Available online at http://ajol.info/index.php/ijbcs

Int. J. Biol. Chem. Sci. 3(4): 796-803, August 2009

International Journal of Biological and Chemical Sciences

ISSN 1991-8631

Original Paper

http://indexmedicus.afro.who.int

Soil structure of an Oxisol as influenced by land use systems in the forest margin zone of Southern Cameroon

Tarcisius NYOBE [1], BIRANG A MADONG [1*], Nérée Awana ONGUENE [1], Victor AGOUME [1] and BIDZANGA NOMO [2]

[1] *Soil, Water and Atmosphere Department, Institute of Agricultural Research for Development (IRAD), P.O. Box 2067 Messa Yaoundé, Cameroon.*
[2] *Directorate of Scientific Research, IRAD.*
[*] *Corresponding author, Email: crbirang@yahoo.com; Tel: (237) 99 62 20 13, Fax: (237) 22 23 35 38 / 22 22 33 62*

ABSTRACT

Soil structure is the key for controlling soil quality. To assess changes in soil structure and its related indices under different land-use systems, an on-farm investigation was carried out on an Oxisol of Southern Province of Cameroon. Six land-use systems (LUS) consisting of a primary forest, a 30-year old secondary forest, a 25-year old cocoa field, a 15-year old natural fallow, a 3- year old *Chromolaena odorata* fallow and a 2-month old groundnut (*Arachis hypogea*) field were tested. Soil samples were collected at 0-5 and 5-10 cm depths and were used to determine particle size distribution (hydrometer method), bulk density and aggregate stability. Soil resistance to penetrometer was measured at the same depths in the field using a hand penetrometer. It was found that the primary forest and the cocoa field were associated with highest clay contents (74.6 and 52.0%, respectively) compared to other LUS. However, bulk density was significantly higher under cocoa field (1.09-1.26 $g.cm^{-3}$) as compared to primary forest (0.72-0.89 $g.cm^{-3}$). Soil resistance to penetrometer was the lowest under forests (1.2 - 5.2 bars) as compared to cropped fields (9 -12.5 bars) at 0-5 cm depth. Similar trend was observed at 5-10 cm depth. The proportion of aggregates less than 2 mm in diameter was the least under primary forest (27%) as compared to groundnut field (52%). In contrast, soil aggregates under primary forest and cocoa field were more stable, with the highest mean weight diameter (MWD) of 3.37 and 3.00 mm, respectively.

Keywords: Cameroon, humid forest, land use systems, Oxisol, soil structure, structural stability.

INTRODUCTION

Shifting cultivation and its related bush fallow are still utilized throughout the tropical rainforest belt. These systems allow a maximum cropping period of 2 to 3 years on the same land, after which period soil fertility declines. Fertility of the forest cleared by slash-and-burn can be restored if the land is allowed to revert to a fallow phase or with appropriate use of nutrient inputs. However a more general problem often occurs due to deterioration of soil physical conditions during the cropping period. This deterioration described as degradation of soil structure, is the most alarming issue of soil management for sustained productivity in the tropics.

Soil structure and its stability are the productive potential of a soil. When the soil structure collapses, all other productivity factors including water and fertilizer use are affected. Agboola (1994) reported that one of the keys to solving the problem of soil structure and its stability is to maintain soil organic matter (SOM) at a sufficient level.

The importance of organic matter content to the structural stability of soil aggregates has been widely investigated (Charney and Swift, 1984; Pojasok and Kay, 1990**;** Mclaren and Cameron, 1996). The main organic components that stabilize soil aggregates include organo-mineral complexes and root exudates. Besides organic matter effect on soil structure, biological activity has been reported as one the other important factor affecting the stability of soil aggregates (Molope, 1987; Arshad and Coen, 1992). In large areas of humid tropics earthworms are the most important soil-dwelling invertebrates. Organic matter in the forests of the humid tropics is tied up in the aboveground biomass rather than in the soil (Brussaard et al., 1993). As a result of deforestation or land clearing, the relatively small amount of organic matter in the soil is rapidly decomposing. Brussaard et al. (1993) reported that the disappearance of the organic food sources and the drastic changes in abiotic conditions often lead to the demise of soil fauna, resulting in the decline in structural properties of the soil. SOM and soil fauna management during the fallow phase contribute to restore soil structure. Environment, the age and type of land use control this restoration. For example, Morel and Quantin (1972) reported improved stable soil aggregates in an Alfisol under a 2-year old fallow. They attributed this positive effect of fallow to SOM restoration, to the influence of soil microflora and fauna. Investigations on the impact of land use systems on physical soil properties are mostly documented in Alfisols (Boli and Roose, 1999; Morel and Quantin, 1972). Such information is scanty in the humid forest where shifting cultivation is still in vogue (Yemefack and Nounamo, 1999). The objective of this study was therefore to evaluate the structural stability of different land use systems in an Oxisol of the humid forest of Southern Cameroon.

MATERIALS AND METHODS

Study site

The study was conducted in the rainforest zone at Akok (2° 44’ N and 11° 14’ E). This site is located at about 30 km from Ebolowa in the Southern Province of Cameroon. The region is characterized by a bimodal rainfall pattern separated by one dry spell from July to mid-August and one long dry-season (December-mid-March). The relief is gently sloping to sloping forming a peneplain foot slope mainly characterized by marshy areas. Land-use intensification throughout the area is low with shifting cultivation being the dominant farming system including a fallow period to restore soil fertility depleted during the cropping phase. Population density is low (<5 inhabitants/km^2). As a result, Akok is one of the rare sites still having the primary forest among the existing land uses. Mean annual diurnal soil temperatures range from 28 to 32 °C. Vegetation depends on the land use system. For example, *Chromolaena* (*Chromolaena odorata*) is the dominant weed species in young-aged fallows. This weed gradually disappears as new woody species invade the land, usually after five to seven years after its invasion. Being agriculturally less disturbed, soils of the area offer a very rich biodiversity. Most soils of the area are classified as Typic Kandiudox (USDA, 1986), with very deep profile.

Experimental design

On already established farmers’ fields, it was not possible to assign the treatments randomly as in a conventional experiment. In this on-farm experiment, six land-use systems were selected and considered as treatments, which included (i) a primary forest (Control), (ii) a 30-year old secondary forest, (iii) a 25-year old cocoa field, (iv) a 15-year old natural fallow, (v) a 3-year old *Chromolaena odorata* fallow and (vi) a 2-month old groundnut field. Each village was considered as a site that represented a replicate. One site consisted of at least five land-use systems or treatments. This was because primary forest was not encountered in every site. There were six replicates (villages). The size of the cropped field varied from 0.4 to 0.7 ha.

Soil sampling and laboratory procedures

In each land use system, a 5 m wide and 100 meter long transect was opened, except in Afub Ewondo where a 5 m wide and 50 m transect was considered. Soil sampling was carried out at 20-meter interval. This systematic soil sampling was used by the multi-disciplinary team, which dealt with soil physics, soil chemistry, soil fauna biodiversity (earthworm, termites, ants, etc.).

At each 20-meter interval within the transect, a 30 x 30 cm mini-pit of 30 cm depth was dug. Disturbed soil samples were vertically collected using a knife on the walls of the pits at 0-5 and 5-10 cm depth, air-dried, sieved at 2 mm (mesh diameter) and used for determining the soil particle distribution by hydrometer method (Bouyoucos, 1962).

Soil resistance to penetrometer was measured at the same depths using a hand penetrometer Eijkelkamp type. The cone (1 cm^2) was pushed at right angle into the ground at constant rate of 2 cm/sec. The same operation was done in at least six positions between 15 and 20 cm from the mini-pit to obtain representative readings that were then expressed in bars. At this particular rainy period, soil moisture was assumed constantly uniform (at field capacity).

Similarly, three 100 cm^3 soil cores were horizontally collected at the walls of the mini-pit at 0-5 and 5-10 cm and used to determine soil bulk density (Black, 1965).

Four to five undisturbed bulk soil samples were collected at 0-10 cm depth in each land use system. These samples were air-dried, and sieved through the 10 and 5 mm diameter sieves. Only aggregates that passed through the 10 mm diameter sieve but retained on the 5 mm diameter were used for the wet sieving (Yoder, 1936). The wet sieving device consisted of an electric motor connected to the main power supply and a cylinder, 40 cm high and 18.75 cm in diameter, where the nest of sieves (4, 2, 1, 0.250, 0.125 and 0.0625 mm diameter) containing the aggregate samples was placed. The cylinder was filled with water to the base of the topmost sieve, so that the sample was wet for 5 minutes before a 15-minute vertically mechanical shaking. At the end of this exercise, soil aggregates retained on each individual sieve were carefully removed and placed into a moisture can for oven drying at 105 °C. Dry samples were weighed, the aggregate size distribution determined and the mean weighted diameter (MWD [mm]) of the aggregate calculated by:

$$MWD = \sum_{i=1}^{n} X_i W_i$$

With X_i being the mean diameter [mm] of any particular size range of aggregates; W_i the fraction of the aggregates at that range.

Another set of 30 soil aggregates were collected from the same 5 mm diameter sieve weighed and used to test the raindrop impact (Farres, 1980) with a single drop rainfall simulator placed at 150 cm fall height. The drop size was approximately 3 mm in diameter with a velocity of 5.2 m/sec. Fifty drops of water were successively dropped over each individual aggregate placed on a 4-mm sieve. Depending on the resistance associated with each aggregate, the latter was stable or reduced to primary particles through impacting force of successive water drops. When the whole aggregate was not destroyed, the portion remaining on the 4 mm sieve was collected, oven-dried and weighed. Result was expressed as the percentage of stable aggregates (SA [%]) as follows:

$$\% SA = \frac{\text{Total weight of stable aggregates after droptest impact}}{\text{Total weight of aggregates before droptest impact}} \times 100$$

Because all LUS were seldom encountered in each replicate, the analysis of variance was performed using the General Linear Model (GLM) of the Statistical Analysis System (SAS, 1999). The Duncan Multiple Range Test (DMRT) was used to separate the means where the differences were significant at 5% level of probability.

RESULTS

Particle size distribution (PSD)

At 0-5 cm depth, the data indicated that primary forest was associated with significantly highest clay content, lowest sand and silt contents compared to old fallow (Table 1). On the contrary highest sand, lowest clay and highest silt contents were found under old fallow and secondary forest, respectively. Variations in PSD were not substantial among other LUS.

Bulk density

The respective bulk density values ranged from 0.72 to 1.09 and from 0.89 to 1.26 $g.cm^{-3}$ (Table 2). These values increased with soil depths although the trend of variations among LUS was similar from one depth to another. Highest bulk density was found under cocoa field. Primary forest invariably exhibited lowest bulk density, which was not different from that of secondary forest. Also, bulk density between primary and secondary forests was similar and invariably the lowest as compared to that of other land-use systems. The differences in bulk density between *Chromolaena* fallow, groundnut field and 15-year old fallow were not statistically significant.

Soil resistance to penetrometer

Similar to bulk density values, soil resistance to penetrometer was the lowest under forests compared to cropped or fallowed land use systems, with highest value in cocoa field (Table 2). Generally, soil resistance to penetration was similar among the 3-year old *Chromolaena* fallow and cropped fields at both sampled depths. Also differences in soil resistance to penetrometer between the 15-year old natural fallow and both primary and secondary forests were not significant.

Aggregate size distribution and mean weight diameter

Primary forest had the lowest proportion of aggregates less than 2 mm as compared to the other land-use systems (Table 3). However, this proportion did not differ significantly between primary forest and cocoa field. The same held true between groundnut field, *Chromolaena* fallow and 15-year old natural fallow and between secondary forest, cocoa field, *Chromolaena* fallow and 15-year old natural fallow.

Mean weighted diameter (MWD) varied between 2.3 and 3.4 mm (Table 3). The data showed a significantly highest MWD in primary forest as compared to groundnut field. Also, MWD in cocoa field was significantly higher than in groundnut field or *Chromolaena* fallow. However no significant differences could be found between primary forest and cocoa field, or between cocoa field, secondary forest and 15-year old natural fallow, or between *Chromolaena* fallow and groundnut field.

Raindrop impact

The percentage of stable aggregates after impacting raindrops was significantly higher under primary forest than in groundnut field, 15-year old natural fallow and *Chromolaena* fallow (Table 4). However, there was no significant difference in stable aggregates between primary forest, secondary forest and cocoa field, or among 15-year old fallow, *Chromolaena* fallow and groundnut field whose percentage was significantly lower than that of secondary forest and cocoa field.

Table 1: Variation of soil particle size distribution (%) among the land use systems.

	0-5 cm depth			5-10 cm depth		
	Sand (%)	**Silt (%)**	**Clay (%)**	**Sand (%)**	**Silt (%)**	**Clay (%)**
3-year old Chromolaena fallow	47.5^{b}	8.1^{ab}	44.4^{b}	39.6^{ab}	6.5^{b}	53.8^{bc}
25-year old Cocoa field	45.9^{b}	10.1^{a}	52.0^{b}	35.5^{c}	6.5^{b}	58.0^{b}
2-month old Groundnut field	44.7^{b}	8.6^{ab}	46.7^{b}	37.9^{bc}	6.9^{b}	55.1^{bc}
15-year old natural fallow	56.5^{a}	9.7^{ab}	33.3^{b}	43.6^{a}	7.4^{ab}	48.9^{d}
Primary forest (Control)	19.3^{c}	6.1^{e}	74.6^{a}	14.1^{d}	5.1^{e}	80.8^{a}
30-year old Secondary forest	42.5^{b}	10.1^{a}	47.4^{b}	$39.7a^{b}$	8.3^{a}	51.9^{cd}
C.V. (%)	***9.3***	***14.2***	***8.0***	***8.2***	***13.3***	***5.6***

Values are average of six replications. Any two means followed by the same letter are not significantly different within the columns at the 5% level of the Duncan's new multiple range test.

Table 2: Bulk density (BD) and penetrometer resistance (PR) as affected by six land use systems.

	Soil properties (0-5 cm)		**5-10 cm**	
	BD(g cm^{-3})	**PR(bars)**	**BD(g cm^{-3})**	**PR(bars)**
3-year old *Chromolaena* fallow	1.06^{a}	10.0^{a}	1.14^{a}	11.0^{ab}
25-year old Cocoa field	1.09^{a}	12.5^{a}	1.26^{a}	14.7^{a}
2-month old Groundnut field	1.04^{a}	9.0^{ab}	1.20^{a}	12.0^{a}
15-year old natural fallow	0.98^{a}	5.2^{bc}	1.19^{a}	6.2^{bc}
Primary forest (Control)	0.72^{b}	1.2^{c}	0.89^{b}	4.0^{c}
30-year old Secondary forest	0.74^{b}	3.7^{c}	0.91^{b}	6.0^{c}
C.V. (%)	***9.7***	***41.1***	***7.6***	***35.8***

Values are average of six replications. Any two means followed by the same letter are not significantly different within the columns at the 5% level of the Duncan's new multiple range test.

Table 3: Aggregate size distribution and mean weight diameter as affected by six land use systems.

Land-use systems	**Aggregates < 2 mm in diameter (%)**	**Mean weighted diameter (mm)**
3-year old *Chromolaena* fallow	51^{ab}	2.43^{cd}
25-year old Cocoa field	34^{cd}	3.00^{ab}
2-month old Groundnut field	52^{a}	2.30^{d}
15-year old natural fallow	43^{ab}	2.77^{bc}
Primary forest (Control)	27^{d}	3.37^{a}
30-year old Secondary forest	42^{bc}	2.80^{bc}
C.V. (%)	***11.7***	***7.6***

Values are average of six replications. Any two means followed by the same letter are not significantly different within the columns at the 5% level of the Duncan's new multiple range test.

DISCUSSION

The clearance of the forest followed by cultivation results in a series of changes in the soil. The results of this study show highest clay content at both sampled depths under primary forest (control) compared to 15-year old fallow [which in turn had highest sand content]. These results confirm earlier findings in the region (Moukam et al., 1999). High clay content could be attributed to biotic interference, mostly earthworms resulting in the transport of clay particles from the subsoil to the surface through their channels.

Adequate soil organic matter under primary forest implied a favourable environment where biodiversity (earthworm, termites ants, etc.) were well integrated making the topsoil fairly porous due to the numerous channels this macrofauna introduced in the soil. As a result, topsoil was less compacted under primary forest than cocoa field. In a related study in the same sites, Birang (2004) found higher earthworm, termite and ant richness and abundance in secondary forest than in cocoa field. Conversely, 15-year old natural fallow, in turn, had highest sand content. High compaction under cocoa field might be attributed to foot traffic during slash, harvest and phytosanitary treatments. Moukam and Kotto-Same (1995) and Moukam et al. (1999) reported similar results under primary forest and cocoa field.

Although the primary forest differed significantly from the cocoa field in terms of soil compaction, both developed stable aggregates owing to high clay content and organic matter associated with these land uses, but mostly to greater earthworm activity under these land use systems**.** This above result confirmed previous findings of Aweto (1988). The amount and quality of soil organic matter (SOM) affect structural stability. Previous authors reported that **t**he main components that stabilize soil aggregates include organo-mineral complexes, polysaccharides and root exudates (Lal and Kang, 1982; Molope, 1987). These compounds probably contributed to bind the soil particles together into micro and macro-aggregates. These aggregates were better developed in the presence of high clay content as found under primary forest and cocoa field. Arshad and Coen (1992) reported the amount of clay as one of the other important factors that affect stability of soil aggregates. In contrast to these land use systems, the two-month-old groundnut field had lowest MWD, owing to soil disturbance and the gradual decomposition of organic matter. As a result, highest proportion of aggregates less than 2 mm in diameter was found under this cropped field compared to other LUS. The practical implication of such land use was its high susceptibility to erosion hazard if no soil conservation strategy was previously defined.

Moreover, with the droptest, the least proportion of stable aggregates resistant to water impact was observed under two-month old groundnut field. This may be attributed to soil structure breakdown during land preparation (hoeing) as a result of mechanical manipulation and subsequent organic matter mineralisation. According to Tulaphitak et al. (1985), soil surface during the first two months after clearing and burning is more prone to rapid breakdown of soil structure because aggregates are exposed and soil organic matter is decreasing owing to high mineralisation and less faunal activity. However, stable aggregates after wet sieving and droptest showed higher values under cocoa, primary and secondary forests probably due to high biotic activities under these land use systems as compared to others. In contrast, Yemefack and Nounamo (1999) found no significant difference in stable aggregates between 15-year old natural fallow and secondary forest.

Table 4: Effect of impacting water drops on aggregate stability.

Land-use systems	**Number of stable aggregates after test (%)**
3-year old *Chromolaena* fallow	33^{b}
25-year old cocoa field	49^{a}
2-month old groundnut field	21^{c}
15-year old natural fallow	24^{bc}
Primary forest (Control)	55^{a}
30-year old Secondary forest	52^{a}
C.V. (%)	***12.8***

Values are average of six replications. Any two means followed by the same letter are not significantly different within the columns at the 5% level of the Duncan's new multiple range test.

Conclusion

Soil stable aggregates were best defined under primary and secondary forests, and cocoa field. Except under cocoa field, bulk density and soil resistance to penetrometer were minimal under primary and secondary forest. The detrimental effects to soil structure held mostly in the 2-year groundnut field, although of limited importance under 15-year old natural fallow and 3-year old *Chromolaena* fallow. The other land use systems (primary forest exclusive) were in their recovery process.

ACKNOWLEDGEMENTS

The authors are grateful to IRAD who provided laboratory facilities and allowed the corresponding author to undertake this research Centre. The financial support was granted by WOTRO (The Netherlands) through its Priority Programme on Biodiversity in Disturbed Ecosystem.

REFERENCES

Agboola AA. 1994. A recipe for continuous arable crop production in the forest zone of western Nigeria. In *Alternatives to Slash-and-burn Agriculture*, Sanchez BA, van Hauten H (eds). 15th International Soil Science Congress: Acapulco, Mexico; 107-120.

Arshad MA, Coen GM. 1992. Characterization of soil quality: physical and chemical criteria. *American Journal of Alternative Agriculture*, **7**(1 and 2): 25-47.

Aweto AO. 1988. Effects of shifting cultivation on tropical rainforest soil in southern Nigeria. *Turrialba*, **38**(1): 19-22.

Birang AM. 2004. Soil macrofauna community structure along a gradient of land use intensification in the humid Forest of Southern Cameroon. *Tropical Resource Management Papers*, **56**.

Blake, G.R. 1965. Bulk density. In *Methods of Soil Analysis, Part I*, Black CA, Evans DD, Ensminger LE, White JL, Clark FE (eds). Agronomy Monograph 9. ASA, Madison, WI; 383-390.

Boli Z, Roose E. 1999. Rôle de la jachère en savane soudanienne humide du Nord-Cameroun. In *La Jachère en Afrique Tropicale, Rôles, Aménagement, Alternatives*. Actes du Séminaire International, 13-16 avril 1999, Dakar, Sénégal, **1**: 149-154.

Bouyoucos GJ. 1962. Hydrometer method improved for making particle size analysis of soils. *Agron. J.*, **54**: 464-465.

Brussaard L, Hauser S, Tian G. 1993. Soil faunal activity in relation to the sustainability of agricultural systems in the humid tropics. In S*oil Organic Matter Dynamics and Sustainability of Tropical Agriculture*, Mulongoy K, Merckx R (eds). Proceedings of an International Symposium organized by the Laboratory of Soil Fertility and Biology, Katholiete Universiteit Leuven (K.U. Leuven) and the International Institute of Tropical Agriculture (IITA) and held on 4-6 November 1991, in Leuven, Belgium; 241-256.

Charney K, Swift RS. 1984. The influence of organic matter on aggregate stability in some British soils. *Journal of Soil Science*, **35**: 223-230.

Farres PJ, Portsmouth. 1980. Some observations on the stability of soil aggregates to raindrop impact. *Catena*, **7**: 223-231.

Lal R, Kang BT. 1982. Management of organic matter in soils of the tropics and subtropics. In *Non-symbiotic Nitrogen Fixation and Organic Matter in the Tropics*, Lal R (ed). Symposia papers, 12th International Congress of Soil Science: New Dehli, India; 152-178.

Mclaren RG, Cameron KC. 1996. *Sustainable Production and Environment Protection* (New edn). Oxford University Press: Oxford.

Molope MB. 1987. Soil aggregate stability: the contribution of biological and physical processes. *S. African J. Plant Soil.*, **4**: 121 – 126.

Morel R, Quantin P. 1972. Observation sur l'évolution à long terme de la fertilité des sols cultivés à Grimari (Rép. Centrafricaine). *Agron. Trop.*, **XXVIL**(6): 667-739.

Moukam A, Samé JK, Woomer PL. 1999. Carbon and nutrient dynamics in a transect of land uses in the humid forest zone of Cameroon. In *La Jachère en Afrique tropicale, Rôles, Aménagement, Alternatives*, Floret CH, Pontanier R (eds). Actes du Séminaire International, 13-16 avril 1999. Dakar, Sénégal ; **1**: 229-235.

Moukam A, Kotto-Samé J. 1995. Carbon and nutrient dynamics of shifting cultivation system in the humid forest zone of Cameroon. Annual Technical Report, C. R. A., Nkolbisson; 14.

Pojasok T, Kay BD. 1990. Assessment of a combination of wet sieving and turbidimetry to characterize the structural stability of moist aggregates. *Canadian J. Soil Sc.*, **70**: 33-42.

SAS. 1999. *The SAS System*. Versiom 8 for windowa. SAS Institute Inc.: Nashville Enabled. Cary. NY.

Tulaphitak T, Kyuma K, Pairintra C. 1985. Changes in soil fertility and tilth under shifting cultivation. III. Soil respiration and soil tilth. *Soil Sci. Plant Nutr.*, **31**: 251-261.

USDA. 1986. Amendments to Soil Taxonomy. Oart 615 (430-VI-NSTH). INCOMLAC. Soil. Conservation Service, Washington, DC.

Yemefack M, Nounamo L. 1999. Dynamique des sols et durée optimale des jachères agricoles au Sud-Cameroun. In *La Jachère en Afrique Tropicale, Rôles, Aménagement, Alternatives*, Floret CH, Pontanier R (eds). Actes du Séminaire International, 13-16 avril 1999 Dakar, Sénégal, **1**: 135-141.

Yoder RE. 1936. A direct method of aggregate analysis of soils and study of the physical nature of erosion losses. *J. Am. Soc. Agron*., **28**: 337-351.