et al., 1994) have been also reported due to burning. Burning had been also identified as a contributor to soil structural degradation (Valzano et al., 1997; Hubbard et al., 2004). Contrary to this, some studies have suggested that burning activities might increase availability of plant nutrients (Scheuner et al., 2004; Niemeyer et al., 2005). Glaser et al. (2002) and Ogudele et al. (2011) also reported that charcoal residues and charred biomass left on kiln sites improve the fertility of tropical soils by direct nutrient addition and retention. However, very few studies have been conducted regarding the impact of burning on soil physical and chemical properties. Therefore the present study is undertaken in order to investigate the impact of different biomass burning activities on selected soil properties as compared to adjacent cultivated lands.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Jimma, Southwest Ethiopia in the year 2011. It is located at 70, 33'N and 36^0, 57' E at an altitude of 1710 meter above sea level. The mean annual maximum and minimum temperatures are 26.8^0C and 11.4^0C and the relative humidities are 91.4% and 39.92% respectively. The mean annual rainfall of the study area is 1500mm (BPEDORS, 2000). The soils of the study area are dominated by Nitisol (World Reference Base 2006).

Soil Sampling and Analysis

To asses the impact of biomass burning on soil properties, composite soil samples were collected from the depth of 0-20 cm from cultivated land, a charcoal production site, and farmlands where crop residues are burned for land preparation. The experiment has three treatments arranged in a randomized complete block design. The soils were sampled so as to ensure similar soil properties for comparison. The samples were air-dried, sieved through a 2 mm mesh and used for analysis. Separate soil core samples were also taken for bulk density determination.

Water holding capacity (WHC) was determine by the method of Emmanuel et al. (2010). Air dried soil sample (20 gm) was placed in a plastic container (with a wire mesh at the bottom), in a dish of water. The soil was allowed to become saturated, for approximately six hours. The container was removed from the water and covered with cling-film to prevent loss of water by evaporation. It was then hung on a retort stand overnight to allow drainage. All samples were allowed to drain for the same length of time. Next, soil was carefully removed, put in a pre-weighed container (M1) and the total weight of moist soil and moisture container (M2) was taken. The samples were then dried in an oven at 105^oC until no further water loss occurred, and reweighed to record the oven-dried sample (M3). The WHC was calculated as:

$$WHC\ (\%) = \left(\frac{M2-M3}{M3-M1}\right) X100 \qquad (1)$$

Bulk density was determined after drying the core samples in an oven at $105\ ^OC$ for 24h and calculated as:

$$Bulk\ Density\left(\frac{g}{cm3}\right) = \frac{W2-W1}{V} \qquad (2)$$

Where W2 and W1 are weights of moist and oven-dry soils, respectively, and V is the volume of the cylindrical core.

Soil texture was determined by hydrometer. Soil pH was measured by using a pH meter in a 1:2.5 soil: water ratio. Electrical conductivity (EC) was measured in water at a soil to water ratio of 1:2.5. Soil organic carbon was determined by the Walkley-Black method and total nitrogen (N) by the Kjeldahl method (Van Reeuwijk, 1992). Available phosphorous (P) was determined using Bray I extraction method for adjacent farmlands since the pH was less than 7 while the Olsen method was used for soils at charcoal production sites (Van Reeuwijk,1992). Total exchangeable bases were determined after leaching the soils with ammonium acetate. Amounts of Ca^{2+} and Mg^{2+} in the leachate were analyzed by atomic absorption spectrophotometer. K^+ and Na^+ were analyzed by flame photometer. Cation exchange capacity was determined at soil pH 7 after displacement by using 1N ammonium acetate method in which it was, thereafter, estimated titrimetrically by distillation of ammonium that was displaced by sodium (Chapman, 1965).

Statistical Analysis

One way Analysis of variance (ANOVA) was performed to assess the significance differences in soil parameters between different treatments, using the general linear model (GLM) procedure of SAS 9.2. Means separation was done using least significant difference (LSD) test after the treatments were found significant at $P <0.05$.

Table 1. Mean Values of Soil Properties at Crop Residue Burned Farmlands, Charcoal Site and Cultivated Land in Southwestern Ethiopia

Treatments	Clay (%)	Silt (%)	Sand (%)	Textural Class	Bd (g/cm3)	WHC (%)
Crop residue burned	26.67b	38.00	35.33a	Loam	1.20b	49.34
Charcoal site	24.67b	37.33	38.00a	Loam	1.16b	49.49
Cultivated land	39.33a	39.33	21.34b	Clay loam	1.29a	52.85
LSD (0.05)	7.09	6.59	10.58	-	0.07	3.97
P-value	**	NS	*	-	*	NS
CV (%)	10.35	7.60	14.79	-	2.61	3.46

Means with different letter in the same column are significant; *,** significant at P<0.05 and P<0.01, respectively; NS = non significance; Bd = bulk density; WHC = water holding capacity; LSD = least significant difference; CV = coefficient of variance

Correlation analysis was also used to test if there were relationships between soil parameters. Relative change in soil properties due to burning of biomass as compared to adjacent cultivated land was also computed as:

$$Relative\ Change = \frac{(Pk - Pa)}{Pa} X100$$

Where Pk is the soil property measured on the burning sites and Pa is the soil property measured on the adjacent sites.

RESULTS AND DISCUSSION

Soil Physical Properties

Data on the effect of biomass burning on the selected soil physical properties are given in Table 1. Burning of biomass changed the soil textural class from clay loam soil to loam soil. The present study also revealed that, biomass burning affected percentage of clay and sand significantly (P<0.01) and (P<0.05) respectively, however the observed difference in silt percentage was non-significant (P>0.05) (Table 1). The highest percentage of clay was observed at cultivated lands whilst the smallest values were observed at charcoal production site. The higher percentage of sand was observed at biomass burned sites whilst the lower percentage was observed at cultivated lands (Table 1). As compared to adjacent cultivated lands, burning of biomass reduced clay content by 32.20% and 37.29% at residue burned farmlands and charcoal production site, respectively but the sand percentage was increased by 65.63% at crop residue burned farmlands and by 78.13% at charcoal production site (Table 4). 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 (Sertsu and Sanchez, 1978; Ketterings et al., 2000). Oguntunde et al. (2004) also observed a significant decrease in clay fraction and corresponding increase in sand content in severely burnt soils.

Soil bulk density was also significantly (P<0.05) affected by burning of biomass. Soil bulk density was highest at cultivated lands but it decreased significantly (P<0.05) at burned sites. The bulk density was reduced by 7.15% and 9.97% at crop residue burned farmlands and charcoal sites, respectively (Table 4). This variation in bulk density could be because of the porous nature of charcoal and charred biomass left on soils at burned sites. The increase in sand fraction due to burning may also contributes to the reduction of soil bulk density at burned sites. The correlation matrix (Table 5) also revealed a significant negative relationship between sand and bulk density (r = -0.932**). Oguntunde et al. (2008); Ajayi et al. (2009) and Kevin (2010) also reported reduction in bulk density due to burning of soils.

Though the coarsening of severely heated surface soils eventually leads to poor WHC (Ulery and Graham, 1993), WHC was not significantly (P>0.05) affected by burning of biomass. However as compared to cultivated land, the lowest WHC was recorded at burned sites (Table 1). The insignificant relative change in WHC regardless of change in clay content could result from the presence of charcoal and charred biomass left at burning sites. Piccolo and Mbagwu, (1990); Piccolo et al. (1997) also found that the presence of charcoal affect soil physical properties such as soil water retention and aggregate stability, leading to enhanced crop water availability.

Soil pH, EC and Exchangeable Acidity

The mean values of soil pH, EC and exchangeable acidity at cultivated lands, charcoal production sites and crop residue burned farmlands are given in Table 2. The statistical analysis revealed a significant (P<0.01) difference in pH, EC and exchangeable acidity between cultivated lands and burned sites. The highest values of pH and EC were observed at crop residue burned farm-

Table 2. Mean values of pH, EC, exchangeable acidity, OC, TN, AVP at Crop Residue Burned Farmlands, Charcoal Site and Cultivated Land in Southwestern Ethiopia

Treatments	pH	EC (mmhos)	Ex. Ac (meq/100g)	OC (%)	TN (%)	C/N	AVP (ppm)
Crop residue burned	8.12a	0.811a	0.197c	3.42b	0.35b	9.73a	13.48a
Charcoal site	7.51b	0.766a	0.170b	5.13a	0.66a	7.77b	14.55a
Cultivated land	5.63c	0.084b	0.263a	3.84b	0.38b	10.21a	7.77b
LSD (0.05)	0.45	0.14	0.03	0.43	0.04	1.42	3.02
P-value	**	**	**	**	**	*	**
CV (%)	2.81	11.43	5.50	4.59	3.52	6.79	11.18

Means with different letter in the same column are significant; *,** significant at $P<0.05$ and $P<0.01$, respectively; EC= electrical conductivity; Ex. Ac = exchangeable acidity; OC= organic carbon; TN= total nitrogen; AVP= available phosphorous; LSD = least significant difference; CV = coefficient of variance

lands whilst the lowest value of pH and EC were recorded at cultivated lands (Table 2). Contrary to this, the lowest value of exchangeable acidity was observed at burned sites. As compared to cultivated lands, burning of biomass increased soil pH by 44.20% and 33.37% at crop residue burned site and charcoal production site. Burning activities also increased EC by 10 times as compared to cultivated lands. However, exchangeable acidity was reduced by 25.32% at farmlands where crop residue burned for land preparation and by 35.44% at charcoal production site (Table 4). Increase in soil pH and EC after burning was generally attributed to ash accretion as ash residues are generally dominated by carbonates of alkali and alkaline earth metals, variable amounts of silica, heavy metals, sesquioxides, phosphates and small amounts of organic and inorganic N (Raison, 1979). The correlation matrix (Table 5) also showed a positive and significant relationship between pH, EC and exchangeable bases.

Another reason for high soil pH at biomass burned sites could be because of the porous nature of charred biomass that increases the CEC of the soil. Thus there could be a chance for Al and Fe to bind with the exchange site. The correlation matrix (Table 5) also revealed a positive and significant relationship between soil pH and CEC. In agreement with this finding, Arocena and Opio 2003; Khanna *et al.* (1994) reported the capacity of ashes to neutralize the acidic soil. Ulery et al. (1993); Naidu and Srivasuki (1994); Hernandez et al. (1997) also found an increase in soil pH by as much as three units immediately after burning.

Soil Organic C, Total N and Available P

Burning of biomass significantly ($P<0.01$) altered soil organic C, total N and available P but the observed variation in carbon to nitrogen ratio was not significant ($P<0.05$). The highest value of organic carbon and total nitrogen were observed at charcoal site. Due to severe burning, the lowest values of organic carbon and total nitrogen were recorded at farmland where crop residues are burned for land preparation (Table 2). As compared to adjacent cultivated land, charcoal production increased organic C and total N by 33.50% and 75.22%, respectively whereas on farm burning of crop residues decreased soil organic C and total N by 10.90% and 6.19%, respectively (Table 4). The highest value of organic carbon and total nitrogen at charcoal site resulted from the presence of carbon and nitrogen rich charcoal residues whilst severe fire during land preparation decreased soil organic carbon and total nitrogen. In harmony with this finding, Solomon et al. (2007) and Liang *et al.,* (2006) revealed the higher organic C and total N at the ancient *terra preta* compared with adjacent soils. The previous studies (Sertsu and Sanchez 1978; FAO 1983) have also reported significant reduction in the organic C content of soils exposed to severe fire.

Available phosphorous was also significantly ($P<0.01$) increased by biomass burning. Available phosphorous was increased from 7.77ppm at cultivated land to 14.55ppm at charcoal production sites (Table 2). As compared to cultivated land, burning of crop residues for land preparation increased available phosphorous by 73.41% whereas burning of biomass for charcoal production increased available phosphorus by 87.14% (Table 4). The increase in available phosphorus at burning sites could be due to the presence of wood ash which is rich in phosphorus (Ogundele *et al.,* 2011). The increase in soil pH and CEC, that reduce the activity of Fe and Al, could be the other reasons for the increased in available phosphorous at burned sites. The correlation matrix (Table 4) also revealed a positive and significant relationship between soil pH and available phosphorous ($r = 0.875^{**}$) and available phosphorous and CEC ($r = 868^{**}$). In line with this findings, Ogundele et al. (2011), reported the increase in available phosphorous from 2.07

Table 3. Mean Values of CEC and Exchangeable bases at Crop Residue Burned Farmlands, Charcoal Site and Cultivated Land in Southwestern Ethiopia

Treatments	CEC	K	Na	Ca	Mg
			meq/100g		
Crop residue burned	29.27a	15.49a	0.25b	16.64	6.27a
Charcoal site	30.06a	14.16a	0.39a	19.64	6.22a
Cultivated land	25.33b	2.27b	0.13c	10.22	2.60b
LSD (0.05)	1.30	4.05	0.06	7.77	0.56
P-value	**	**	**	NS	**
CV (%)	2.03	16.80	9.93	22.11	4.89

Means with different letter in the same column are significant; *,** significant at P<0.05 and P<0.01, respectively; NS = non significance; CEC = cation exchange capacity; LSD = least significant difference; CV = coefficient of variance

Table 4. Relative Change in soil properties due to Burning of Biomass as Compared to Cultivated Land in Southwestern Ethiopia

Soil parameters	RC due to Burning of crop Residues (%)	RC due to Charcoal Production (%)
Clay (%)	-32.20	-37.29
Silt (%)	-3.39	-5.08
Sand (%)	65.63	78.13
WHC (%)	-6.65	-6.36
Bulk density (g/cm^3)	-7.15	-9.97
pH	44.20	33.37
EC (mmhos)	866.45	812.65
EX.Ac (meq/100g)	-25.32	-35.44
OC (%)	-10.90	33.50
TN (%)	-6.19	75.22
C/N	-4.70	-23.89
AVP (ppm)	73.41	87.14
CEC (meq/100g)	15.58	18.68
K (meq/100g)	583.53	524.71
Na (meq/100g)	90.00	192.50
Ca (meq/100g)	62.87	92.23
Mg (meq/100g)	140.85	139.05

RC = relative change; WHC = water holding capacity; EC = electrical conductivity; Ex. Ac = exchangeable acidity; OC = organic carbon; TN= total nitrogen; AVP = available phosphorous; CEC = cation exchange capacity

to 11.21 ppm under adjacent sites and charcoal production sites, respectively. Dormaar et al. (1979) also reported a significant (P<0.05) increase in available phosphorous due to burning of crop residues.

Cation Exchange Capacity and Exchangeable Bases

The mean values of CEC and exchangeable bases at cultivated land and burned sites are presented in Table 3. Cation exchange capacity and exchangeable bases were significantly (P<0.01) affected by burning of biomass however the observed variation in exchangeable calcium was not significant (P>0.05) (Table 3). The highest and the lowest values of CEC were recorded at charcoal production site and cultivated lands, respectively. CEC was increased by 15.58% and 18.68% due to burning of crop residues and charcoal production, respectively (Table 4). The increase in CEC due to burning, in spite of decrease in clay percentage, could be due to the presence of charcoal and charred biomass left on the soil. Available evidence suggested that on a mass basis, the intrinsic CEC of biochar/charred biomass is consistently higher than that of whole soil, clays or

Table 5. Correlation Matrix for the Selected Soil Physicochemical Properties

	Clay	Silt	Sand	WHC	Bd	pH	EC	EXA	OC	TN	C/N	AVP	CEC	K	Na	Ca	Mg
Clay	-																
Silt	0.351	-															
Sand	-0.960**	-0.599	-														
WHC	0.727*	0.142	-0.664	-													
Bd	0.897**	0.550	-0.932**	0.577	-												
pH	-0.857**	-0.345	0.836**	-0.664	-0.796*	-											
EC	-0.937**	-0.390	0.917**	-0.737*	-0.862**	0.969**	-										
ECA	0.941**	0.341	-0.906**	0.694	0.901**	-0.817**	-0.925**	-									
OC	-0.376	-0.170	0.372	-0.166	-0.446	0.045	0.205	-0.461	-								
TN	-0.509	-0.254	0.511	-0.270	-0.603	0.209	0.380	-0.638	0.962**	-							
C/N	0.573	0.320	-0.586	0.341	0.697*	-0.388	-0.547	0.770*	-0.723*	-0.882**	-						
AVP	-0.887**	-0.217	0.885**	-0.533	-0.906**	0.862*	0.889**	0.378	0.541	-0.667	0.929**	-					
CEC	-0.966**	-0.484	0.971**	-0.625	-0.954**	0.895**	0.953**	-0.945**	0.403	0.554	-0.648	0.868**	-				
K	-0.857**	-0.176	0.786*	-0.752*	-0.755*	0.958**	0.956**	-0.862**	0.178	0.328	-0.468	0.855**	0.867**	-			
Na	-0.871**	-0.451	0.880**	-0.558	-0.914**	0.672*	0.803**	-0.930**	0.708*	0.839**	-0.872**	0.810**	0.911**	0.710*	-		
Ca	-0.843**	-0.480	0.865**	-0.677	-0.916**	0.684*	0.745*	-0.762*	0.489	0.568	-0.534	0.927**	0.848**	0.658	0.825**	-	
Mg	-0.912**	-0.310	0.872**	-0.674	-0.863**	0.966**	0.963**	-0.878**	0.278	0.411	-0.498	-0.906**	0.944**	0.964**	0.792*	0.784*	-

*, ** significant at P<0.05 and P<0.01, respectively; WHC= water holding capacity; Bd = bulk density; ECA = exchangeable acidity; OC= organic carbon; TN = total nitrogen; AVP = available phosphorous; CEC = cation exchange capacity

soil organic matter (Sohi et al., *2009*). Sohi et al., also revealed the increase in soil cation exchange capacity after the application of charcoal and/or biochar. Moreover, Ketterings (2002) unveiled that heating of soil increases bulk soil specific surface area which in turn increases soil CEC. The increase in soil CEC due to burning of soil was also reported by Almendros et al. (1990); Oguntunde et al. (2004) and Glaser et al. (2002).

The highest and the lowest values of exchangeable bases were also recorded at burned sites and cultivated lands, respectively (Table 3). As compared to cultivated land, burning of crop residues for land preparation increased exchangeable K, Na, Ca and Mg by 583.53%, 90.00%, 62.87% and 140.85%, respectively while charcoal production increased exchangeable K, Na, Ca and Mg by 524.71%, 192.50%, 92.23% and 139.05%, respectively (Table 4). The highest exchangeable bases at burned sites might be due to the accumulation of wood ashes and/ or charred biomass. The ash deposits after burning, helps for the immediate release of the occluded mineral nutrients for crop use (Scheuner et al., 2004; Nimeyer et al., 2005). Due to excess accumulation of ash which is rich in basic cations, the percentage of base saturation at burned sites was more than 100%.

CONCLUSION AND RECOMMENDATION

Most of the selected soil physical and chemical properties were significantly affected by biomass burning except silt percentage, WHC and C:N ratio. Biomass burning increased the percentage of sand and decreased clay content and bulk density as compared to adjacent cultivated land. Moreover, soil pH, EC, available P, CEC, and exchangeable bases were significantly increased by burning of biomass. Charcoal production also increased organic carbon and total nitrogen however severe fire during burning of crop residues for land preparation decreased the

values of organic carbon and total nitrogen. The increase in soil pH, EC, and exchangeable cations could be resulted from the production of ashes during burning of biomass while the increase in CEC may be attributed to the dominating effect of charred biomass left on burned sites and the increase in surface area due to burning of soil. Though burning of biomass improved some soil properties, this practice causes significant environmental pollution and kills beneficial soil microorganisms. Therefore it is useful to consider biochar strategy in order to manage soil health and reduce impact of biomass burning on environment. Moreover more research is required to evaluate the effect of fire on soil properties.

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