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Contributions of soil chemical and physical properties in the dynamics of soil quality in the southern Cameroon plateau shifting agricultural landscape

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ABSTRACT

Soil quality results from combination of chemical, physical and biological characteristics; according to ecosystems, some of these aspects become dominant. This Study was carried out on soils under 08 land cover types in the southern Cameroon ((bare soil with burned vegetation (FR1), bare soil with unburned vegetation (FR), *Chromolaena odorata* fallow (JC), bush ligneous fallow (JR), secondary forest (FS), primary forest (FC), *Gilbertiodendron dewevei* forest (FG), and raffia forest (RA) to assess the contributions of soil chemical and physical indicators into global soil quality index (IQSg). Topsoil samples were analyzed for physico-chemical characterizations and IQSg computed. Multiples statistical tests were used to compare the contribution of soil quality indicators and to select those that contributed the most in IQSg. Thus, under FR1, FC, FG and RA, IQSg was relatively high and the main contributors were chemical, estimated at more than 70%. Under FR, IQSg remains high and chemical contribution predominant (65%) on physical (35%). On the contrary, under fallows, IQSg is relatively low; these two types of contributions are nearly equivalents. Thus, the main indicators helping to assess IQSg in lower cost, contributing significantly to global soil quality and representatives of indicators are: organic matter (MO), pHw, and C/N ratio. The difference in contribution is due to the types of cultural practices, quality and quantity of MO brought by land cover types and topographical position.

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Keywords: Soil quality; land cover; shifting agriculture; south Cameroon.

INTRODUCTION

In the tropical slash and burn agriculture system, changes in the chemical properties of soil were much more evident and broader than changes in the physical properties (Edivaldo et al., 2014). At the beginning of the cropping period, soil chemical properties changed significantly due to the liming effect of ashes. This effect is

more pronounced in older fallows prepared for cultivation than younger ones. Organic carbon and CEC (exchange cation capacity) are the chemical properties the least variable while the pH, exchangeable bases and exchange acidity are the most variable (Nounamo et al., 2002; Yemefack, 2005). Aggregate stability was significantly lower after burning. Bulk density was not affected

by clearing and burning at the beginning of cropping but somewhat higher at the end of two year cropping period (Yemefack, 2005). This latter acted indirectly on crop growth by influencing several other soil properties (permeability, water retention,...) that can individually or collectively impact directly on crop productivity (Douglas et al., 2003; Ali Ashraf Amirinejad et al., 2011). Owing to the poor status of ferrallitic soils, natural regeneration provided by MO from different land covers seems insufficient (Bilong et al., 2017); chemical contributions brought by organic manure (guano, and sheep) according to Biaou et al. (2017) improved significantly soil fertility. These soils characteristics or soil quality indicators can be divided into: inherent soil quality indicators when they reflected differences due to soil forming factors (climate, topography, parental material, time, ...); and processes and dynamic soil quality indicators, reflecting spatial or temporal changes depending on management history of soil resource (Douglas et al., 2003 ; Teklu et al., 2004 ; Bastida et al., 2008).

Several soil properties served as indicators of soil quality concerning productivity and sustainable management of soils. However, the challenge is to identify those which were more sensible or those which contributed significantly to the current functioning of soils identified under different land cover types, inherent from shifting agriculture. According to the type of agricultural system or to the type of soil management, several studies have been made (Andrews et al., 2002a,b ; Seyed et al., 2006 ; Mairura et al., 2007 ; Ping Li et al., 2012), identifying keys indicators in expression of soil quality and determine the characteristics (chemical, physical or biological) which are the predominant in the accomplishment of soil functions, precisely the main ones (production). However, under shifting agricultural system of South Cameroon plateau, such studies are still scarce. Consequently, the platform for activities planning to upgrade these of soil basing on the knowledge of different indicators lacks

enough useful and reliable data. This study appreciates the contribution of chemical and physical characteristics of soil in the IQSg under different land cover types. The specific objectives of this work were: (i) to compute global soil quality index that comes from soil chemical and physical indicators under each land cover types, (ii) to isolate the contribution of each type of indicator in global soil quality index of each class of soil, and (iii) to identify among data set, those with a significant contribution to the global soil quality of the site.

MATERIALS AND METHODS

Study site and the research design

The experiment was conducted at the Nsimi village in the Zoétélé subdivision in the South region of Cameroon (Figure 1). The area is located at 120 km SSE of Yaoundé and 13 Km of Zoétélé, between 3°07' - 3°15' N and 11°45' - 11°52' E. The annual rainfall shows a bimodal distribution pattern, leading to two rainy seasons corresponding to two cropping periods (March-June and September-November). The annual rainfall varies between 1400 and 1900 mm and the mean annual temperature is 24 °C (Santoir et Bopda, 1995). The area is an undulating landscape with altitudes ranging between 600 and 705 m (a.s.l).

Shifting cultivation is the main agricultural land use system practiced by small scale farmers, which results in a mosaic spatial landscape pattern where some portions of primary forests are replaced by annual food crop fields, perennial plantations (cocoa, oil palm or rubber) or diverse fallow cover types (Nyeck, 2005; Yemefack, 2005). Depending on the dominant plant species, homogeneous plots have been delimited. They correspond to different regrowth ages of vegetation and the local conditions of their reuse for agricultural purpose in area. Our research design included the following land cover types: bare soil with burned vegetation biomass (FR1), bare soil with unburned vegetation biomass (FR), *Chromolaena odorata* fallows (JC), Bush ligneous fallows (JR), secondary forest (FS), *Gilbertiodendron dewevei* forest (FG), *raffia*

and *uapaca* forest (RA) and primary forest (FC). Their descriptions were given in Table 1.

In the field, direct observations of the physiognomy of land cover coupled with the identification of dominant plant species and interviews of local farmers helped to determine the cover types and their age ranges. Dominant soils across the area are acrisols and Ferralsols (WRB, 2006); they are acidic in the level of series (Adibime et al., 2016). They were located in the upper gently sloping valleys. Whereas few gleysoils or hydromorphic soils occupy the swampy valleys. These soils are developed on pyroxene granites (Champetier de Ribes et Aubague, 1956). Composite soil samples were collected using an Edelman auger at 0 - 20 cm depth under each land cover type with three replications. These soil samples were air-dried before grinding and sieving, then, used for routine laboratory analyses.

Soil sampling and chemical analyses

Soil samples were analyzed at IITA (International Institute of Tropical Agriculture) laboratory of Nkolbisson (Cameroon) for the following: pH_w in water, determined in suspension soil/water equal to 1 / 2.5 ratio. Exchangeable bases (Ca, Mg, K), available P and Fe were extracted by the Mehlich-3 procedure (Mehlich, 1984). Exchangeable bases and Fe were determined by atomic adsorption spectrophotometry and, available P by Bray II procedure (Motomizu et al., 1983). Exchangeable Al was determined using 1M KCl and extracted colorimetrically using pyrocatechol violet. Cation exchange capacity (CEC) was carried out using the ammonium acetate method at pH 7 (Summer and Miller, 1996). Total N using the Kjeldahl method for digestion and ammonium electrode determination (Bremner and Tabatabai, 1976), organic carbon (OC) using chromic acid digestion and spectrophotometric analysis (Heanes, 1984), organic matter (MO) was obtained using conversion factors for surface horizons of 1.724 for soils under anthropogenic land cover

types and 2.0 for soils under undisturbed land cover types (Nelson and Sommers, 1972).

Physical soil analyses

Physical parameters analysed included: particle size and bulk density determination. For bulk density, three core samples were taken under each land cover type, at 0±5, 5±10 and 10±15 cm depth. Cores were 5 cm long and had a volume of 100 cm³. They were obtained following the ratio weight of dry sample under his volume (W/V) before already subtract the weight of sampling bag. Soil particle size was determined by chemical dispersion using hexametaphosphate (soil:liquid ratio, 1:20, wt/wt). Looking at the correlation between different particle sizes (sand, clays and silt), strong negative correlations ($r = - 99$ and $r = - 0.70$) were observed; respectively between sand and clay fractions on the one hand and between silt and clay fraction on the other hand. Moreover, silt fraction was found very low in the forest ferrallitic soils of South Cameroon (Yemefack et al., 2004). Therefore, clay fraction represents in this study sand and silt fraction in the assessment of soil physical quality.

Computation of global soil quality index (IQSg)

Soil quality index is a numerical value that can be used to monitor the long – term changes in soil quality (Fabrice et al., 2003). Its determination is done in three main steps: (1) a good selection of indicators that best represent soil function, (2) normalization of indicators or variables and determination of their proportional coefficients (scores), and (3) combination of the normalized data by their proportional coefficient to a product for each variable and summation of the product of variable gives the global soil quality index under each land cover type. Soil quality is determined by both inherent and dynamic properties and processes interacting within a living dynamic medium (Douglas et al., 2003; Teklu et al., 2004; Bastida et al., 2008). Monitoring soil quality is also important because, it provides a valuable base upon which subsequent and future measurements

can be evaluated (Yanbing et al., 2009). In this study, soil chemical and physical indicators were used.

The indicators were chosen at first according to general approach which considers the available wide data set (Seyed et al., 2006; Yanbing et al., 2009). Then, the minimum data set is obtained on the basis of statistical analyses (Andrews et al., 2002; Fabrice et al., 2003; Yemefack et al., 2006; Yanbing et al., 2009). For data normalization, each value of indicator was divided by its standard deviation so that at the end, all the indicators received a standard deviation equal to 1. For the determination of proportional coefficient, the method used is the linear scoring; here, the normalized value of each indicator are ranked in ascending or descending order depending on whether a higher value was considered “good” or “bad” in terms of soil function. For “more is better” indicators, each value of indicator was divided by the highest observed value (divisor) such that the highest observed value received a score of 1 and the remainder less than 1. For “less is better” indicators, the lowest observed value (numerator) was divided by each value of indicator (denominator) such that the lowest observed value received a score of 1 and the remainder less than 1. The indicator scores vary between 0 and 1. A score of 1 was given when an indicator value represented high soil function. A Combination of normalized value with their proportional coefficients give a product ($W_i X_i$) and the sum of the products of indicators give global soil quality index (IQSg) under each land cover type according to the equation (1) described by Andrews et al. (2002).

$$IQSg = \sum_{i=1}^n W_i X_i \quad (1).$$

Where W is the normalized value of indicator; X is the indicator score; $IQSg$ is the global soil quality index without unit; i is a soil property and n the number of soil properties. Each soil sampled under a specific land cover type is characterized by it $IQSg$. High global soil quality index indicates better soil quality (Andrews et al., 2002, 2003). Doran et al. (1994) considered that the highest

soil quality would correspond to natural undisturbed lands. Therefore, the soil will be of good quality when it $IQSg$ will be equal or higher than that under primary forest (FC) and vice versa.

Assessment of absolute and relative contributions of indicators in the global soil quality index

Absolute contribution of soil quality indicator into global index represents $W_i X_i$ product of each variable where W_i is normalized variable and X_i proportional coefficient of this variable. This product therefore represents the quality index of each variable or indicator. It is a product without unit.

Relative contribution expressed in percent (%) was obtained according to the following equation: $x\ cont (\%) = \frac{IQSi \cdot 100}{IQSg} \%$ (2) where $x\ cont (\%)$ is the relative contribution of indicator; $IQSi$ represents soil quality index resulting from a variable or indicator under a given type of land cover; i represents indicator or variable and $IQSg$ global soil quality index resulting from all the indicators (chemical and physical soil quality indicators) under a given land cover type.

Statistical analysis

The 12 soil quality indicators under investigation were subjected to a descriptive statistical study using summary statistics. The analysis of variance (ANOVA) was performed to appreciate changes in chemical and physical contributions under different land cover types. The separation of means among the different land cover types was made using the least significant difference test at 0.05 probabilities (Tukey’s test). Principal component analysis (ACP) was also used in order to select the indicator that contributed the most in the global soil quality of the site. These analyses were performed using STAT/SE version 11/0 (Statacorp LP, 2016) and XLSTAT 2007.

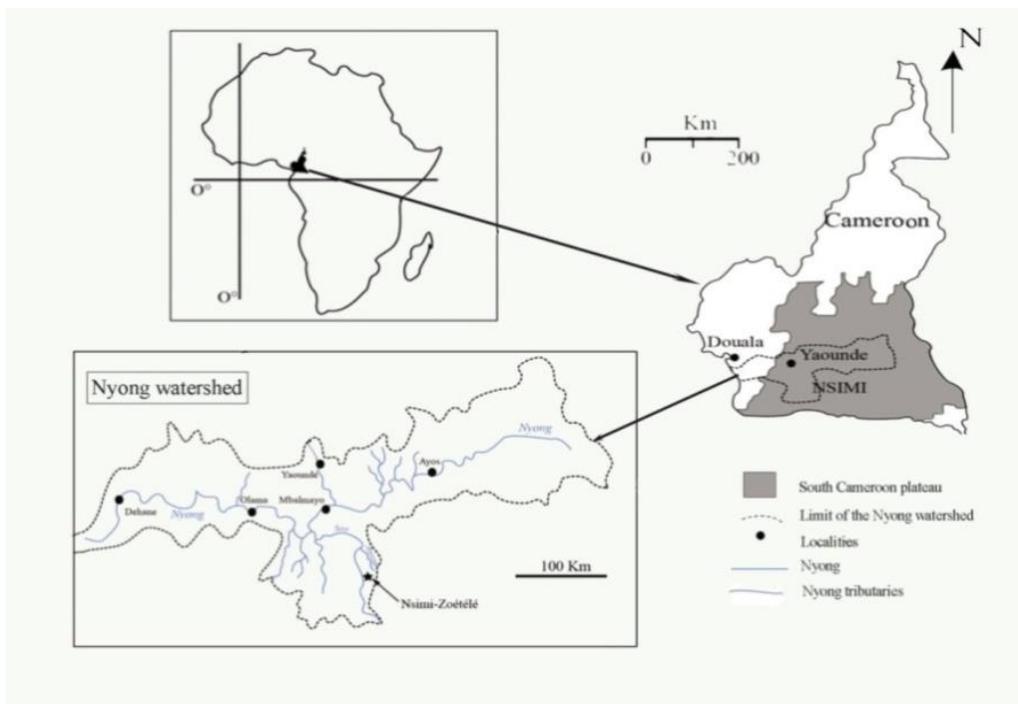


Figure 1: Localization of the Nsimi-Zoétélé watershed within the Nyong watershed.

Table 1: Descriptions of the main land cover types identify in the forest area of South Cameroon.

Land covers types	age (year)	Physionomy
FR1	0 (< 3 months)	Clearing and burned plots with dry and burned abundant vegetal biomass underground
FR	0 (< 3 months)	Clearing plots with abundant vegetal biomass dry underground
JC	2 – 5	Plots in majority covered by <i>Chromolaena Odorata</i> shrub species
JR	7 – 9	Plots in majority covered by bush ligneous and some young shrubs
FS	12- 15	Plots covered by young shrubs and some forests species
FC	>50	Plots covered by tropical forest species (<i>Baillonella toxisperma</i> , <i>Ceiba pantadia</i> , <i>Terminalia superba</i> , <i>Troplochiton</i>)
FG	>50	Plot in majority covered by <i>Gilbertiodendron Dewevei</i> species
RA	>50	Plots of swampy area colonized by raffia, <i>Haumania dankelmaniana</i>

FR1: bare soil with burned vegetation biomass; FR: bare soil with unburned vegetation biomass; JC: *Chromolaena Odorata* fallow; JR: bush ligneous fallow; FS: secondary forest; FC: primary forest; FG: *Gilbertiodendron Dewevei* forest; RA: raffia and *uapacca* forest.

RESULTS

Summary statistics contributions of chemical and physical soil quality indicators

Soil quality is determined under the basis of available indicators defining one or more given functions (Yanbing et al., 2009). Soil quality index (SQI) in the site differs in function of land cover type (Ngo Mbogba et al., 2015). The twelve indicators contributing to this difference are: pHw, MO, CEC, Ca, Mg, K, C/N ratio, available P, Fe, Al, clay particles and bulk density. Table 2 summarizes the statistics contributions of these indicators into global soil quality index under eight land cover types.

These contributions except of clay fractions showed a positive skewness with coefficient varying between 1.26 and 3.46. Significant contributions in global soil quality index were brought by pHw, C/N ratio, clay fraction, CEC, MO, Ca, Mg and available P. However, under soils with burned vegetation biomass (FR1) where global soil quality index was very high (35.35), significant contributions were due to pHw (9.17), Ca (4.34) and Mg (3.71). Under forest soils (FC, FG, RA) where global soil quality index meaningful higher, (21.07, 27.12 and 28.66 respectively), the most important contributions were from MO, CEC, C/N ratio and available P. Under soils with unburned vegetation biomass (FR) which also presented high global soil quality index (25.98), main contributions were due to pHw (5.05), Mg (1.70), C/N ratio (4.45) and clay fraction (2.91). On the contrary, soils under fallows (JC, JR, FS) presented a relatively low global soil quality index; 20.03, 19.26; 19.56 respectively. Here, clay fraction, C/N ratio and pHw were the main contributors in IQSg (Figure 2). Contributions brought by K, Fe, and exchangeable Al were negligible; those generated by bulk density were important but did not help to discriminate soil according land cover types.

Soils with burned vegetation biomass (FR1) and forest covers (FC, FG, RA) contributions were essentially chemicals and representing 75% and 63%, 72%, 78% of

global soil quality index respectively. Under soils with unburned vegetation biomass (FR), chemical indicators contributed for 65% and physical indicators for 35%. The main indicators were clay fractions (physical indicator) with 11.20% and chemical indicators (pHw, Mg and C/N ratio) for 43%. Under fallow soils (JC, JR, FS) soil quality depends on chemical and physical indicators as well. Contributions were almost equivalent. Chemical indicators participated for 52% and physical indicators for 48% on the average. Main contributions were provided by pHw (18%), C/N ratio (23%) and clay fraction (14%) (Figure 3).

Thus, chemical quality of soil was controlled by ash from burned vegetation biomass land cover type, and internal drainage linked to topographical position was predominate to the physical ones. Physical quality was conjointly controlled by hand ploughing (tillage) and topography. Therefore, chemical soil quality indicators determine global soil quality in the site.

Variability of indicators contributions with land covers types

The contribution of indicators significantly ($P = 0.000$) variable were subjected for the analyses of variances (ANOVA) and mean separations (Tukey's HSD). The results of ANOVA and means separations as presented in Table 3 shows highly significant differences of contributions from one land cover type to another.

Contributions of pHw and exchangeables bases (Ca, Mg) were significantly higher under bare soils with burned vegetation biomass (FR1) as compared to those under bare soils with unburned vegetation biomass (FR), under fallows (JC, JR, FS) and under forest soils (FC, FG, RA). Contributions of organic matter (MO) were also significantly higher under forest soils (FC, FG, RA) and involved higher contributions of CEC under FG and RA even higher contributions of available P under RA in the global soil quality index. Contributions of clay fraction in global soil quality were significantly higher under fallows, under soils

with unburned vegetation biomass (FR) and under soils with burned vegetation biomass (FR1) as compared to soils under forest land cover types.

The affinities of soils modalities obtained under different land covers types were recorded in Table 4. Whatever soil quality indicator, we always notice affinity of soils under the three fallows which were gathered in the same modality. Contributions of basics cations (Ca, Mg), MO and pHw always discriminates soils under the two types of bare soils (FR1 and FR), even each type of land cover underlined. Contributions of available P are related to swampy areas which were particularly discriminated by MO, pHw, CEC, and clay fraction. Variability of this latter marked by topography distributed soils under different land cover types along the slope. Variability contributions of C/N ratio which distinguished soils under FG had discriminated species characterizing land cover type and then quality of organic matter brought by this specie.

Minimum data contributing most in the global soil quality

Some parameters are more sensitive to changes related to management practices than others. These parameters contributed most to soil quality and must be integrated among data set which expresses soil functioning within this traditional system. For their selection, Principal Component analysis (PCA) was used (Yemefack et al., 2006; Yanbing et al., 2009; Ping Li et al., 2013). According to the procedure described by Andrews et al. (2002), only principal components (Pcs) with eigen values ≥ 1 were considered for the minimum data set (MDS). For each PC, indicators receiving weighted loading value within 10% of the highest weighted loading were selected for the minimum data set. Soil chemical and physical indicators constitute the list of soil quality indicators contributing to global soil quality. Three principal components (PC1, PC2, PC3) had eigen values ≥ 1 according to the method indicated above. These principal components explained more than 91% of

variability of indicators contributions into IQSg (Table 5).

Highly weighted indicators for the first principal component (PC1) included: organic matter (MO), CEC, available P, Fe and clay fraction. Correlation coefficients between these five indicators were well correlated (pearson coefficient correlation > 0.70). However, contributions of MO were most highly correlated and thus chosen for the minimum data as most representative of that group. For PC2, highly weighted indicators were pHw, Ca, and Mg; they were well correlated. PC3 was represented by K and C/N ratio, which were highly weighted indicators. Thus, pHw and C/N ratio were the most highly correlated and thus chosen for the minimum data as most representative respectively of group 2 and group 3

Finally, indicators determining global soil quality index value and representatives of chemical and physical indicators in the site were: MO, pHw and C/N ratio. Under fallows (JC, JR and FS), there were no significant differences in the contributions of these indicators. They contributed for 43% in their global soil quality index. Under bare soils (FR1 and FR) and forest soils (FC, FG and RA) there were significant differences within contributions. Under bare soils with burned vegetation biomass (FR1), these indicators contributed for 44% in global soil quality index and 38% under bare soils with unburned vegetation biomass (FR). Under forest soils (FC, FG, and RA), they contributed for 43%, 54% and 36% respectively (Figure 4). Capture of total variability of soil quality index by this minimum data set within the traditional landscape shifting cultivation helps to reduce considerably the cost of land evaluation by determining only the three soil indicators instead of twelve.

Table 2: Summary statistics of absolute contributions of indicators in the global soil quality index (n = 16 composite samples).

Stats	MO	pHw	CEC	Ca	Mg	K	C/N	Bray P	Fe	Al	Clay	Dad	IQSg
Mean	0.89	3.98	1.41	0.40	0.59	0.38	5.00	0.98	1.18	0.01	2.19	6.25	23.27
Max	4.60	9.17	4.14	4.34	3.70	4.09	9.73	4.14	5.01	0.01	4.26	6.26	35.35
Min	0.13	2.85	0.22	0.00	0.01	0.01	3.37	0.18	0.19	0.01	0.07	6.25	19.26
Sd	1.12	1.54	1.28	1.06	1.09	1.03	1.56	1.16	1.16	0	1.11	0.00	5.44
CV	1.26	0.39	0.91	2.65	1.84	2.69	0.31	1.19	0.99	0	0.51	0.00	0.23
Kurtosis	8.77	9.21	3.24	13.3	6.37	12.0	6.38	4.99	8.56	-	2.82	6.14	3.14
Range	4.46	6.32	3.92	4.33	3.70	4.09	6.36	3.96	4.82	0	4.19	0.01	16.09
skewness	2.48	2.58	2.26	3.46	2.25	3.22	1.74	1.76	2.34	-	-0.35	2.27	1.26

Min: minimum; Max: maximum; Sd: standard deviation; CV: coefficient of variation; IQSg: global soil quality index; Dad: bulk density; CV: coefficient of variation; Sd: standard deviation; MO: organic matter.

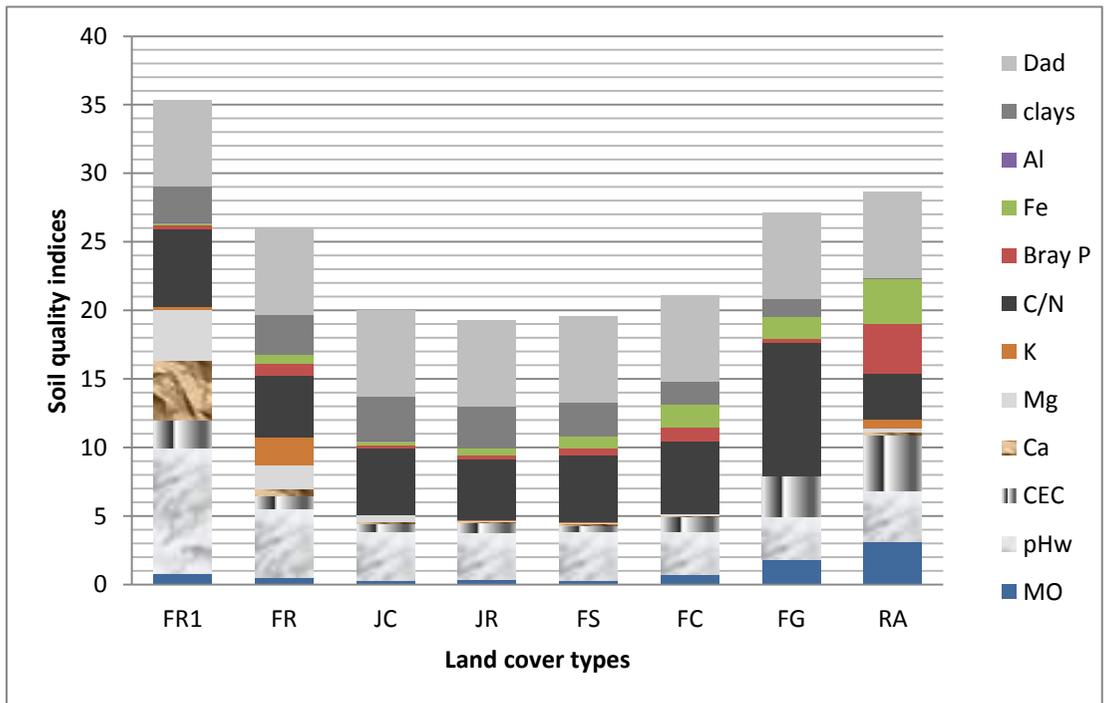


Figure 2: Absolute contributions of soil quality indicators in the global soil quality index. FR1: bare soil with burned vegetation biomass; FR: bare soil with unburned vegetation biomass; JC: *Chromolaena odorata* fallow; JR: bush ligneous fallow; FS: secondary forest; FC: primary forest; FG: *Gilbertiodendron dewevei* forest; RA: raffia and *uapacca* forest; Dad: bulk density; MO: organic matter

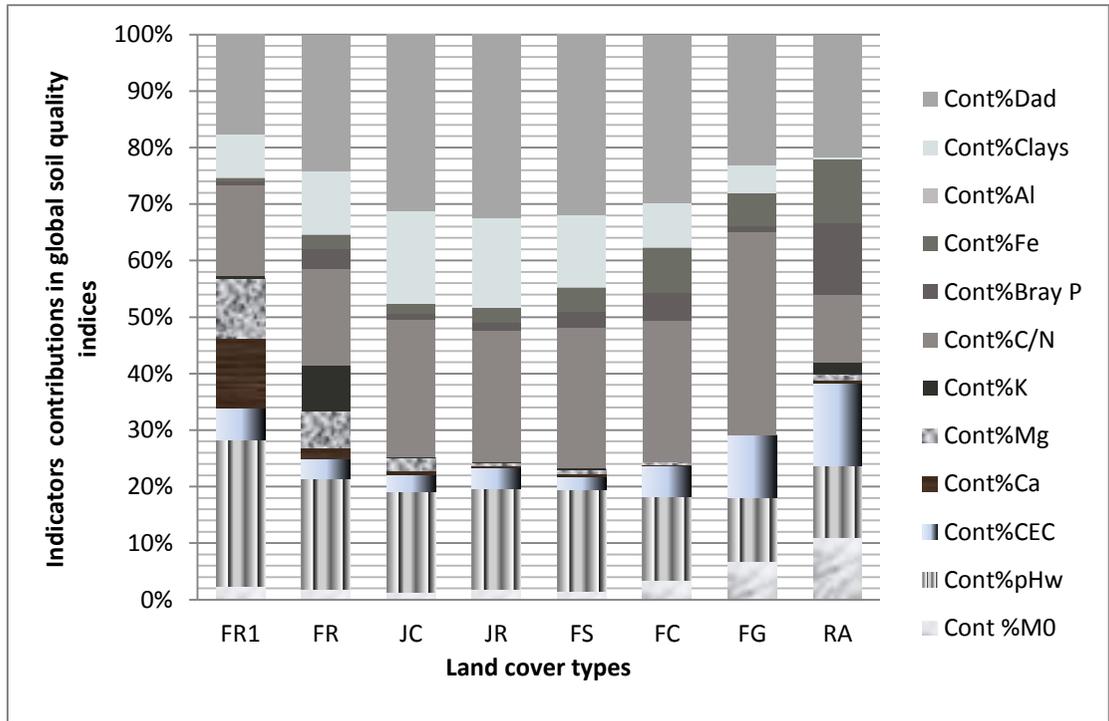


Figure 3: Relatives contributions of soil quality indicators in the global soil quality index (IQSg). FR1: bare soil with burned vegetation biomass; FR: bare soil with unburned vegetation biomass; JC: *Chromolaena odorata* fallow; JR: bush ligneous fallow; FS: secondary forest; FC: primary forest; FG: *Gilbertiodendron dewevei* forest; RA: raffia and uapacca forest; Dad: bulk density; MO: organic matter, Cont %: relative contributions of indicators.

Table 3: Comparison of soil quality indicators contributions under different land cover types (n = 16 samples).

Land cover types	MO	pHw	CEC	Ca	Mg	C/N	Bray P	Clays
	R ² = 0.74	R ² = 0.97	R ² =0.95	R2 = 0.99	R2 = 0.88	R2 = 0.88	R2 = 0.89	R2 = 0.84
	P = 0.021	P = 0.000	P = 0.000	P = 0.000	P = 0.001	P = 0.001	P= 0.000	P = 0.002
FR1	0.82ab	9.17a	2.03bc	4.34a	3.71a	5.68b	0.27b	2.67a
FR	0.50b	5.05b	0.94cd	0.47b	1.70ab	4.45b	0.92b	2.91a
JC	0.26b	3.57bc	0.61d	0.14bc	0.45b	4.84b	0.21b	3.26a
JR	0.34b	3.44c	0.71d	0.06bc	0.11b	4.47b	0.29b	3.05a
FS	0.30b	3.53c	0.45d	0.10bc	0.13b	4.85b	0.58b	2.48a
FC	0.71b	3.14c	1.13cd	0.04c	0.09b	5.25b	1.05b	1.64ab
FG	1.84ab	3.07c	2.98ab	0.00c	0.01b	9.73a	0.29b	1.34ab
RA	3.13a	3.67bc	4.14a	0.15bc	0.29b	3.38b	3.65a	0.12b

Values followed by the same letters are not statistically different (p < 0.05) according to least significant difference (Tukey’s test). MO: organic matter; R² = coefficient of regression; FR1: bare soil with burned vegetation biomass; FR: bare soil with unburned vegetation biomass; JC: *Chromolaena odorata* fallow; JR: bush ligneous fallow; FS: secondary forest; FC: primary forest; FG: *Gilbertiodendron dewevei* forest; RA: raffia and uapacca forest.

Table 4: Different associations of soils modalities under different land cover types by indicator.

Indicators	Associations of soils modalities under different land covers types according to indicator contributions in the global soil quality									
MO	FG FR1		JC JR FS FC				RA			
			FR							
pHw	FR1	FR		JC JR FS FC			FG	RA		
CEC	FR1		FR FC		JC JR FS			FG		RA
Ca	FR1		FR		JC JR FS			FC FG		
					RA					
Mg	FR1	FR		JC JR FS			FC FG RA			
C/N ratio	FG			FR1 FR JC JR FS			FC RA			
Available P	FR1	FR	JC	JR	FS	FC	RA			
	FG									
Clay fraction%	FR1	FR	JC	JR	FS	FC FG		RA		

FR1: bare soil with burned vegetation biomass; FR: bare soil with unburned vegetation biomass; JC: *Chromolaena odorata* fallow; JR: bush ligneous fallow; FS: secondary forest; FC: primary forest; FG: *Gilbertiodendron dewevei* forest; RA: raffia and uapacca forest

Table 5: Results of Principal Component analyses of indicators contributions in soil quality under different land cover types.

PCs	PC1	PC2	PC3	PC4
Valeur propre	4.741	2.826	1.587	0.732
Variabilité (%)	47.407	28.258	15.871	7.317
Pourcentage cumulé	47.407	75.665	91.536	98.853
Variables pondérées				
MO (%)	0.901	0.378	0.143	0.049
pHw	-0.488	0.869	0.030	-0.064
CEC (Cmol/kg)	<u>0.789</u>	0.519	0.271	0.084
Ca (Cmol/kg)	-0.458	<u>0.847</u>	0.192	-0.181
Mg (Cmol/Kg)	-0.511	<u>0.855</u>	-0.043	0.054
K (Cmol/kg)	0.014	0.283	<u>-0.693</u>	<u>0.663</u>
C/N	-0.024	-0.077	0.879	0.467
Bray P (ppm)	<u>0.853</u>	0.278	-0.415	-0.149
Fe (ppm)	<u>0.987</u>	0.062	-0.037	-0.040
Al (Cmol/kg)	0.000	0.000	0.000	0.000
Clays (%)	-0.945	-0.207	-0.168	0.030
Dad	0.000	0.000	0.000	0.000

Pc: principal component; underlined factor loadings are considered highly weighted; Factor loadings in bold correspond to the indicators included in the MDS.

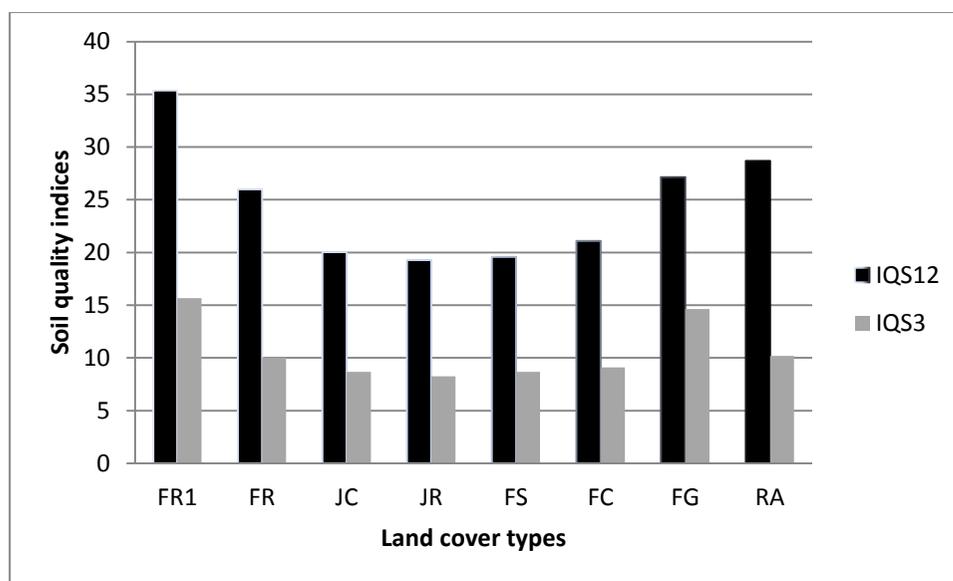


Figure 4: Representativeness of minimum data set contributions into global soil quality. FR1: bare soil with burned vegetation biomass; FR: bare soil with unburned vegetation biomass; JC: *Chromolaena odorata* fallow; JR: bush ligneous fallow; FS: secondary forest; FC: primary forest; FG: *Gilbertiodendron dewevei* forest; RA: raffia and uapacca forest

DISCUSSION

Indicators contributions on soil chemical and physical quality

Significant contributions of chemical indicators (pHw, Ca, Mg) of soil with burned vegetation biomass (FR1) could be explained by ashes from burned vegetation biomass which had improved considerably soil pHw and consequently concentrations of basic cations (Ca, Mg). These effects of ashes were also observed by several authors (Nounamo et al., 2002; Yemefack, 2005) in plots of shifting agriculture in Center and South Cameroon and also by Tchata et al. (2004) in the management of home gardens of the same area. Here, ashes from kitchen which were regularly thrown around homes improved soil quality by increasing pH, concentration of exchangeable bases and by reducing exchange acidity. Under Forest soils (FC, FG, RA), main chemical contributions (MO, CEC, C/N, available P) were due to i) high production of vegetal biomass which supply a higher content of organic matter (MO), ii)

topographic position occupied by soils of swampy areas (FG, RA). Here, mineralization of MO was very low (Miralles et al., 2009) because of higher humidity and anaerobic conditions. Higher correlations observed between MO and several indicators (CEC; $r = 0.86$; available P; $r = 0.83$) suggest that their fluctuations remained under control of MO. Under soils with unburned vegetation (FR) and fallows (JC, JR, FS) chemical contributions of indicators could be explained by: i) differential inputs of MO by different land cover under which rapid mineralization of MO, favored by climate and drainage (soils from upper valleys) involve release of nutrient elements and ii) light post positive burned effects of ash that would continue to act some years latter under fallows (JC, JR, FS). The evidence of this post burn effect was brought by fragment of charcoals found while ploughing soils under fallows for seeding. Significant contribution of clay fraction under fallows could be due on one hand to the hand plough or tillage (with hoe) which has

homogenized cultural profile by mixing deeper mineral horizons with surface organo-mineral horizons; on the other hand, the topographical position of these soils (upper valleys) relatively to those under forest (FC, FG, RA) (downstream) favour their enrichment in this fraction. Lateral drainage responsible of nutrient lixiviation could be less active than downstream under forest (FC, FG, RA). Furthermore under FG, the quality of organic matter supply to soils by *Gilbertiodendron dewevei* species was potentially rich in free fulvic acid fraction (Ngo Mbogba, 2008). This fraction might be responsible of impoverishment of basic cations and then subsequent enrichment of exchangeable Al. According to Temgoua et al. (2017), MO provided by *Gilbertiodendron dewevei* species is of mediocre quality (C/N ratio > 10). Thus, beside influence of ashes, land cover types on soil quality, pedogenetic evolution of catena as underlined by Nyeck (2005) in the characterization of poral space was marked by impoverishment of soils in clay fraction and bases from upstream to downstream. Therefore, differentiation of clay fraction in the soil depend on one soil forming factor which is topography, this physical property is qualify as inherent soil property. Likewise, the low contributions of basic elements (Ca, Mg, K) under forest soils was confirmed by their topographical position where proximity with ground water indicated by Nyeck (2005) accentuates their desaturation favoring their enrichment in exchangeable Al.

Minimum data set contributing into IQSg

Ideally, a more balance data set has to include soil biological properties. However, these indicators selected (MO, pHw, C/N ratio) for the minimum data set contributed to one or more soil functions as proposed by Doran and Parkin (1996) and participated more to global soil quality index value. Two of them were similar to those retained by Yemefack et al. (2006). They were affected by agricultural practices (Yemefack et al., 2006; Ping Li et al., 2012). Soil pHw was most sensitive to land management and easily to

manage even at the village level (Tchatat et al., 2004). Its contribution in soils identified under different land cover types was manifested on humification and mineralization processes; since it directly acted in biological activity and availability of nutrient elements. It also indirectly acted on some soil physical properties (structure). C/N ratio which was low (< 25) in the whole soils is an indicator which informed on the evolution of soil organic matter and then the rate of release of nutrient elements; it was therefore excellent upon the whole soils (Temgoua et al., 2017). Finally, soil organic matter is an indicator of high importance and even fundamental in the definition of soil quality; since it controlled at same time chemical, physical (Bilong et al., 2017) and biological aspects which governed soil fertility (Kanmegne et al., 2004). Moreover, here soils of the forest area were poor in nutrient elements (Yemefack, 2005); because surface horizons were weakly influenced by geological substratum (more than 35 m depth below) (Nyeck, 2005), their agronomic quality depends mainly on organic matter decomposition to maintain their fertility.

These three indicators, despite their chemical nature, gave an account of global soil quality and are representatives of both physical and biological soil quality indicators. Directly or indirectly, it influenced physical (porosity, structure,...) and biological (humification and mineralization processes of organic matter) soil functions. Thus, representative chemical, physical and biological aspects and capturing total variability of soil quality index in this traditional shifting cultivation system, this minimum data set, help considerably to reduce land evaluation cost by determining only the three indicators instead of twelve.

Conclusion

This study aimed at appreciating and measuring contributions of soil chemical and physical indicators in the global soil quality identified under different land cover types within shifting agricultural landscape of South Cameroon. Chemical and physical

contributions of soil quality indicators mainly differ according to land cover type and soil internal drainage due to topographical position. Thus, bare soil with burned vegetation biomass (FR1) and soils under forest had high global soil quality index; indicators contributing in their global soil quality were chemicals. Specially, pHw, Ca and Mg were contributed under FR1; MO, CEC, C/N ratio and available P under forest land cover. Under soils with unburned vegetation biomass (FR) where global soil quality index was still high, contributions were both chemical and physical; soil quality indicators were pHw, Mg, C/N ratio and clay fraction. Under fallows (JC, JR and FS), global soil quality index was relatively low; both chemical and physical indicators contributed. They were clay fraction, C/N ratio, and pHw. These differences in contributions were due to: ashes from burned vegetation biomass (FR1), quantity and quality of soil organic matter supply by forest land cover, traditional ploughing or tillage (JC, JR and FS) and topographical position favorable to soils of upstream. Minimum data set allowing land evaluation at lower cost and contributing most in the global soil quality index whatever land cover type was summarized to three indicators: MO, pHw and C/N ratio. These indicators were representative of available wide data set and influenced directly or indirectly physical and biological soil functions of different soils.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHOR'S CONTRIBUTIONS

NB Participated in definition of the problem and framework of the study, supervision of sampling on the field and reviewed the manuscript. NMM participated for Sampling on the field, followed up laboratory analysis, compiling data, conceived and reviewed the manuscript. NIK has reviewed the manuscript. BP has defined the problem and reviewed the manuscript. YM

has achieved Statistical analysis of data and reviewed the manuscript.

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