Erodibility of Cultivated Soils in the Foumbot Area (West Cameroon)

J.D. Ngandeu-Mboyo[1*], M. Yemefack[1], R. Yongue-Fouateu[2] & P. Bilong[2]

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Summary

Agricultural lands in Western highlands of Cameroon are likely to face severe erosion because of the interactions of the following factors: high intensity of agricultural activities, poor farming practices and high rainfall intensity. However, the severity of this soil erosion can vary significantly with the ease with which soil is detached and transported by erosion agents. That is why a study was carried out in the Foumbot area in order to evaluate the soil erosion risk variation with some soil types. Thirty one soil samples were collected at 0–20 cm depth from three main soil types encountered in the area (Andosols, Acrisols and Ferralsols). Soil samples were analyzed for particle size distribution (Total clay, Total silt, Water dispersible clay, Water dispersible silt), Soil organic matter, Soil reaction, CEC, Exchangeable bases, clay dispersion ratio, dispersion ratio, clay aggregation and Mean weight diameter). Soil erodibility indicators were determined and used to estimate soil erosion risk for the three soil types. The results showed high dispersive potential of the three soil types. Soil characteristics and the deriving soil erodibility vary from one soil type to another. The most vulnerable soils are the Acrisols and the less erodible are the Andosols. Soil mineralogy seems to be the key factor regulating soil erodibility variation in the area. The Water-Dispersible Silt (WDS) correlates positively with the Soil organic matter (r=+0.67, p=0.000). The Water-Dispersible Clay (WDC) significantly correlates negatively with the soil organic matter (r=-0.61, p=0.000). WDC also showed significant negative correlation with calcium (r=-0.67, p=0.016) and potassium (r=-0.74, p=0.000). Based on its strong correlation with erodibility parameters, soil organic matter content appeared as the main soil characteristic through which soil conservation measures could easily be implemented in the studied area.

Résumé

Erodibilité des sols cultivés de la région de Foumbot (Ouest Cameroun)

Les sols cultivés des Hautes Terres de l'Ouest-Cameroun encourent des risques d'érosion sévère du fait de l'interaction entre la forte intensité des activités agricoles, des pratiques culturales rudimentaires et la forte intensité des pluies. Cependant, la sévérité de l'érosion de ces sols peut varier en fonction de la facilité avec laquelle les éléments du sol sont détachés et transportés par les agents de l'érosion. Une étude a été entreprise dans la région de Foumbot afin d'évaluer la variabilité des risques d'érosion en fonction de différents types de sol. Trente-et-un échantillons de sol ont été prélevés entre 0 et 20 cm de profondeur dans les trois principaux types de sol de la région (Andosols, Acrisols et Ferralsols). Les analyses de ces sols ont porté sur la granulométrie (Teneur totale en argile, Teneur totale en limon, Teneur en argile dispersée dans l'eau, Teneur en limon dispersé dans l'eau), la matière organique, le pH, la CEC, les bases échangeables, le taux de dispersion de l'argile, le taux de dispersion, l'agrégation de l'argile et le diamètre moyen pondéral. Les indices d'érodibilité des sols ont été déterminés et utilisés pour estimer les risques d'érosion pour ces trois principaux types de sol. Les résultats montrent que ces sols ont tous trois un potentiel de dispersion élevé. Les caractéristiques des sols et leur érodibilité qui en découle varient d'un type de sol à un autre. Les Acrisols sont les plus vulnérables à l'érosion alors que les Andosols sont les moins affectés. La minéralogie des sols semble être le principal facteur qui influence la variation de l'érodibilité des sols dans cette région. Il existe une corrélation positive entre le Limon Dispersé dans l'Eau (LDE) et la matière organique du sol (r=+0,67; p=0,000).

[1]University of Yaoundé I, Department of Earth Sciences, UMMISCO Unit, Yaoundé, Cameroon.

[2]International Institute of Tropical Agriculture, Yaoundé, Cameroon & Institute of Agricultural Research for Development, Nkolbisson, Cameroon

*Corresponding author: Email: desirengandeu@yahoo.fr

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L'Argile Dispersée dans l'Eau (ADE) montre une corrélation négative significative avec la matière organique du sol (r=-0,61; p=0,000). Il en est de même avec le calcium (r=-0,67; p=0,016) et le potassium (r= 0,74; p=0,000). Sur la base de sa forte corrélation avec les indices d'érodibilité des sols, la matière organique semble être la principale caractéristique des sols par laquelle des mesures de gestion conservatoire des sols peuvent être appliquées dans la région de Foumbot.

Introduction

Soil erodibility is the ease with which soil is detached and transported by agents of erosion. It depends on the physical and chemical characteristics of the soil, which are: the nature and amount of soil aggregates, organic matter content, particle size distribution as well as the swelling and shrinking forces and dispersion potential of the soil (5, 15, 26). The erodibility of a soil is defined by its resistance to two energy sources: the splash effect on the soil surface and the shearing action of runoff between clods in grooves or rills (4). Soil erodibility is then related to the integrated effect of rainfall, runoff, and limited infiltration on soil loss and is commonly call the soil-erodibility factor (*K*) (23).

For a particular soil, the *K*-factor is the rate of erosion per unit erosion index from a standard plot and reflects the fact that different soils erode at different rates. Thus, depending on their erodibility, soils react at varying speeds to raindrop attack and structural degradation. The *K*-factor also has a strong relationship with several soil properties. Soil texture, soil organic matter, soil structure affect K-factor through their influence on detachment and infiltration rates (7). A better estimation of K-factor would thus require rainfall, runoff and infiltration data, which are often not readily available at plot use level. That is why several other methods can be used to estimate soil erodibility factor, making use of its strong relationship with some soil characteristics. The most used method is the monograph method based on the particle size parameter, the percent organic matter, the soil structure index, the profile-permeability class factor and the percent clay (35) .

Beside the *K*-factor parameter, soil aggregate stability is one of the main factors controlling soil erodibility (2, 7) and the destruction of soil structural stability will lead to the increase of soil erodibility (18). Moreover, land use systems such as slash and burn agricultural systems result in accelerated soil degradation due to exposure of the soil surface layer to the impact of raindrops and runoff (20, 21) and to the impact of fire in decreasing soil aggregate stability (31).

Any scientific planning for soil conservation and water management requires knowledge of the relations among those factors that cause soil and water losses and those that help to reduce such losses.

Direct methods based on the rainfall simulation for measurement (through dispersion, raindrop impacts or ultrasounds) of the strength of the aggregate against water forces (16, 23, 37) and indirect methods based on the analysis of soil physical characteristics (12, 17) are generally used to estimate soil erodibility. Although the *K*-factor is recommended by the universal soil loss equation (23) for the determination of the soil erodibility, a whole series of laboratory and field tests has thus been set up for defining structural stability with respect to water. Many erodibility indices have thus been derived from physical and chemical soil characteristics. Some of them are the followings: Water Dispersible Clay (*WDC*), Dispersion Ratio (*DR*), Clay Dispersion Ratio (*CDR*), Clay Flocculation Index (*CFI*) (1), Water Stable Aggregates, Soil Texture, Mean-weight Diameter (1, 15, 24).

The Foumbot area, situated in the Noun valley and surrounding landscapes, is subject to a tropical climate characterized by high intensity of rainfall.

Soils of the area are classified in three main groups defined by the World Reference Base for soil classification (8): young Andosols (derived from volcanic ashes), Acrisols and Ferralsols. They are all submitted to intensive agricultural activities for annual and seasonal food crop production, using mostly farming practices unsuitable for soil conservation. Rainfall intensity combined with such inappropriate farming systems are likely to cause severe erosion in agricultural land of the area. We hypothesized that the severity of this erosion process may vary from one soil type to another owing to the resistance of their particles to detachment and transport by the erosion agents. This study was thus carried out in order to estimate soil erosion risk variation in the area as a premise for developing appropriate soil conservation strategies for a sustainable agricultural production and environmental protection, using basic soil characteristics and derived indices.

Material and methods

The study area

Foumbot area lies between latitude 5°25′-5°35′ N and longitude 10°33′-10°44′ E. It is located in the Noun valley, situated between the Bamileke and the Bamoun plateaus. The Noun valley is 10 to 20 km wide (34). It is subject to a mountainous tropical climate characterized by an average annual precipitation of about 1713 mm and a mean monthly temperature of 21 °C (28). The study area is an undulated plain with a mean altitude around 1100 m, embedded on a geological substratum made of metamorphic rocks (gneiss and migmatites), with many intrusions of various types of granitoid, and partly covered by a thick layer of lapillus (34). According to the World Reference Base for soil classification (8), soils of the research area (Figure 1) belong to the following five groups of which the first three are the most important: Andosols, Acrisols, Ferralsols, Regosols and Gleysols in some valley bottom.

Samples collection

In the field, data were collected in three soil types, chosen according to their extent in the area: Andosol occupying approximately 55%, Acrisols (12%) and Ferralsols (18%).

A total of 31 soil samples were collected at 0-20 cm depth throughout the three soil types (Figure 1).

Physical and chemical analysis

Soil samples were analyzed in the soil laboratory of the Institute of Agricultural Research for Development (IRAD) at Nkolbisson, Yaoundé (Cameroun) using the following techniques (22, 33). The particle size distribution was determined using the Robinson Köhn method. The method consists of the destruction of organic matter by hydrogen peroxide, the chemical dispersion of soil particles by sodium hexametaphosphate, the mechanical separation of the soil particles by shaking, the pipetting of silt and clay fractions and the sieving of sand fraction. The organic carbon was determined by the Walkley and Black method which uses potassium dichromate and concentrated sulphuric acid to oxidize soil organic matter. In the resulting solution, percentage of soil organic carbon is determined by colorimetry. The total nitrogen was obtained by the Kjedhal method which consists of the digestion of the soil sample with concentrated sulphuric acid in presence of a sodium sulphate catalyst in a digester. The total nitrogen is determined by colorimetry. The pH of soil was measured with a pH-meter in a soil and water suspension of 1:2.5. For the determination of exchangeable bases and *CEC*, the soil sample is leached with normal ammonium acetate at pH 7. The exchangeable bases are determined by flame photometry (Na, K and Ca) and by Atomic Absorption Spectrometry (Mg).

The *CEC* is determined immediately after the exchangeable bases using the same sample and tube. The excess salt is washed out with ethanol 80%. The whole sample is distilled and the evolved ammonia is titrated using 0.05 M HCl.

Total clay (*TC*) and total silt (*TS*) are the percentage of clay and the percentage of silt obtained by the Robinson Köhn method. The Water Dispersible Clay (*WDC*) and the Water Dispersible Silt (*WDS*) are the percentage of clay and the percentage of silt obtained by the same method but without the dispersion agent (sodium hexametaphosphate).

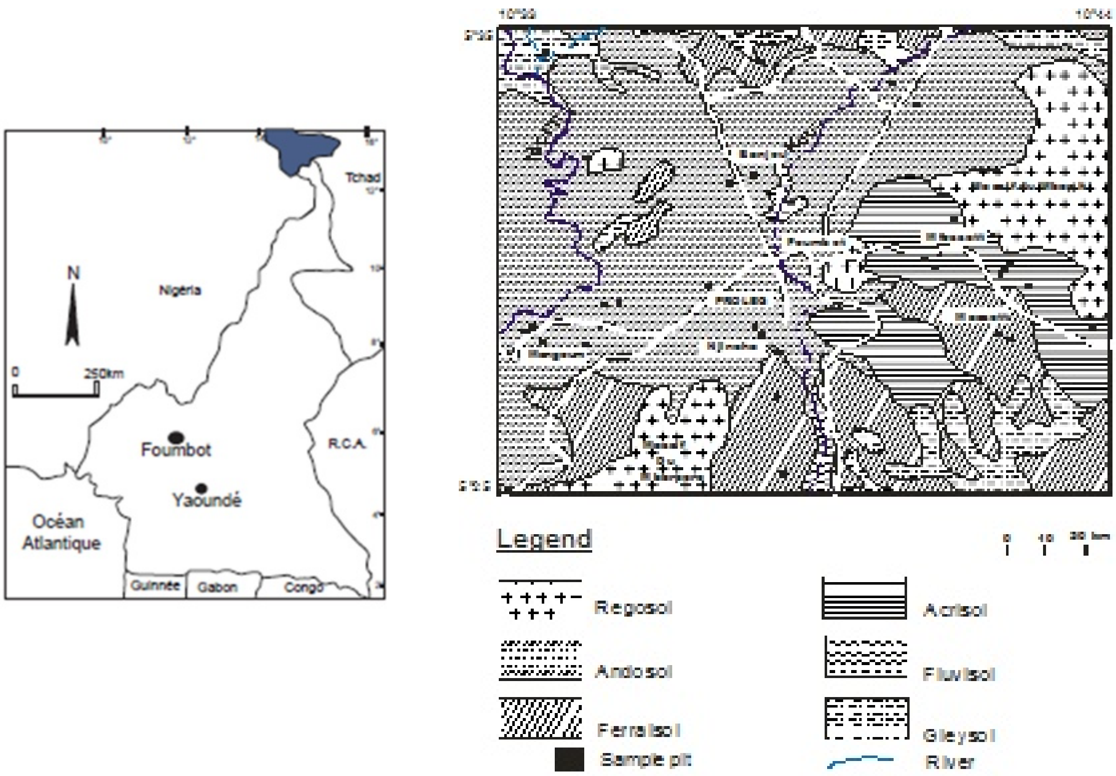

Figure 1: Soils of the Foumbot area as adapted from Segalen (26).

Other soil erodibility indicators such as Clay Dispersion Ratio (*CDR*), Dispersion Ratio (*DR*) and Clay Aggregation (*CA*) were calculated in the equations I, II and III.

$$CDR = WDC/TC \qquad \text{I}$$

$$DR = (WDC+WDS)/(TC+TS) \qquad \text{II}$$

$$CA = (TC-WDC)/TC \qquad \text{III}$$

Separation of water stable aggregate

A Yoder type machine was used for the aggregate stability determination (36). Twenty grams of air-dried soils sieved at 5 mm were put in the topmost sieve of a column of four sieves with respectively 4.5; 3; 1.5 and 0.625 mm meshes. The column was soaked in a cylinder of de-ionized water for one minute. Then, the column was oscillated vertically during seven minutes in the water. After this, the resistant soil aggregates in each sieve (water stable aggregates) and the unstable aggregates (<0.625 mm) were dried at 105 °C during 48 hours and weighed.

The data obtained were used for the calculation of the Mean-Weight Diameter (*MWD*); Equation IV.

$$MWD = \sum X_i W_i \qquad \text{IV}$$

Where X_i is the diameter of the ith sieve size and W_i the proportion of the total aggregates in the ith sieve.

Data analysis

Statistical data analyses, carried out using the SPSS 12 computer package, included summary statistics, analyses of variance (ANOVA) and mean separation (Turkey HSD) for evaluating the differences between treatments.

Results and discussion

Soils characteristics variation among the soil types

Prior to the estimation of soil erosion risk variation in the Foumbot area, analyses of variance (ANOVA) and mean separation were carried on soil characteristics of the three soil groups as shown in table 1. Most of these characteristics vary significantly at p=0.05 between the three soil groups. Soil particle size distribution varies from clayey (Acrisols) to sandy-loam (Andosols).

Ferralsols are very acidic (pH=4.5). The three soil types are all very rich in soil organic matter, although Andosols have a significant highest content. The cation exchange capacity (*CEC*) is low for Ferralsols (8.9 cmol/kg), medium for Acrisols (21.3 cmol/kg) and higher for Andosols (28.8 cmol/kg). The highly significant differences between the three soil types tend to confirm our hypothesis that they may present quite different resistance potentials to raindrops on the soil surface and to shearing actions of runoff.

The relative high content of soil organic matter in the three soil types is likely to reduce erodibility because it produces compounds that bind particles together, increasing aggregation and reducing the susceptibility of the particles to detachment by raindrop impact and surface runoff. Soil organic matter may also improve biological activity and increase an infiltration rate, which reduces runoff and erosion.

Soil erodibility

Several soil erodibility indices were used to assess the erosion risk on the three soil groups. The analysis of the variance (ANOVA) of these soil erodibility indices in table 2 reveals highly significant differences between the three soil groups in terms of water dispersible clay (P<0.000), water dispersible silt (P<0.002), total clay (P<0.000), total silt (P<0.014), clay dispersion ratio (P<0.003), dispersion ratio (P<0.007), clay aggregation (P<0.0001) and medium weight diameter (P<0.000). The separation of means showed that WDC, TC and CDR were significantly lower for Andosols as compared to Acrisols and Ferralsols.

Table 1

Average soil characteristics of the three main soil groups of Foumbot area.

Soil type	Particle size			Chemical properties							
	%			%			cmol/kg				
	Clay	Silt	Sand	OM	Total N	pH	Ca_2^+	Mg_2^+	K^+	Na^+	CEC
Acrisols	44.5 a	30.6 a	24.4 a	7.9 a	0.35 a	5.3 a	1.6 a	2.97 a	0.3 a	0.04 a	21.34 a
Andosols	23.3 b	28.8 a	47.1 b	9.1 b	0.54 b	5.9 a	11 b	2.64 a	1.8 b	0.13 b	28.8 b
Ferralsols	40.4 a	23.6 b	34.9 c	6.6 a	0.11 c	4.5 b	0.8 c	0.75 b	0.2 a	0.03 a	8.87 c

Significantly different at p=0.05.

Table 2

ANOVA and mean separation results for soils particle size parameters and erodibility indices of the Foumbot area (n=31).

Soil types		Erodibility indices							
		WDC (%)	*WDS* (%)	*TC* (%)	*TS* (%)	*CDR*	*DR*	*CA*	*MWD*
	P	0.000	0.002	0.000	0.014	0.003	0.007	0.001	0.000
Acrisols	Average	39.1 a	27.7 a	44.5 a	30.6 a	0.88 a	0.89 a	0.12 a	1.24 a
	SD	5.1	4.5	5.2	5.3	0.02	0.01	0.05	0.26
Andosols	Average	17.7 b	25.0 a	23.3 b	28.8 a	0.76 b	0.82 b	0.24 b	2.46 b
	SD	3.1	3.8	3.6	4.1	0.07	0.02	0.13	0.31
Ferralsols	Average	34.1 a	19.1 b	40.4 a	23.6 b	0.81 c	0.81 b	0.19 b	2.86 b
	SD	11.2	6.3	11.5	5.6	0.08	0.05	0.06	0.55

Notes: *TC*= Total Clay; *TS*= Total Silt; *WDC*= Water-Dispersible Clay; *WDS*= Water-Dispersible Silt; *CDR*= Clay Dispersion Ratio; *DR*= Dispersion Ratio; *CA*= Clay Aggregation; *MWD*= Mean-Weight Diameter.

Figures followed in the same column by the same letter are not significantly different at p=0.05.

Meanwhile *WDS*, *TS* and *DR* were lower for Ferralsols as compared to Acrisols. No significant difference was observed between Andosols and Ferralsols for *DR*, *CA* and *MWD* as compared to Acrisols.

The three soil groups are thus highly different as far as erodibility is concerned.

Lower values of *WDC* and *CDR*, and high values of *CA* and *MWD* actually infer high resistance to erosion. Based on these indices, the susceptibility to erosion between the three soil groups of Foumbot area could thus be ranked as follows: Acrisols>Ferralsols>Andosols. Acrisols appeared to be more susceptible to detachment and transportation by erosion agents in the area whereas Andosols seems to be the most resistant to erosion.

Andosols here have the relative highest organic matter content and they are known to be characterized by the presence of allophane in their mineral fraction which is an amorphous or cryptocrystalline and hydrated mineral substance (11, 29). Allophane contributes, alongside clay minerals and organic matter to the aggregation of soil constituents (30). This mineral phase may explain why the Foumbot Andosols have the highest resistance to water erosion. In addition, the low bulk density of Andosols induces high infiltration of water, reducing at the same time runoff, which is the main agent of aggregate transportation in water erosion. The *CEC* which is slightly higher in Andosols may also play a significant role to stabilized aggregates (7). Indeed, aggregates containing polyvalent cations (Ca_2^+, Al_3^+ and Fe_3^+) are resistant to slaking (30).

Although Clay Aggregation (*CA*), Dispersion Ratio (*DR*) and the Mean-Weight Diameter of water stable aggregates (*MWD*) could not significantly differentiate Ferralsols and Andosols, their values showed similar trends, with a slightly high resistance of Andosols.

This might infers that soil parameters used to compute these indices (*WDC*, *CA*, *CDR*, and *MWD*) may not be the only soil characteristics for explaining and predicting soil erodibility in the area. According to other authors (21), other soil characteristics such as soil mineralogy, soil organic matter content and forms or other intrinsic characteristics of the soil may equally influence the predictability of soil erodibility in this area. In addition, some authors, while investigating recently on appropriate aggregate stability methods that can enable to better distinguish the soil physical quality of different soil types, came out with a similar conclusion that the aggregate stability should be used judiciously and in concert with other indicators for an overall assessment of the conditions of soil physical quality (19).

The study has shown that in terms of resistance to water erosion, the soils of the Foumbot area are ranked from Andosols to Acrisols.

Knowing that they are all rich in organic matter and that the less resistant to erosion has the higher amount of clay of the three, an intrinsic characteristic of these soils may be the key factor controlling soil erodibility variation in the area. The most resistant soils (Andosols) are volcanic soils in which non crystalline minerals play an important role in the aggregation because of their high surface areas. Iron and aluminum oxides are the main factor controlling soil aggregation in the Ferralsols then the resistance to erosion (6). The Acrisols are rich in kaolinite characterized by low *CEC* and low surface area that decrease aggregates stability (3). So soil mineralogy is the main factor regulating soil erosion in the Foumbot area. Field observation reveals that water erosion is the main type of erosion encounter in this area. In Andosols, erosion ranges from splash erosion in lowlands to rill erosion on the slope whereas in Acrisols, it ranges from sheet erosion to gully erosion. In Ferralsols, the water erosion ranges from sheet erosion in lowlands to rill erosion on slope.

Relationships between erodibility indices and soils characteristics

Looking for potential relationship between erosion risk and soil characteristics, many soil erodibility indices correlate with some soil characteristics (Table 3).

Table 3

Pearson's Coefficients of Correlation (*PCC*) between erodibility indices and soils properties in the Foumbot area.

Chemical properties	*PCC*	*WDC*	*WDS*	*CDR*	*DR*	*CA*	*MWD*
OM (N=31)	*PCC*	-0.606(**)	0.686(**)	-0.442(*)	-0.021	-0.442(*)	-0.393(*)
	p	0.000	0.000	0.013	0.909	0.013	0.029
pH (N=12)	*PCC*	-0.301	0.245	-0.032	-0.157	0.032	-0.066
	p	0.341	0.443	0.92	0.626	0.92	0.838
Ca^+ (N=12)	*PCC*	-0.673(*)	0.069	-0.555	-0.305	0.555	0.461
	p	0.016	0.832	0.061	0.335	0.061	0.131
Mg^+ (N=12)	*PCC*	-0.174	0.294	0.073	0.157	-0.073	-0.317
	p	0.589	0.354	0.822	0.627	0.822	0.315
K^+ (N=12)	*PCC*	-0.736(**)	0.122	-0.463	-0.195	0.463	0.393
	p	0.000	0.705	0.129	0.543	0.129	0.206
Na^+(N=12)	*PCC*	-0.298	0.111	0.233	0.346	-0.233	0.043
	p	0.346	0.731	0.466	0.271	0.466	0.894
CEC (N=12)	*PCC*	-0.283	0.032	-0.146	-0.039	0.146	0.202
	p	0.373	0.921	0.651	0.904	0.651	0.530

Notes: *WDC*= Water-Dispersible Clay; *WDS*= Water-Dispersible Silt; *CDR*= Clay Dispersion Ratio; *DR*= Dispersion Ratio; *CA*= Clay Aggregation; *MWD*= Mean-Weight Diameter; *SOM*= Soil organic Matter; *CEC*= Cation Exchange Capacity;

(*; ** correlation is significant at p<0.05 and 0.01 respectively).

The Water Dispersible Clay (*WDC*) significantly correlates negatively with the Soil Organic Matter (*OM*) (r=-0.61, p=0.000). This means that higher organic matter will reduce the water dispersible clay, thus the soil erodibility. As mentioned above, soil organic matter is one of the key factors increasing soil aggregation (3). That is why it is primarily used for computing the soil erodibility *K*-factor (35).

It acts as bonds to form aggregates with clay particles in the soil. It so controls the aggregation and disaggregation of soil clay (12). Significant negative correlation exists between calcium (r=0.67, p=0.016), potassium (r=-0.74, p=0.000) and Water Dispersible Clay. Some bivalent cations as calcium and sometimes magnesium through their cationic bridging with clay particles and soil organic matter improve soil aggregation which is an indicator of soil structure (27). This implies that higher values of these soil characteristics will reduce *WDC* hence, soil erodibility. This is what certainly explains the resistance of Andosols of the Foumbot area. This is also the case of the Clay Dispersion Ratio (*CDR*) which correlates negatively with organic matter (r=-0.44, p=0.013).

The water dispersible silt (WDS) correlates positively with the organic matter (r= +0.67, p=0.000).

Soil erodibility and soil conservation

The Foumbot area is subjected to naturally high rainfall intensity. High values of Water Dispersible Clay and Clay Dispersion Ratio indicate a risk of high soil erodibility and thus high soil degradation. Moreover, unsuitable traditional farming practices leading to the destruction of organic matter by fire for land preparation, seedbeds oriented alongside the slope and intensive exploitation of soil are non-benefic practices to soil conservation in the area. They all induce high soil erosion risk and expose the area to severe land degradation and desertification (32). Erosion process on these soil in the undulated landscape of the Foumbot area is likely to produce clay and silt deposition in low-land areas, leading to the formation and the increase of existing marshy land areas. Such marshy lands are known to be improper for agriculture in this area where agricultural lands are rather under high pressure due to the high demography.

According to several authors (5, 9); one of the most common strategies for soil erosion control and soil conservation on such agricultural lands would be a suitable preservation of the vegetation cover on soil. Such vegetation cover limits soil degradation by decreasing soil erosion and soil surface evaporation, by increasing CEC, soil aggregate stability and water infiltration (3).

It also reduces the impact of raindrop on soil aggregates and particles (14) and contributes to the improvement of physical and chemical characteristics of soils (10).

Vegetation cover has the capacity of increasing the amount of soil organic matter which is one of the main soil characteristics that influences soil erodibility. However, the question is how to conserve organic matter in these soils under high intensity use? For a sustainable management option in the Founbot area, special attention should thus be paid to incorporating household and livestock sub-products for increasing soil organic matter content and soil stability. On these aspects, researches on agro-forestry systems involving soil vegetation cover types in Cameroon have shown that there is a wide range of plant species that could be used in improved fallow technologies aiming at soil conservation (13, 25). It has been shown that a reasonable quantity of plant biomass incorporated in agricultural soil significantly increases soil organic matter, base saturation and soil pH. Applying plow ridges along the contour lines will also reduce transportation of particles and increase water infiltration. Other soil management practices such as intercropping with leguminous crop may reduce soil loss on moderate slopes of less than 10% (25).

Conclusion

Four erodibility indices (*WDC*, *CDR*, *CA* and *MWD*) used to predict soil erosion risk in the Foumbot area, have shown that the three types of soil have high dispersive potentials. High values of water dispersible clay and clay dispersion ratio indicate high soil erodibility and thus high soil degradation. Soil characteristics and soil erodibility vary from one class of soil to another.

The most erodible soils are Acrisols and the less vulnerable soils are Andosols. Soil mineralogy appeared to be one of the factors controlling soil erodibility variation in the area.

The relationships between soils characteristics and soil erodibility indices indicated that some soil characteristics such as organic matter highly influences soil erodibility in the area. Higher organic matter reduces soil erodibility and can suitably be used to control soil erosion in the Foumbot area. This is possible with cropping systems that cover the soil surface, limit soil transportation by water and protect soil against clay dispersion.

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J.D. Ngandeu-Mboyo, Cameroonian, PhD Student, University of Yaoundé I, Department of Earth Sciences and UMMISCO Unit, Yaoundé, Cameroon.

M. Yemefack, Cameroonian, PhD, Senior Research Officer, International Institute of Tropical Agriculture, Yaoundé, Cameroon & Institute of Agricultural Research for Development, Nkolbisson, Cameroon.

R. Yongue-Fouateu, Cameroonian, PhD, Associate Professor, University of Yaoundé I, Department of Earth Sciences, Yaoundé, Cameroon.

P. Bilong, Cameroonian, PhD, Professor, University of Yaoundé I, Department of Earth Sciences, Yaoundé, Cameroon.