Research Article

IMPACT OF AGRICULTURAL PRACTICES ON SOIL ORGANIC CARBON STOCK IN THE FOREKE-DSCHANG ESCARPMENT (CAMEROON WESTERN HIGHLANDS)

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Abstract

The soils of the Foreke-Dschang escarpment are very fragile and prone to erosion and landslides. These soils are under intense demographic pressure with the heavy conversion of forest into agroforestry systems. This work aims to highlight both the positive and negative effects of agricultural practices on the soil organic carbon stock (SOCS) of the Dschang-Foreke escarpment and to propose suitable conservation measures. Soil samples were taken from different agroforestry systems and analysed in the laboratory for physic-chemical characteristics by standard procedures. The main results revealed that the organic matter content is higher (2.45±1.70%) in the foot slope (BP) than in the upslope (SP) (2.16±0.78%), midslope (MP) (1.85±0.45%), upslope forest soils (PFCS) (1.58±0.18%) and Disturbed soil samples for midslopeforest soils (PFCM) (1.20±0.90%). The SOCS in agroforestry soils are higher in BP (42.55±6.13 t/ha) than in MP (21.02±5.48 t/ha) and SP (2.15±1.39 t/ha) as well as the C/N ratio (18.45, 11.12 and 1.91). BP soils have relatively higher humin (6.57±4.60% DM) and C/N ratio (18.45), but lowerfulvic acid-to-humic acid (AF/AH) ratio (0.38) and low soil structural instability index (SI) (1.76±0.56). This might justify the structural stability of soils in this topographic position. In forest zones, although the SOCS is higher at the top (33.16±5.79t/ha) than in MP (19.70±6.76t/ha) as well as the C/ N ratio (20.03 and 8.72). Forest soils in MP were structurally more stable thanks to their low AF/AH ratio (0.58) and low structural instability index (6.07±1.87t/ha). Only the reconversion of the forest into lowland crop plots would have better stored carbon. To improve the structural stability of soils in MP and SP, the contribution of compost or biochar and poultry manure is strongly recommended.

Keywords:Agricultural practise, organic matter fractionation; soil conservation; SOCS; Foreke-Dschang escarpment; Cameroon Western Highlands.

INTRODUCTION

The Foreke-Dschang escarpment is marked by very rugged landscapes with steep slopes and an altitudinal difference of about 700 m between Dschang and Santchou (Fotsing, 1999). The soils are very fragile due tohigh topography that favours erosion and landslides during heavy rains. This area is highly stressed with strong conversion of forest into agroforestry systems. This is attributed to demographic pressure (451 inhabitants/km²) on land within the Dschang City (BUCREP, 2010). Dueto the precariousness of jobs in large cities (Douala and Yaoundé),rural migration and demographic explosion (3.2% growth rate)has contributed to rapid colonization of this area where crops such as coffee, cocoa and food crops are grown (BUCREP, 2010). The combined effect of rudimentary farming practices, high rainfall, relief and soil type (thin profiles) has promoted water erosion, leading to soil degradation and a decline in agricultural production potential (Djoukeng, 2016). Agroforestry systems, by storing carbon in plant tissues and soils, contribute to reducing the concentration of greenhouse gases in the atmosphere and sustainably improve soil health (Temgoua et al., 2014; Djoukeng, 2016). Although agricultural practices can degrade soils, improved management practices are alsoknown tocontribute to soil health and sustainability. This work aims to highlight both the positive and negative effects of agriculture on the soils of the Foreke-Dschang escarpment and propose the most appropriate conservation management jpoment methods.

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MATERIALS AND METHODS

Study site

The Foreke-Dschang escarpment is located atabout 10 km southwest of the city of Dschang. It has an altitudinal difference of 700 m between the city of Dschang (1400 m) and Santchou (700 m). The climate of the area is generally temperate by altitude and depends on a unit of factors which are linked to relief, exposure to major atmospheric currents and its geographical position and distance from the sea (Aboubakar et al., 2013). Annual precipitation is abundant (1400 mm ≤ Pmoy ≤ 2500 mm) with peaks between July and October, decreasing from south to north while increasing in the vicinity of the mountain ranges. The drainage network is linked to the morphology of the region (Aboubakar et al., 2013). The forest and woody savannah vegetation is heavily anthropogenisedby a predominantly agricultural population (Moundjeu, 2022). The geomorphology, the geological nature and age of the formations, as well as tectonic activityof the regioncombine with climatic conditions and sometimes anthropogenic activitiesto put the area at high risk of mass movement (Aboubakar, 2010). Throughout the escarpment, scars of old land movements and signs of aborted or ongoing movements are observed (Aboubakar et al., 2013).The soils of the of the area are classified into four categories (Moundjeu , 2022): poorly differentiated soils (or lithosols, developed on the crystalline basement, observed at the top of the interfluves and on very steep slopes); very desaturated arid ferrallitic soils on basement (develop on slopes less than 13% and at the foot of steep slopes), moderately desaturated ferrallitic soils on

volcanic rocks (observed on the slopes of the interfluves) and more or less saturated lowland soils (most often hydromorphic soils, more or less humiferous, located at the footslopes and strongly influenced by water table).Geologically, there is a Pan-African granito-gneissic basement underlain by Tertiary to present volcanic rocks (rhyolitic and trachytic basaltic flows and basaltic and ignimbritic projections) (Aboubakar *et al.,* 2013).The main activity of the inhabitants is agriculture, especially intensive agriculture. In this region most farmers practice mixed cropping of Arabica coffee, plantains, banana, beans, maize, cassava, etc.
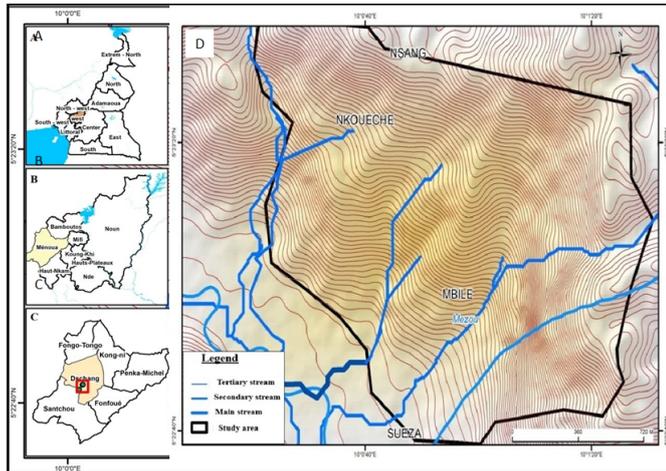

Figure 1. Location map of the study area (A) in Cameroon, (B) in the West region, (C) in the Menoua department. (D) Topographic map of the site

METHODOLOGY

Fieldwork and sample collection: This was to enable to have an overview of the evolution of SOCS based on land occupation type and toposequence as well as the influence of these two factorson the soil stability in the different studied plots. Disturbed soil samples for cocoa-coffee agroforests based at the footslope (BP), midslope (MP) for cocoa-based agroforests and upslope (SP) for coffee-based agroforests; Disturbed soil samples for midslope (PFCM) and upslope (PFCS) forests were collected with three replicates for physical and chemical analyses within the profile depths of 0-10 cm, 10-20 cm, 20-30 cm, 30-50 cm, 50-80 cm and 80-100 cm.

Laboratory analysis: These analysis concerned bulk density (Da), organic carbon (OC) and total nitrogen (N) contained in the soils of the study area, determined following the methods recommended by Pauwels et al. (1992) and respecting ISO and AFNOR standards in the Research Unit for Soil Analysis and Environmental Chemistry at the University of Dschang (Cameroon). Thus, total nitrogen was dosed by the Kjeldahl method while organic carbon was determined by the Walkley and Black method (1934). The organic matter was estimated from OC by the Sprengel coefficient (Sprengel, 1886):

$$\% \ OM = \% \ SOC \times 1.724 \qquad \dots\dots\dots\dots\dots\dots\dots\dots(1)$$

For each profile depth, SOCS were calculated according to Penman et al. (2003):

$$SOCS = Da \ x \ 10 \ x \ (1 - EG) \ x \ SOC \ x \ Eh \qquad \dots\dots\dots\dots(2)$$

Where, SOCS(tC/ha); Da: bulk density (g/dm^3); EG: coarse fragments of soil (>2 mm diameter)(%);SOC = Soil organic carbon content (g/kg); E_h: soil layer thickness (m).

The totalSOCSof the profile was determined by the summation of the SOCS of the different depths. The stability index (Is) was determined by the following formula of Lal (1994):

$$Is = \frac{1.724 OC}{Silt+clay} x100, 0\leq IS<\infty\dots\dots\dots\dots\dots\dots\dots\dots(3)$$

Where, IS:stability index; OC: organic carbon content (%).

The characterization soil OM was based on Dabin (1976)'s method.

RESULTS

Variation of soil properties and SOCS with topographic position and agricultural practise

The main results showed that, based on topographic position, Soil OM was 2.45±1.70% in BP, 1.85±0.45% in MP, 2.16±0.78 in SP, 1.58±0.18% in PFCS and 1.20±0.90% in PFCM**.**Table 2 shows that average SOCS for agroforest in SP is 2.15 ± 1.39 t/ha, followed by MP (21.02 ± 5.48 t/ha).

Table 1. Selected physico-chemical characteristics of soils based on topographic position and forests

Code	BP	MP	SP	PFCS	PFCM
OC%	1.42 ±0.71	1.08±0.67	1.25±0.94	0.92±0.05	0.697±0.524
OM%	2.45 ±1.70	1.85±0.45	2.16±0.78	1.58±0.18	1.20±0.90
N(g/kg)	0.54 ±0.11	0.89±0.07	1.09±0.90	0.70±0.04	0.09±0.04
C/N	18.45	11,12	1.91	20.03	8.72
Da(g/cm3)	1.12±0.06	1.17±0.02	0.72±0.02	1.24±0.08	1.20±0.13

Key:OC: organic carbon; OM: Organic matter; N: Nitrogen; C/N Ratio:carbon-to-nitrogen ratio; Footslope (BP), Midslope (MP);Upslope(SP); PFCM: Midslope forests; PFCS: Upslopeforests.

Table 2. Average SOCS and C/N ratio as a function oftopographic position

Sample code	SOCS (tC /ha)	C/N
P$_{Sp}$	2.15±1.39	1.91
P$_{Mp}$	21.02±5.48	11,12
P$_{Bp}$	42.55±6.13	18.45
PFCS	33.16±5.79	20.03
PFCM	19.70±6.76	8.72

Key:P$_{Sp}$:upslope soil; PMp; midslope soil; P$_{Bp}$; Footslope soil; PFCS:upslope forest; PFCM: Midslope forest; SOCS : Soil organic carbon stock (tC/ha); C/N ratio: Carbon-to- nitrogen ratio.

Table 3.Humus fractions inthe studied soils

Different fractions	BP	MP	SP	PFCM	PFCS
FA%MS	2.87±1.86	1.36±0.43	1.93±0.31	1.56±0.34	2.01±1.22
HA% MS	6.12±4.25	2.55±0.60	1.17±0.15	2.65±1.02	1.38±1.01
H% MS	6.57±4.60	2.61±0.86	1.96±1.24	2.70±1.10	2.11±1.21
HM% MS	6.80±4.02	3.91±0.27	3.80±1.16	3.98±1.04	4.01±1.98
TC% MS	7.28±0.31	6.52±0.97	5.77±1.51	6.60±2.12	5.90±2.24
N% MS	0.95±0.03	1.62± 0.27	2.45±0.11	1.70±0.87	1.98±1.07
CT/N	8.66	4.02	2.35	3.88	2.97
AH/H	0.93	0.97	0.60	0.98	0.65
MH/H	1.35	1.76	20	1.47	1.90
FA/HA	0.38	0.70	1.65	0.58	1.46
H*100/CT	90	38	32	41	36
MH*100/TC	54	61	67	60	68
SI	1.71±0.56	6.41±0.52	8.56±0.52	6.07±1.87	8.10±2.45

FA: Fulvic acids; HA: Humic acids; H: Humin; TC: Total carbon; HM: Humus; SI: Instability index; MS: Dry matter.

Finally in BP, the average SOCS is 42.55 ± 6.13 t/ha (the highest). The forests have the SOCS of 33.16 ± 5.79 tC /ha and 19.70 ± 6.76 tC/ha at SP and MPrespectively. The C/N ratio at PFCS is 1.91 followed by that of the forests (8.72) and the agroforest (11.12) of MP, at the BP,C/N ratio is 18.45 for the agroforest, finally the upslope forests have the highest ratio (C/N: 20.03).

Variation of humusfractions with topographic position and agricultural practise

The results of organic matter fractionation are compiled in table 3. Fluvic acid (FA) is 2.87±1.86% in MP, 1.36±0.43% in MP and in SP, and 1.17±0.15% for the agroforest. In SP,FA is 1.56±0.34% and 1.38±1.01% in MP for the forest. Humic acid (HA) in BP is 6.12±4.25%, in MP is 2.55±0.60% and in SP is 1.93±0.31% for the agroforest and 2.01±1.22% in MP and SP is 2.65±1.02% for the forest. In BP, humin (H) is 6.57±4.60%; in MP, it is 2.61±0.86%; in SP, it is 1.96±1.24% for the agroforest. Humin stands at 2.11±1.21% in SP and in MP, and 2.70±1.10% for the forest. The FA/HA ratio in the BP is 0.38 in MP and SP 0.70 and 1.65 for the agroforest area. In MP and SP, FA/HA ratio is 1.46 and 0.68 for the forest respectively. The instability index in BP, MP and HP is respectively 1.71±0.56, 6.41±0.52 and 8.56±0.52 for the agroforest and 6.07±1.87 and 8.10±2.45 for the forest, in MP and SP respectively.

DISCUSSION

The highest SOCS was obtained in BP plantations and the lowest stock in SP plantations. This might mean that erosion at the top of the slope and soil management method in BP is be at the origin of the increase in organic carbon in the soil in BP. Moundjeu (2022) showed that the spatial variation in SOCS is mainly due to the types of cropping systems and topography. The results obtained confirm the role of the topography as more anthropogenized land management methods (plantations) lead to SOCS decreases with altitude. The SOCS in this study follows the hypsometric gradient of the management methods. These results corroborate those obtained by Atchada *et al.*(2018). In addition, the erosion and drainage observed along the toposequence might have facilitated the transport of soil organic carbon from the top of the slope to its accumulation at the bottom of the slope. Drainage is an important factor to consider since it influences carbon sequestration capacity with the largest stocks in the areas with very poor drainage (Atchada *et al.,* 2018). Similar results have been reported by by Callesen *et al.* (2003). In view of the SOCS obtained in the different management systems,

It is worth noting that the only possible reconversion could be that of the forest into cropland at the bottom of the slope because of its higher SOCS relative to the upslope and mid slope forests. The difference between the SOCS observed along the toposequence can also be linked to farming practices and the diversity of woody species which are not necessarily the same in the three topographicpositions. These results are in agreement with those of Youssié (2019).

The role of organic matter in the formation and stabilization of aggregates, although recognized, is still poorly understood. Significant relationships between soil organic matter content and structural stability have been highlighted (Le Bissonnais and Arrouays, 1997; Bronnick and LaI, 2005). According to the hierarchical model of Tisdall and Oades (1982), the type of soil organic matter involved in aggregation might vary according to the size of the aggregates (micro-aggregates or macro-aggregates) ranging from humic substances at fine scale to coarse microbial structures at millimeter scale. This model agrees with field observations, especially as it is mainly macro-aggregates that vary rapidly with changes in cropping systems. In BP, organic matter appears to be relatively immobile and inaccessible to biodegradation (high C/N and low FA/HA). The high C/N ratio indicates that carbon mineralization occurs slowly. However, the humus produced under such conditions is very stable (Moundjeu, 2022). The instability index of BP is low (1.71±0.56) (Lal, 1994). Mineralization is slow, the low FA/HA ratio and the instability index could justify the good structural stability of this part of the study area. The high humin content is important to resist erosion and downstream carbon transport. These results corroborate those found by Dabin (1970).

In MP and SP, there is complete humification with good biological activity (low C/N and high FA/HA ratio). The high FA/HA ratio indicates a high structural instability of the soil which would be manifested by the decrease of humin. This decrease corresponds to an increase of the fulvic acid concentration (Dabin, 1970). The structural instability index is high in SP and medium in MP (Lal, 1994). The low C/N ratio, the high FA/HA ratio ratio and the high structural instability index could justify the structural instability in SP and MP. Similar results have been documented by Dabin (1970).The C/N ratios in SP (1.91) and forest in MP (8.72) indicate complete humification with good biological activity. These soils might be degraded because they lose a significant amount of carbon, hence the net decrease in C/Nratio. This can be confirmed by the high FA/HA ratio in MP and SP. Fulvic acids, being the dominant fraction, are potentially more easily biodegradable than humic acids according to Dabin (1970).

The moderate C/N ratio (11.12) of MP might imply that organic matter incorporated into the soil has remained abundant, hence its C/N ratio remains close to 14. The soils of BP have a C/N ratio of 18.45 and those of the SP forests have the highest C/N ratio (20.03). These high ratios in BP and in the slope top forests (PFCS) are unfavorable for organic matter biodegradation. The FA/HA ratio is low and allows the soils to resist degradation thanks to all the forms of humin found in the organic matter. These results agree with those of Dabin (1970). The management methods in MP and SP allow biodegradation of organic matter because of the low C/N ratio. This could have a negative impact on the structure of these soils. In BP, organic matter is not accessible to biodegradation, so mineralization is blocked and humin content is high. This could justify the good structural stability of the soils. Sustainable management of this area is complex in terms of soil mechanics. The stability of soil organic matter has led to structural instability in SP and MP in the study area. The contribution of compost or biochar and poultry manure, which seems more stable, could provide cohesion between the mineral fractions of the soil, good water infiltration through the improvement of pores and good soil aeration.

Conclusion

The objective of this study was to highlight the positive and negative effects of agricultural practises on SOCS and to propose the most suitable soil conservation methods. It appears from this study that the midslope and upslope soil management methods promote the structural instability of soils due to the rapid biodegradation of their organic matter. Only footslope management methods are suitable because they allow better storage of carbon which could improve the physical and chemical properties of soils. In addition, the organic matter of the footslope soils is not accessible to biodegradation because of the high level of humic acid and humin which contribute to good structural stability of these soils. The addition of compost or biochar and poultry manure to MP and SP soils can be recommended to improve their structural stability in the cocoa-coffee crop association.

Abbreviations

FA:Fulvic acids
PFCS: Upslope forest
OC: organic carbon
HA: Humic acids
PFCM: Midslope forest
OM: organic matter
H: Humin
SI: Instability index
N: Nitrogen
BP: Foot slopesoil
MS: Dry matter
C/N ratio: carbon-to-nitrogen ratio
MP: Mid slope soil
TC: Total carbon
SP: Upslope soil
SOC: Soil organic carbon content

Conflicts of interest: The authors declare that there is no conflict of interest.

REFERENCES

Aboubakar, B. 2010. Etude géologique et géotechnique des mouvements des masses dans les hautes terres de l'Ouest Cameron : cas des sites de Lepoh et Nteingue (département de la Menoua) et de Tchouaffé (département du Haut-Nkam). These master, Univ. Dschang. 130 p.

Aboubakar B., KagouDongmo A., Nkouathio1 DG &Ngapgue F. (2013). Ground instabilities in the highlands of western Cameroon: geological and geotechnical characterization of the Kekem landslide. *Bulletin of the Scientific Institute,* Rabat, Earth Sciences Section, No. 35, 39–51.

ATCHADA C.C, A.G. Zoffoun, T. M. Akplo, A H. A, Agoussou, B Tente et J .G, Djego 2018. Modes d'utilisation des terres et stock de carbone organiques du sol dans le bassin supérieur de Magou au Benin. *International Journal of Biological and chemical Sciences,* 12(6);2818-2829.

Bureau Central des Recensements et des Etudes de Population. 2010. Yaoundé Cameroun.

Callesen, I., J., Liski, K.,Raulund-Rasmussen, M.T., Olsson, L.,Tau-Strand, L.,Vesterdal., C.J., Westman, 2003. Soil carbon stores in Nordic Well-drained forest Soils - relationships with climate and texture class. *Glob. Change Biol.* 9,358-370. Doi:10.1046/J.1365-2486.2003.00587.X

Champaud. 1973. Atlas régional de l'ouest II. Document O.R.S.T.O.M. 74 P.

Dabin, B., et C. Thomann. 1970. Étude comparative de deux méthodes de fractionnement des composés humiques (Méthode Tiurin et méthode èlectrophorétique.) O.RS.T.O.M., 1970. Initiation/Documentation Technique no 16.

Dabin, B. 1976.Méthode d'extraction et de fractionnement des matières humiques du Sol. Application il quelques études pédologiques et agronomiques dans les sols tropicaux. Cah. O.H.S.T.O.M., Sér. Pédol., vol. XIV, no 4, 1976.

Djoukeng, H.G. 2016. Le billonage cloisonné en agriculture des montagnes.

Fotsing, JM. 1999a. Croissance démographique et mise en culture des réserves forestières dans l'Ouest Cameroun. In Population and Deforestation in the Humid Tropics, Bilsborrow RE, Hogan D (eds). International Union for Scientific Study of Population: Liège, Belgique; 76-98.

Fotsing, J.M. 1999b. Excursion dans les agroforêts de l'Ouest: pays Bamiléké et Bamoun. Carnet de tournée. Colloque international l'homme et l'érosion du

Jastrow, JD., R.M. Miller.1998. Soil aggregate stabilization and carbon sequestration: feedbacks through organomineral associations. Pp 207-223.

Lal, R. 1994. Methods of guidelines for assessing sustainability use of soil and water resources in the tropics.Soil Management Support TechnicalMonograph, 21: 78 p.

Le bissonnais, Y., M.J. Singer, J. Bradford. 1993. Assessment of soil erodibility: the relationship between soil properties, erosion processes and susceptibility to erosion in farm land erosion in temperate plains environment and hills. Wicherek(Ed) Elsevier 87-96

Moundjeu, E.D. (2022). Characterization of steep slope soils and stability of slopes of the Foréké-Dschang Cliff, West Cameroon. PhDthesis, Univ. Dschang, Dschang, 115p.

Pauwels, J. M., E. V. Ranst., M. Verloo, et A. Mvondo-Ze. 1992. Manuel de laboratoire de pédologie: Méthodes d'analyses des sols et de plantes, équipements, gestion des stocks de verrerie et de produits chimiques. Vol. 28. Bruxelles : Publications Agricoles.

Penman, J.M., Gytarsky, T. Hiraishi.K. Thelma, K. Dina, P. Riitta, B. Leandro, M. Kyoko, N.Todd, T. Kiyoto., and W. Fabian. 2003. Good practice guidance for land use, land use change, and forestry. Institute for Global Environmental Strategies for the Intergovernmental Panel on Climate Change, Hayama, Kanagawa,Japan, 502P.

Sprengel, C. (1886). Uber Pflanenzhumus, Humusssaure and Humussaure Slaze. Kasne's Arch. Ges. Naturelehre 8, 45-220.

Temgoua E., Djoukouo J., Likeng J.D., Tematio P., 2014.Structural stability of Andisols and AndicFerralsols from Mount Bambouto, West Cameroon highlands. *Cameroon Journal of Experimental Biology* 2014 Vol. 10 N° 01, 26-34

Tisdall, J.M and J.M. Oades. 1982. Organic matter and water stable aggregates in soils. *J. Soil Sci.*33: 141-163.

Walkley A.J., and I.A. Black.1934. Estimation du carbone organique du sol par la méthode de titrage de l'acide chromique. *SoilSci* 37, 29-38.

YoussiéKabiwa, J.P. 2019. Potentiel de stockage du carbone organique par les agroforetsa base de cafeiers dans la Falaise de Foreke- Dschang- Ouest Cameroun *Master thesis, Université of Dschang, Dschang.*

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