International Journal of Soil Science and Agronomy ISSN: 1725-3497 Vol. 4 (5), pp. 143-148, September, 2017.
Available online at www.advancedscholarsjournals.org © Advanced Scholars Journals

Full Length Research papers

Dynamic soil properties used to monitor soil quality in Cameroon

***Timothée Minala Ekeng, Joseph N'Guémo and Yazid Achidi Maigari**

Department of Soil Science, Faculty of Agronomy and Agricultural Sciences, University of Dschang, West Region, Cameroon.

Accepted 19 August, 2017

With slash-and-burn agriculture, changes in soil properties occur, which could influence crop production and future soil fertility recommendations. The objectives of this study were to: Identify dynamic soil properties that could be used to monitor soil quality; evaluate residual effects of slash-and-burn; and establish P and K fertilizer equivalence values of ash from slash-and-burn. Each experimental site was divided into 3 blocks within which treatments were randomly allocated. Broadcast burning and pile burning were carried out as practiced by local farmers. Soil samples were collected before burning (control), immediately after burning (burned) and one year after burning and cropping (burned-cropped), hereafter referred to as treatments. Soil samples were analyzed following standard analytical methods. P and K fertilizer equivalence values of the soil tests immediately before burning and after one year cropping of burned land were established and compared. The most sensitive soil properties to slash-and-burn were coarse silt, fine silt, pH, organic carbon (OC), total N (totN), P, Ca, Mg, K, Na, exchange acidity, effective cation exchange capacity (ECEC) and base saturation (BS). Between 47 and 87% of increases in content of exchangeable bases and available P resulting from burning of forest vegetation cover is lost after one year of cropping positive. Benefits in soil P and K attributed to slash and burn agriculture after one year cropping in terms of fertilizer equivalence was between 1 to 18 kg P_2O_5 and 22 to 76 K_2O. P and K fertilizer recommendations for targeted crop yields based on the initial soil fertility status of the secondary forest in the humid forest zone of Cameroon should be 9 kg P_2O_5 and 49 kg K_2O less in the second year of cropping.

Key words: Slash-and-burn, soil properties, humid forest zone, shifting cultivation, Southern-Cameroon.

INTRODUCTION

Slash and burn agriculture is practiced by many rural farmers in the humid forest region of Cameroon. Fire has been a traditionally used to clear land for agricultural production. The practice is that a relatively small patch of forest is under-brushed, felled and burned, often with several trees remaining in the field (Koto-Same et al., 1997). As more land is being cleared and prepared for cropping annually, burning in the forest zone has become the easiest and most convenient method quite often employed (Pantami et al., 2010). Burning takes place in two steps: Broadcast burn followed by pile and burn (Ketterings et al., 1999), after which a mixture of annual and perennial food crops are established without widespread soil tillage, for one to four cropping cycles. Shifting cultivators practiced field rotation by slashing and burning a new plot of land after the existing plot has lost its fertility. The reasons for using fire as a land clearing method are that fire is a very cheap means to

*Corresponding Author. Email: minala.ekeng@yahoo.com

increase accessibility and management of new farms, addition of wood ash (nutrients), improvement of the soil structure, reduction in weed and tree re-growth and decreased occurrence of pests and diseases (Ketterings et al., 1999).Both negative and positive effects have been reported on burning activities on soils and crop production. Although some studies have shown that burning activities increase availability of plant nutrients (Nigussie and Kissi, 2011), burning of biomass for conventional land preparation methods have a net negative impact on soil properties as well as on the environment (Pantami et al., 2010, Nigussie and Kissi, 2011). Loss of plant nutrients up to 80% of N, 25% of P, 21% of K and 4 to 60% of S have been reported (Nigussie and Kissi, 2011). In many cases, the impacts of slash- and-burn practices on soil properties are either negligible or short-lived and thus have little if any, impact on the overall ecosystem. In some cases however, the impact of the fire on soil conditions can be moderate or severe (Oluwole et al., 2008). The overall degree and longevity of the impact of fire on soil conditions is determined by numerous factors including fire severity, temperature, fire frequency, soil type and moisture, vegetation type, topography, season of burning, and pre- and post-fire weather conditions (Oluwole et al., 2008; Pantami et al., 2010). Because of population pressure, shifting cultivation is no longer a common land use even though farmers continue to use fire as a land clearing method. Soil fertility in the cleared land cannot recover to optimal levels under current management practices and shortened or inexistent fallows. From the environmental perspective, smallholder slash-and-burn agriculture is the major source of deforestation in Cameroon (Kotto-Same et al., 2002) and source of CO_2 emissions in Africa (Vagen et al., 2005). These drawbacks called for the introduction of alternatives to slash-and-burn.

The Alternatives to Slash-and-Burn programme (ASB) involved a global consortium of national and international research institutes and was a system-wide initiative of the Consultative Group on International Agricultural Research (CGIAR) (Kotto-Same et al., 2002). The programme's purpose was to develop and test strategies for reducing environmental degradation and improving rural livelihoods along the forest margins of the tropics. Its objectives were to develop improved land-use systems and to make policy recommendations capable of alleviating the pressures on forest resources that are associated with slash-and-burn agricultural techniques. Beside the small-scale farmers' agriculture, the sustainable use and management of the national forests has become a challenge at national as well as international levels (Yemefack et al., 2010). Research was conducted in benchmark sites across the pan-tropics Tabi et al. 1991to guide decision-making in the management of forest resources. Major outputs from the programme guided agricultural intensification through adoption of alternative technologies to slash-and-burn like perennial crop agroforests and seed-fertilizer technology systems. With respect to seed-fertilizer technology systems, more specific information is required on the effects of biomass burning on nutrient availability during the first year; which soil properties sensitive to fire disturbance and could serve as soil quality indicators; and the fertilizer substitution effect of ash in relation to P and K after one year of cropping. Such information will guide soil fertility restoration and provide a basis for sustainable intensification of alternatives to slash and burn agriculture. The specific objectives of this study were to:

1. Identify dynamic soil properties that could be used to monitor soil quality in forest soils converted for agriculture;
2. Evaluate residual effects associated with slash-and-burn agriculture after one year of cropping; and
3. Establish P and K fertilizer substitution effects of ash from slash-and burn.

MATERIALS AND METHODS

Description of the study area

The study was conducted in three villages of the South region of Cameroon: Ngoulemekong, situated 5 km from Sangmelima, the capital of Dja and Lobo Division; Ndjana, about 30 km from Ebolowa, within the Mvila Division and Akam-messi situated 40 km from Ambam within the Ntem valley Division. The South region is situated between latitudes 2°10' and 3°40' N and longitude 9°50' and 13°40' E. the climate is described as classic equatorial, with four distinct seasons: A long rainy season (August-November), a long dry season (December to February), a short rainy season (March to May) and a short dry season (June to August). Mean annual rainfall is 1716 mm in Ebolowa, 1710 mm in Sangmelima and 1920 mm in Ambam. The soils are classified as typic Kandiudox (Kotto-Same et al., 1997). The soils are deep (> 1 m), well-drained with clay loam and clayey textures. The forests are of secondary origin, showing some degree of degradation. The climax vegetation in the area is of two main types: The dense semi-deciduous forests characteristic of the Yaoundé block extending southwards into the Mbalmayo, and the dense, humid, Congolese forest in the southern reaches of the Mbalmayo extending to Ebolowa (Kotto-Same et al., 2002). In addition, there are small pockets along the western border of the Ebolowa and Mbalmayo that are characterized by the biologically diverse, moist, evergreen, Atlantic forest (Kotto-Same et al., 2002). Farmers clear the under storey of the forest in December or January and burn the residue by the end of February.

Soil sampling and analysis

Broadcast burning and pile burning (equivalent to heavy burning) were carried out as practiced by local farmers. Within each village, three blocks (in Ndjana) and four blocks (in Akam-Messi and Ngoulemekong) were demarcated in which treatments were randomly allotted. Each plot had a dimension of 10 m by 10 m. Soil samples were from the topsoil (0 to 20 cm) from each plot. Treatments were: Before burning (control), immediately after burning (burned) and one year after burning and cropping (burned-cropped). The experimental design was a randomized complete block design. Plant residue on each plot was not quantified before

Table 1. Means (±SE) of top soil (0-20 cm depth) physical properties of samples taken before burning (control), immediately after burning (burned) and one year after cropping burned land (cropped).

Location		Sand	Coarse Silt	Fine Silt	Silt	Clay
		%				
Akam-Messi	Control	46.00±1.16[a]	2.67±0.67[a]	15.00±1.16[a]	17.67±1.76[a]	36.33±0.67[a]
	Burned	51.00±3.06[a]	7.67±3.71[a]	5.00±1.75[b]	12.67±2.60[a]	36.33±5.36[a]
	Cropped	52.33±2.96[a]	9.67±3.18[a]	4.00±0.58[b]	13.67±3.28[a]	34.00±4.51[a]
Ndjana	Control	37.00±0.82[b]	3.50±0.29[a]	4.75±0.25[b]	8.25±0.25[a]	54.75±0.85[a]
	Burned	31.50±2.60[c]	6.00±2.04[a]	11.75±3.30[a]	18.00±5.12[a]	50.75±5.36[a]
	Cropped	42.38±0.85[a]	4.78±1.13[a]	6.20±0.66[ab]	11.00±1.23[a]	46.50±4.51[a]
Ngoulemekong	Control	47.50±2.06[b]	4.00±0.82[a]	7.75±0.25[a]	11.75±0.85[a]	40.75±1.70[a]
	Burned	31.50±2.60[b]	6.00±2.04[a]	11.75±3.30[a]	18.00±5.12[a]	50.75±5.51[a]
	Cropped	54.00±0.82[a]	2.75±0.48[a]	6.25±0.63[a]	7.25±0.48[a]	38.75±1.25[a]

Means in each column followed by the same letter are not significantly different at 5% probability; In Ndjana, sand, fine sil t and total silt were sensitive to treatments, while in Ngoulemekong, only sand and total silt were different ($p<0.01$).

burning. In burned plots, burning was carried out to ensure complete burning of crop residue. The collected soil samples were air dried, sieved through a 2 mm mesh and used for laboratory analysis. Soil texture was determined using the USDA standard sieve method after dispersion with calgon (Na-hexametaphosphate). The soil pH was determined both in water and KCl in a soil-water/KCl suspension of 1:2.5. Exchangeable Ca, Mg, Na and K were extracted with 1 M ammonium acetate (1 M NH_4OAc) solution buffered at pH 7.0 as described by Anderson and Ingram (1998). Potassium and sodium in the extract were read on a flame photometer (Okalebo et al., 1993). The extracts were diluted two times with the addition of 2 ml of 6.5% lanthanum chloride to prevent ionic interference before Ca and Mg were read. The Ca and Mg were read on an atomic absorption spectrophotometer (AAS). The sum of Ca, Mg, Na and K gave total exchangeable bases. Exchange acidity (Al + H) in the 1M KCl extract was determined by titrating with 0.1 M sodium hydroxide (1 M NaOH) solution as described by Anderson and Ingram (1998). Effective CEC was calculated from the summation of exchangeable bases determined by 1 M NH_4OAc extraction and the exchange acidity by 1 M KCl extraction as described by Anderson and Ingram (1998). Percentage base saturation was calculated by dividing the total exchangeable cations (Ca, Mg, K and Na) by the effective cation exchange capacity (ECEC) obtained by the 1 M NH_4OAc (pH 7.0) method. The exchangeable sodium percentage (ESP) was calculated as the proportion of the ECEC occupied by exchangeable sodium. The organic carbon content was determined by the wet oxidation method of Walkley and Black (1934) as described by Nelson and Sommers (1982). The reaction was activated with the addition of concentrated sulphuric acid as a catalyst. The total N content was determined using the Macro-Kjeldahl technique as described by Bremner (1982). Available P was extracted using the Bray II procedures (Tchuenteu and Schalk, 1988). Based on results of soil analysis, P and K fertilizer recommendations immediately before burning and one year after cropping of burnt land were established and compared. The difference between the two values reflects the P and K fertilizer replacement values of ash one year after cropping.

Statistical analysis

Treatment means were compared using analysis of variance (GENSTAT v. 9) Treatment means were separated using the least significant difference (LSD) test after treatments were declared significantly different at $p < 0.05$.

RESULTS AND DISCUSSION

Before applying burning treatments, there were differences ($p<0.05$) in most of the soil properties considered between the three locations. The mean values of soil physical properties (sand, coarse silt, fine silt, total silt and clay) are shown in Table 1. Although mean values changed, there was no effect of treatments on clay and coarse silt contents in all three sites. On the other hand, the effect of treatment on sand content was significant ($p<0.05$) in Ndjana and Ngoulemekong but not in Akam-Messi. Similarly, the effect of treatment on fine silt was significant in Akam-Messi and Ndjana but not in Ngoulemekong (Table 1). The effects of treatments on soil properties were either positive or negative for different sites. Oguntunde et al. (2004) observed a significant increase in sand content and corresponding decrease in clay content in severely burnt soils in Nigeria. The direction of change in soil properties resulting from slash-and-burn is not universal. The degree of impact and direction of change is influenced by a number of factors among which are: Fire severity, fire frequency, temperature, soil type and moisture conditions, season of burning and vegetation type and amount, topography andpre- and post-fire weather conditions (Pantami et al., 2010).

The mean values of pH (in water and KCl) organic carbon (OC), total nitrogen (Tot.N) and available P are shown in Table 2. The soils under forest vegetation were extremely acidic, very low in available P, OC and Total N.

All the chemical properties examined (Tables 2 and 3)

Table 2. Means of top soil (0-20 cm) pH, organic carbon (OC), total nitrogen (TotN) and available phosphorus (Avail. P) taken before burning (control), immediately after burning (burned) and one year after cropping burned land (cropped).

Location		pH (water)	pH (KCl)	OC (%)	Total N (%)	Available P (mg/kg)
Akam-Messi	Control	3.37^{c}	2.97^{c}	4.69^{a}	1.33^{a}	5.30^{b}
	Burned	3.80^{b}	3.47^{b}	1.17^{c}	1.08^{ab}	7.61^{a}
	Cropped	4.87^{a}	4.17^{a}	2.27^{b}	0.96^{b}	5.50^{b}
Ndjana	Control	3.53^{c}	3.30^{b}	2.01^{a}	1.01^{b}	4.95^{c}
	Burned	4.13^{b}	3.70^{ab}	1.15^{b}	1.23^{a}	12.33^{a}
	Cropped	4.70^{a}	4.18^{a}	2.10^{a}	0.73^{c}	8.42^{b}
Ngoulemekong	Control	3.35^{b}	2.98^{b}	3.30^{a}	1.38^{a}	6.07^{b}
	Burned	4.13^{a}	3.70^{a}	1.15^{c}	1.23^{b}	12.33^{a}
	Cropped	4.23^{a}	3.95^{a}	2.35^{b}	0.77^{c}	7.40^{b}

Means in each column followed by the same letters are not significantly different at 5% probability.

were affected by slash-and-burn practices. In all the sites, pH increased significantly ($p<0.01$ in Akam-Messi and Ndjana; $p<0.05$ in Ngoulemekong). An increasing trend in pH was observed in all the sites passing from control vegetation through burning to one year after cropping. pH (water) increased between 0.98 to 1.50 units in the 3 sites. Ekinci (2006) also reported significant increases in soil pH two weeks after burning in Turkey. The large pH increase could be attributed to the high pH of ash from slash and burn. Wood ash is alkalic, calcareous-potassic material (Tothova, 2012). The small particle size of wood ash might have contributed to the more rapid soil pH change than is observed with agricultural lime (Kopecky et al., 2012). Although not measured in this study, the high pH increases could be attributed to moderate-to-high fire temperatures. Verma and Jayakuma (2012) reported that significant increases in pH occur only at higher fire temperatures (450 to 500°C). In addition to the aforementioned, Certini (2005) attributed increase in soil pH to denaturation of organic acids by soil heating.

Slash and burn with subsequent cropping, reduced significantly ($p<0.05$) OC and Total N contents in all the sites, whereas the reserve was observed with available P. The most expected change soils experience during burning is the loss of organic matter. However, the effect of fire on soil organic matter has been reported to be very variable depending on soil type, intensity of fire, soil moisture and the nature of burned materials (Verma and Jayakumar, 2012). Low-intensity prescribed fire usually results in little change in soil carbon, but intense prescribed fire or wildfire can result in a huge loss of soil carbon (Verma and Jayakumar, 2012). The decrease in Total N after burning and subsequent cropping could be attributed to leaching losses of nitrate, volatilization and crop uptake. Moderate to high intensity fires (as reported for slash and burn) convert most organic nitrogen to NH_4^+-N and NO_3^--N, which are available to biota (Certini, 2005). If these N-forms are not promptly taken up by crops, nitrate is leached downwards while ammonium is adsorbed onto the negatively charged surfaces of minerals and organic acids (Mroz et al., 1980). The increase in available P was higher immediately after burning than after one year of cropping relative to the unburned forest vegetation. After one year of cropping, available P in Akam-Messi and Ngoulemekong were not significantly different from the initial P content (before burning). The liming effect of ash will increase the soil pH and make P more available. Addition of wood ash also increases available P. Van Reuler and Janssen (1995) concluded in Cote D'Ivoire that increase in yield in slash and burn trials was mainly a P effect. Kopecky et al. (2012) reported that each ton of wood ash could substitute for 13 to 14 kg of phosphate (P_2O_5).

With respect to exchangeable bases and cation exchange capacity (Table 3) varied responses were obtained for the different communities. Ca, Mg, K and Na increased with burning and subsequent one year cropping, with higher values obtained immediately after burning. Ca was as high as 2.30 to 2.89 $cmol_+kg^{-1}$ immediately after burning. The trend observed with Ca was similar to that of Mg, K, and ECEC. However, after one year of cropping, exchangeable bases and ECEC in treated plots were similar to the control. Wood ash contains all important nutrition elements, except the nitrogen which were originally present in the dendromass (Tothova, 2012).

The results obtained above indicate that there is only a transient effect of burning on nutrient availability. Between 47 and 87% of increases in exchangeable bases and available P associated with burning of forest vegetation cover is lost during the first year of cropping. Although the liming effect of the ash is evident in the second year of cropping, the effects are much limited compared to the first year. Certini (2005) reported that between 3 months and 2 years (sometimes more than 2 years for Ca) are required for soil properties to normalize

Table 3. Means of top soil (0 to 20 cm) exchangeable bases (Ca, Mg, K and Na), exchange acidity (EA), effective cation exchange capacity (ECEC) and percentage base saturation (BS) taken before burning (control), immediately after burning (burned) and one year after cropping burnt land (cropped).

Location		Ca	Mg	K	Na	ECEC	BS
		cmol+/kg					%
Akam-Messi	Control	1.33[b]	0.59[a]	0.17[b]	0.02[b]	2.73[b]	10.02[b]
	Burnt	2.30[a]	0.72[a]	0.32[a]	0.03[b]	3.63[a]	46.75[a]
	Cropped	1.22[b]	0.69[a]	0.19[b]	0.07[a]	2.37[b]	16.40[b]
Ndjana	Control	0.95[c]	0.47[b]	0.16[c]	0.04[b]	2.19[b]	13.04[b]
	Burnt	2.89[a]	0.77[a]	0.33[a]	006[a]	4.37[a]	48.79[a]
	Cropped	1.44[b]	0.53[b]	0.23[b]	0.03[b]	2.47[b]	15.58[b]
Ngoulemekong	Control	0.95[b]	0.55[b]	0.22[b]	0.03[b]	2.30[b]	10.71[b]
	Burnt	2.89[a]	0.77[a]	0.33[a]	0.06[a]	4.37[a]	48.79[a]
	Cropped	1.48[a]	0.55[b]	0.21[b]	0.03[b]	2.53[b]	16.48[b]

Means in each column followed by the same letters are not significantly different at 5% probability.

Table 4. Fertilizer equivalence values of P and K from ash and other pedological changes following slash-and-burn and one year maize cultivation in the humid forest zone.

Location	Nutrient status in mg/kg		Soil nutrient (kg/ha)		Positive effect of S&B	FEV*
Phosphorus						
	Forest	Burned-cropped	Forest	Burned-cropped	kg P/ha	P_2O_5 in kg/ha
Akam-Messi	5.30	5.50	12.19	12.65	0.46	1.05
Ndjana	4.95	8.42	11.39	19.37	7.98	18.28
Ngoulemekong	6.07	7.40	13.96	17.02	3.06	7.01
Potassium						
	Nutrient status in cmol+/kg		Soil nutrient (kg/ha)		Positive effect of S&B	FEV*
	Forest	Burned-cropped	Forest	Burned-cropped	kg K/ha	K_2O in kg/ha
Akam-Messi	0.17	0.19	152.83	170.81	17.98	21.58
Ndjana	0.16	0.23	143.84	206.77	62.93	75.52
Ngoulemekong	0.22	0.21	197.78	188.79		

*FEV is fertilizer equivalence value and S&B is slash-and-burn.

following fire-induced changes in forest soils.

Contributions of ash and other pedological changes due to slash-and-burn agriculture to soil P and K availability are presented in Table 4.

After one year of slash-and-burn agriculture, P increases of between 0.46 and 7.98 kg/ha were still evident on farmers' fields. These values translated to between 1 and 18 kg P_2O $_5$ (mean of 9 kg P_2O_5) fertilizer equivalence. In the case of potassium, positive benefits were still evident in Akam-Messi (18 kg/ha) and Ndjana (63 kg/ha) but not in Ngoulemekong. The respective K fertilizer equivalence values were 22 kg K_2O and 76 kg K_2O (an average of 49 .K_2O). Considering the fact that adequate P_2O_5 and K_2O recommendations for the zone are 50 kg/ha P_2O_5 and 60 kg/ha K_2O (MINAGRI, 2000), slash-and burn agriculture contributes 18% of P requirement and 82% of K requirement of a second maize crop in the humid forest zone of Cameroon.

Fertilizer application is required to increase and sustain crop yields under slash-and-burn agriculture. Pypers et al. (2012) reported that NPK application in slash-and-burn or slashing and incorporation treatments in lowland humid tropics, increased cassava root yield by between 42 and 212% and had residual effects on a second cassava crop, increasing yields by 40 to 74%.

Conclusion

Slash-and-burn agriculture can affect soil physical and chemical characteristics in the humid forest zone of Cameroon. The most sensitive properties to slash-and-burn were coarse and fine silt, pH, OC, Ca, Mg, K, Na, ECEC, P and base saturation, even though most of the effects were only transient. Changes in exchangeable bases and P were drastic immediately after the fire but reduced after cropping for a year. Between 47 and 87% of increases recorded for exchangeable bases and P was lost after one year of cropping. In terms of mineral fertilizer equivalence values, the residual benefits of P and K after one year of cropping following slash-and-burn were 9 kg P_2O_5 and 49 kg K_2O. Slash-and-burn agriculture contributes 18% of P and 82% of K recommendations of a second maize crop. Cropping the same piece of land the third year will require that complete recommendation rates of P and K in addition to N are respected.

ACKNOWLEDGEMENT

The contributions of the anonymous reviewers are highly appreciated.

REFERENCES

Anderson JM, Ingram JSI (1998). Tropical Soil biology and fertility: A handbook of methods. CAB Int. UK. pp. 82-89.

Bremner JM (1982). Inorganic Nitrogen. In: Page AL, Miller RH, and Keeney DR (eds) Methods of Soil Analyses Part 2. 2nd Edition. Am. Soc. Agron. Madison USA. pp. 595-624.

Certini G (2005). Effects of fire on properties of forest soils: a review. Oecologia. 143:1-10.

Ekinci H (2006). Effect of forest fire on some physical, chemical and biological properties of soil in Canakkale, Turkey. Int. J. Agric. Biol. 8(1):102-106.

Ketterings QM, Wibowo TT, van Noordwijk M, Penot E (1999). Farmers' perspectives on slash-and-burn as a land clearing method for small-scale rubber producers in sepunggur, Jambi Province, Sumatra, Indonesia. Forest Ecol. Manage. 120:157-169.

Kopecky MJ, Meyers LN, Wasko W (2012). Using industrial wood ash as a soil amendment. A3635. University of Wisconsin-Extension, Cooperative Extension. P. 4.

Kotto-Same J, Moukam A, Njomgang R, Tiki-Manga T, Tonye J, Diaw C, Gockowski J, Hauser S, Weise S, Nwaga D, Zapfack L, Palm C, Woomer P, Andy Gillison, Bignell D, Tondoh J (2002). Alternatives to Slash-and-Burn Summary Report and Synthesis of Phase II in Cameroon. P. 72.

Kotto-same J, Woomer PL, Moukam A, Zapfack L (1997). Carbon dynamics in slash-and-burn agriculture and land use alternatives of the humid forest zone in Cameroon. Agric. Ecosystems Environ. 65:245-256.

MINAGRI (2000). Guide d'utilisation des engrais au Cameroun. Volume 1: Caracterisation des principales terres agricoles du Cameroun. P. 124.

Mroz GD, Jurgensen MF, Harvey AE, Larsen MJ (1980). Effects of fire on nitrogen in forest floor horizons. Soil Sci. Soc. Am. J. 44:395-400.

Nelson DW, Sommers LE (1982). Organic Carbon In: Page AL (ed) Methods of Soil Analysis, Part 2.. Agron. Monograph. 9. ASA, Madison, Wisconsin. USA. pp. 570-571.

Nigussie A, Kissi E (2011). Impact of biomass burning on selected physicochemical properties of Nitisol in Jimma zone, southwestern Ethiopia. Int. Res. J. Agric. Sci. Soil Sci. 1(9):394-401.

Oguntunde PG, Mathias F, Ayodele EA, Nick G (2004). Effects of charcoal production on mail yield, chemical properties and texture of soil. Biol. Fert. Soils 39:295-299.

Okalebo JR, Gathua KW, and Woomer PL (1993). Laboratory methods of plant and soil analysis: A working manual. TSBF Programme, Nairobi. Kenya. P. 88.

Oluwole FA, Sambo JM, Sikhalazo D (2008). Long-term effects of different burning frequencies on the dry savannah grassland in South Africa. Afr. J. Agric. Res. 3(2):147-153.

Pantami SA, Voncir N, Babaji GA, Mustapha S (2010). Effect of burning on soil chemical properties in the dry sub-humid savanna zone of Nigeria. Researcher. 2(7):78-83.

Pypers P, Bimponda W, Lodi-Lama JP, Lele B, Mulumba R, Kachaka C, Boeckx P, Merckx R, Vanlauwe B (2012). Combining Mineral Fertilizer and Green Manure for Increased, Profitable Cassava Production. Agron. J. 104(1):178-187.

Tchuenteu F, Schalk B (1988). Methods of the ekona laboratory for soil and plant, water and fertilizer analysis. Part 1. Routine methods for soil analysis. FAO/UNDP Soil resources Project CMR/83/004, Manual 3, version 3.1. Institute of agronomic research (IRA), Ekona, Cameroon. P. 85.

Tothova S (2012). The utilization of wood ash as fertilizer in Slovak forestry. ASH. P. 9.

Vagen TG, Lal R, Singh BR (2005). Soil Carbon sequestration in Sub-Saharan Africa: A Review. Land Degr. Dev. 16:53-71.

Van Reuler H, Janssen BH (1995). Comparison of fertilizer effects of ash from burn secondary vegetation and of mineral fertilizer on upland rice in South west Cote d'Ivoire. Nutr. Cycl. Agroecosys. 45:1-11.

Verma S, Jayakuma S (2012). Impact of forest fire on physical, chemical and biological properties of soil: A review. Proc. Int. Acad. Ecol. Environ. Sci. 2(3):168-176.

Walkley A, Black A (1934). An examination of Degtjareff Method of Determining Soil Organic Matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Yemefack M, Njomgang R, Nounamo L, Rossiter DG (2010). Quantified soil dynamics and spatial fragmentation within the shifting agricultural landscape in southern Cameroon. Proceedings 19th World congress of Soil Science, Soil Solutions for a Changing World, 1-6 August, 2010, Brisbane. Australia. pp. 138-141.