Original Research Article

Morphology, physicochemical characterisation and erodibility of soils of Boboyo (Far - North Cameroon)

Abstract

Objectives: The present work contributes to the study of soils in the Northern part of Cameroon, precisely in Boboyo region soils. This work aims to study morphology and physicochemical characteristics of those soils and to assess their vulnerability to erosion. Methodology: Ten wells were dug according to two directions: one direction W-E and one direction NNE-SSW. The principal analyses carried out in a laboratory are the physicochemical analyses: the granulometric analyse and the proportioning of organic carbon, total nitrogen, the exchangeable bases, the pH and residual moisture. The erodibility indices are calculated starting from the physicochemical data of the soils.

Results: six types of soils were identified in Boboyo: alluvial soils (entisols, fluvisols) widely spread in the region, covering the seasonally flooded plain, lithosols were found in the upper part of the landscape, colluvial soils (arenosols, regosols) were located in the Piedmont, the vertical alluvial soils were located in lower part of the slope in flooded plain, vertisols and ferruginous indurate soils were founded between colluvial (arenosols, regosols) and alluvial soils (entisols, fluvisols). The physico-chemical analyses reveal that: the colluvial soils (arenosols, regosols) are neutral to weakly acid (7 to 5,4), clayey-sandy to sandy; the vertisols are weakly acid (pH=6,3), sandy-clay (sand =77,9 and clay=19,6); The alluvial soils (entisols, fluvisols) are acid to neutral (pH= 5,2 to 7), sandy (80%); the vertic alluvial soils are neutral (pH=7), clayey-sandy (clay 34,2 and sand 65,3) and ferruginous indurate soils (luvisols) are acid (pH=5,2), sandy. All these soils are saturated (78 to 98), poor in organic matter (0,72 to 2,89%) and nitrogen and characterised by moderate proportions of exchangeable bases. The assessment of the erodibility based on erodibility indices enables to show that alluvial soils (entisols, fluvisols) are most vulnerable to erosion while the colluvial soils (arenosols, regosols) are less susceptible.

Keywords: Sudano-Sahelian areas, Boboyo, alluvial soils (entisols, fluvisols), erodibility indices.

Introduction

Far North Cameroon has been the subject of several pedological studies which have examined the genesis, the physicochemical characterisation and the determination of the cultural capacities of soils (Martin, 1962, 1963; Brabant and Gavaud, 1985; Patékéré, 2004; Nguetnkam, 2004; Yanga, 2005). Some studies are interested in their behavior in the face of erosion: Seiny et al. (1991); Mahop et al. (1995) set out to characterise soils, quantify runoff and seepage, and assess the sensitivity of these soils to water erosion. These authors used the direct method by rain simulation. In Mouda in Far North Cameroon, Mahop et al. (1995) show that under simulated rain and bare soils, degraded vertisols and hardened soils are the most susceptible to erosion because runoff is observed from the first rainfall. On the other hand, modal vertisols and ferruginous soils are less vulnerable to corrosion. More recent studies have focused on the petrographic and structural study (Bello, 2015) and the mineralogy and geochemistry of Kaélé soils (Nguetnkam, 2012, 2013). Some work has been published on the measurement of soil erodibility based on the use of the indirect or laboratory method (Seta and Karathanasis 1996, Igwé 2001, 2003, 2005, Salako 2001, Teo'genes et al., 2005). This technique consists in evaluating it by calculating the erodibility indices from the physicochemical data of the soils. In 2003, Igwe studied soil erodibility (acrisols, nitosols, gleysols, and ferralsols in the FAO classification) in humid forest areas in southeastern Nigeria. This study shows that water dispersible clay (WDC), clay dispersion ratio (CDR) and dispersion ratio (DR) can be used to predict erodibility of soils. Several recent studies have studied weathering rates and some physicochemical characteristics of soils developed on a calcic toposequences (Dengiz, 2013). The aim of this study is to carry out a pedological assessment of the soils classified as Regosol, Cambisol and Vertisol by taking into consideration FAO classification system formed on different topographic position and the same parent rocks. The second aim of this research is to answer the question about the difference in classification resulting from pedogenic processes or other factors by determining the degree of weathering soils using geochemical data. In 2012, Scherer and *al* studied prediction of soil detachment in agricultural loess catchments: model development and parameterisation. This study shows that cultivation was the first order control of the erosion resistance on conventionally tilled loess soils: crops that are cultivated in rows were strongly susceptible to detachment because runoff is channelled along the intermediate areas of plant rows. These present work asses the morphology and physicochemical characterisation of the soils of Boboyo and the determination of eligibility indices.

Materials and Methods

Location of the study area

Located in the far North of Cameroon, Boboyo area belongs to the district of Kaélé, department of Mayo-kani. It is located in NW part, seven kilometres from Kaélé. The area of Boboyo like the whole region of extreme North Cameroon enjoys a sudano-sahelian climate. This climate is characterized by a mean annual rainfall of 997,3mm and mean annual air temperature of about 31.7°C. The aridity index of De Martonne (1926) shows a dry season from December to April ($I < 20$) and a raining season from June to September ($I > 20$). The rains are concentrated in the three humid months of the year July, August and September ($I > 50$). The direction of the wind is characteristic of the different seasons. The S-SW wind characterises the rainy season and the N dry season wind. The vegetation of Far North Cameroon is characterized by two areas: the Sahelo-Sudanian shrub savanna area and the Sudano-Sahelian shrub savanna savanna area. Boboyo, object of the present study, is a plain in which stand masses of granitic rocks (Tessalé Boboyo) with the look of horst. On Tessalé Boboyo, the heterogeneous calc-alkaline granites model and extend northward in three rocky points (Morin, 2000). Metamorphic rocks (micaschist, orthogneiss and gneiss) and sedimentary formations (laterites, alluviums) outcrop in some places (Martin 1963, Dumort and Peronne 1966, Regnoult 1986). In Boboyo, the outcrops of the lateritic cuirass slabs at Goudjouing and Kassilé are noted. In Far-North Cameroon, the main types of soils encountered are: poorly evolved erosion and input soils, hydromorphic soils, desert to sub-desert soils, fersialitic soils and vertisols.

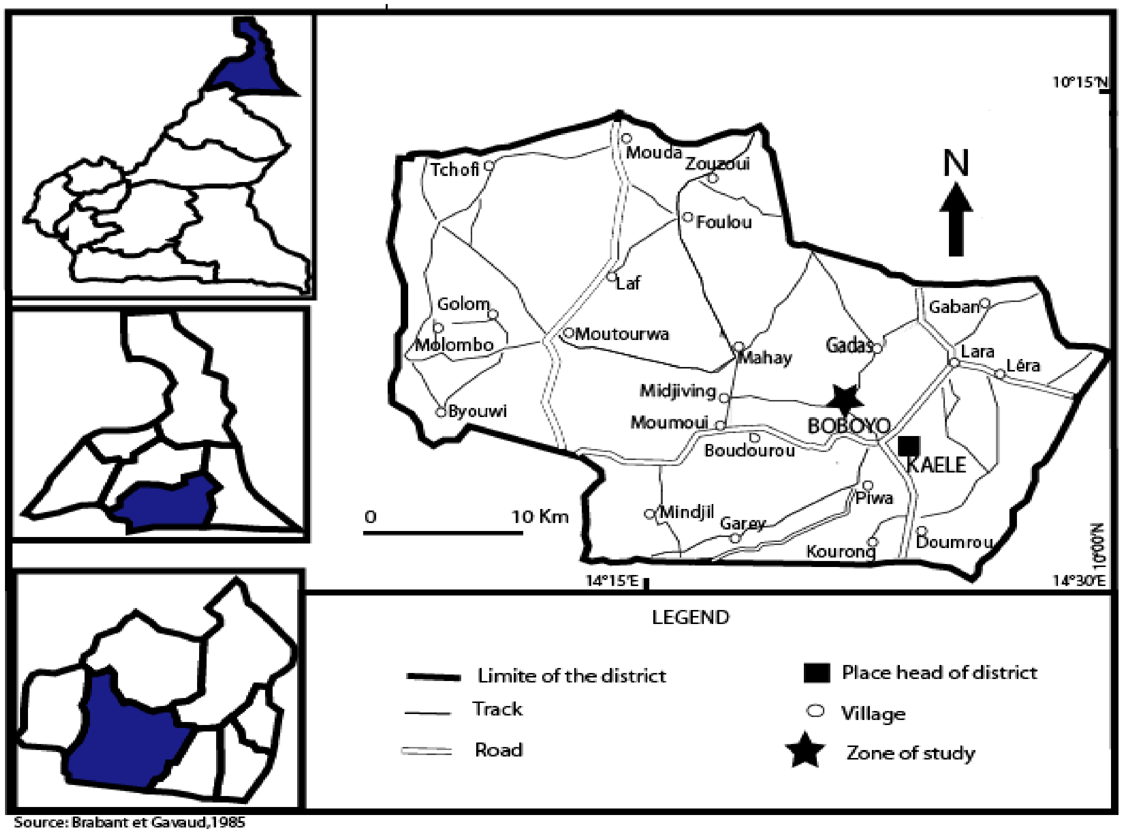


Figure 1: Location map of Boboyo.

On the ground

With the exit of several campaigns of soils, ten wells were produced and exploited. These ten wells were dug according to two directions (transects): one direction W-E and one direction NNE-SSW (figure 2). The open wells were named B11, B12, B13, B14, B15 and B16 following E-W direction and B21, B22, B23, B24 following NNE-SSW direction.

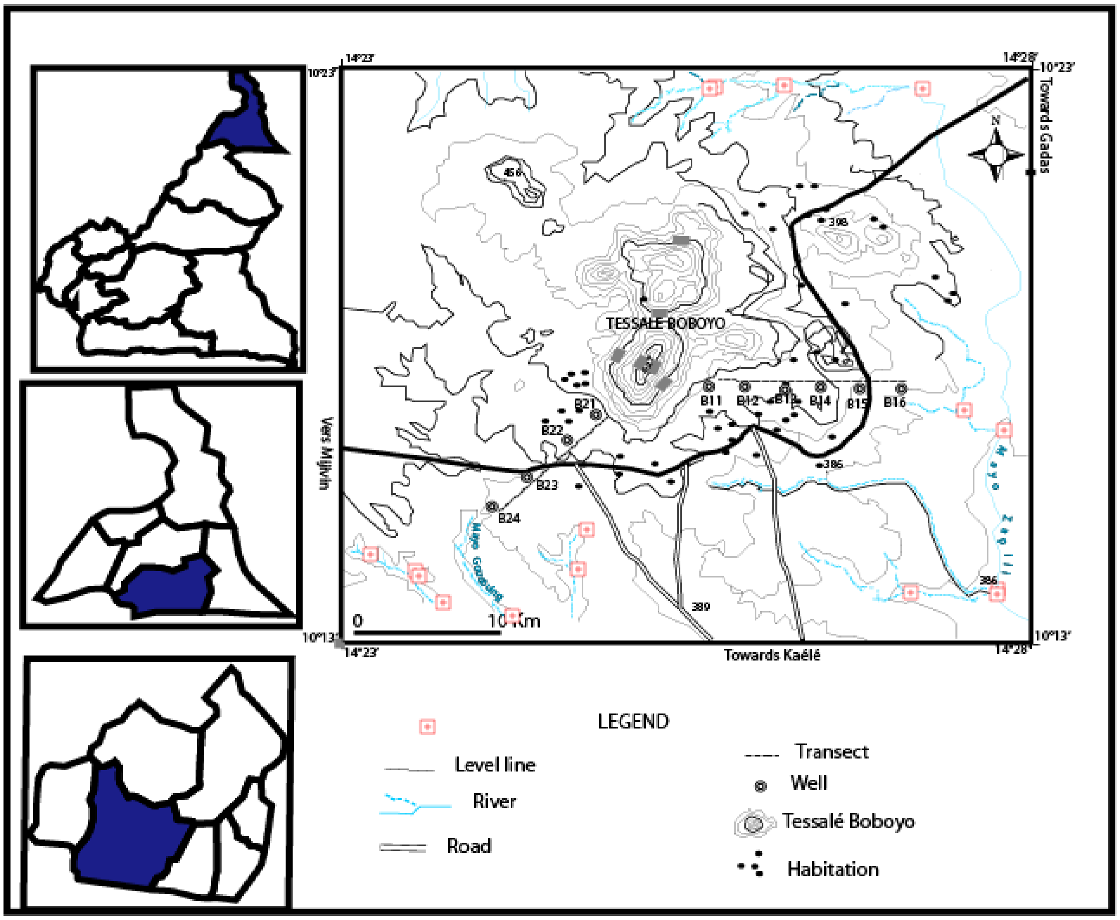


Figure 2: map of sampling of the Boboyo soils

Laboratory

The principal analyses carried out in laboratory are the physicochemical analyses. The samples of soils were dried in the open air, then crushed and sieved at 2mm. The fine soil obtained was used for the granulometric analyze and the proportioning of organic matter by the method Walkley and Black (1934), organic carbon, total nitrogen, the exchangeable bases, the pH and residual moisture. The particle size analysis is carried out using the Robinson Khön pipette method. The principle is based on the law of Stockes which gives the speed of falling of the particles according to the diameter. Organic carbon was measured by the Walkley and Black method (1934) which is a wet oxidation. It consists in oxidizing the organic matter of a soil sample by mixing potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid (H_2SO_4). The reading is done with JENWAY 6300 spectrophotometer. The total nitrogen is determined by the method of Khjedahl. The ammonium acetate percolation method (pH7) is used for the determination of exchangeable bases. The physico-chemical analysis and erodibility data were processed using the Excel software and the correlations were studied under the SPSS software. Differences are considered significant for a probability less than 0.01 and 0.05.

Estimate of the erodibility of the soils

To evaluate the erodibility of the soils, two methods are used: the direct method or simulation of rain consists in producing an artificial downpour on a micro piece, in order to measure the streaming and the losses of induced soil (Diallo and *al*, 1995; Barthès and *al*, 1998) and the indirect or analytical method or of laboratory, it consists in evaluating the erodibility of the soils by using the erodibility indices which are calculated starting from the physicochemical data of the soils. Granulometric analysis with dispersant gives the values of total clay and total silt. Granulometric analysis without dispersant gives the values of clay dispersed in water and silt dispersed in water. Indirect method developed by Middleton (1930) and Igwe (1995, 2001, 2003, 2005) is that which use to evaluate erodibility of Boboyo soils.

The equations used are as follows:

CDR = WDC (%) / TC (%);

CA = TC (%) – WDC (%);

DR = WDC %) + WDS (%) / TC (%) + TS (%);

ESP = (exchangeable Na^+ / CEC) × 100;

ESR = exchangeable Na^+ / exchangeable (Ca^{2+} + Mg^{2+} + K^+).

The indices used are: Total clay: TC, Water Dispersible Clay: WDC, Clay Dispersible Ratio: CDR, Dispersion Ratio: DR, Clay Aggregation: CA and Exchangeable Sodium Percentage: ESP and Exchangeable Sodium Ratio: ESR.

Example of the W-E direction: B11 profile

- Calculation of CDR. WDC = 2,8 and TC = 11,5 → CDR= 2,8/11,5= 0,24 → CDR = 0,24

- Calculation of the CA. → CA= 11,5 – 2,8 = 8,7 → CA = 8,7%

- Calculation of the DR. WDS = 14,4 and TS = 8,9 → DR = (2,8+14,4) / (11,5 + 8,9) = 0,84

- Calculation of the ESR. Exchangeable Na^+ = 0,10 and CEC = 8,20 → ESR = 0,01

- Calculation of the ESP. Exchangeable Ca^{2+} = 5,76; Exchangeable Mg^{2+} = 0,58 ; Exchangeable K^+ = 0,42. → ESP = 0,10 / (5,76 + 0,58+ 0,42) = 1,22. → ESP = 1,22

Results

Macromorphology

For the soils of Boboyo, the FAO classification (1999) was used. The macromorphologic data made it possible to identify the types of soils of Boboyo. Following **W-E** direction we have: lithosols (gray 10YR 5/1) which occupy the high zones of the landscape, of altitude higher than 420 m, and whose profile is reduced to a humus-bearing horizon surmounting the granitic arena; colluvial soils (arenosols, regosols) brown 10YR 4/6 which are located high on Piedmont (410m of altitude), of sandy texture, polyhedral structure, quite porous, friable in the dry state and including three horizons; the vertisols brown grey dark 10YR 3/2 are located between the colluvial soils (arenosols, regosols) and the alluvial soils (entisols, fluvisols), of sandy texture, highly developed polyhedral structure, friable and sticky when dry, presence of withdrawal slot, localized effervescence with HCl and present three horizons having a genetic bond between them; the alluvial soils (entisols, fluvisols) located in bottom of slope are extended, sandy texture, and including four to eight horizons; the vertic alluvial soils (alfisol, ultisol) located completely in bottom of slope, in the alluvial plain, are of sandy-clay texture and understand four horizons. Following **NNE-SSW** direction we have: lithosols which occupy the high zones of the landscape and whose profile is reduced to a humus-bearing horizon surmounting the granitic arena; colluvial soils (arenosols, regosols) which are appear in the uppermost landscape position (of altitude lower than 410m), of sandy texture and including three horizons; ferruginous indurate soils (luvisols), of sandy texture, which cover the zone between the colluvial (or arenosols, regosols) and the alluvial soils (entisols, fluvisols); and alluvial soils which are the most widespread in the region, covering the seasonally flooded plain, sandy texture, and include four to eight horizons. Thus, the two directions are marked by the great extension of the alluvial grounds. However, it appears that the W-E direction presents a large variety of soils, marked by the presence of vertisols in top of slope and vertic alluvial soils completely in bottom of slope.

Table I: Macromorphological properties of alluvial soils.

Macromorphological properties / **Type of soils**	Color	Structure	Consistence	Others properties
Alluvial soils (entisols, fluvisols) B13	brown gray (10YR 4/2	polyhedral structure	friable in the wet state, fragile in the dry state	Porous, presence of quartz gravels and feldspars
Alluvial soils (entisols, fluvisols) B14	gray brown (10YR 5/2)	particle structure	friable in the wet state, fragile in the dry state	quite porous, presence of quartz crystals and feldspars
Alluvial soils (entisols, fluvisols) B15	light grey (2.5Y 8/1)	massive structure	Clayey, very compact, not very friable when wet	non-porous, rift, rusty spots
Alluvial soils (entisols, fluvisols) B16	Brown (10YR 4/3)	polyhedral structure	has a vertisolic horizon characterized by a massive to polyhedral structure, large shrinkage slits, compact, very sticky, friable when wet	
Alluvial soils (entisols, fluvisols) B23	light brown (10YR 6/3)	polyhedral structure	friable in the wet state, fragile in the dry state	some round quartz crystals and ferruginous nodules
Alluvial soils (entisols, fluvisols) B24	gray brown (10YR 5/2)	polyhedral structure	friable in the wet state, fragile in the dry state	quartz crystals rounded with brown hues

Physicochemistry

The physicochemical analysis of the soils of Boboyo following W-E direction shows that: colluvial soils (or arenosols, regosols) are slightly acid, sandy and present average proportions in exchangeable bases and organic matter; vertisols are slightly acid, sandy, present average proportions out of organic matter and exchangeable bases; alluvial soils (entisols, fluvisols) are neutral, sandy, rich in exchangeable bases and present an average content of organic matter; vertic alluvial soils (alfisol, ultisol) is neutral, sandy-clay, low in organic matter and having strong proportions in exchangeable bases. All these soils are saturated and low in nitrogen.

Table II: Physicochemical characters of the surface horizons of W-E direction of Boboyo

Types of soils	Granulometric analysis with dispersant (%)				Granulometric analysis without dispersant (%)				pH		
	Clay	**FS**	**CS**	**FS**	**CS**	**Clay**	**FS**	**CS**	**FS**	**CS**	**H_2O**	**KCl**	**ΔpH**
Colluv soil B11	11 ,5	4,0	4,9	20,4	58,9	2,8	10,0	4,4	22,7	59,9	5,4	4,7	0,7
Vertisol B12	12,8	4,5	2,3	20,1	57,8	5,5	8,0	4,8	22,9	58,1	6,3	5,0	1,3
Alluv soil B13	12,5	1,3	5,8	20,7	58,1	1,3	10,0	6,6	22,1	60,2	8,0	7,4	0,6
Alluv soil B14	12,8	5,3	3,8	29,5	45,9	10,5	4,8	4,4	34,1	45,6	7,1	6,6	0,5
Alluv soil B15	12,8	4,5	6,5	39,9	34,1	10,5	4,3	3,8	48,6	33,1	6,1	4,4	1,7
Vertic soil B16	18,3	4,5	11,4	54,9	10,4	3,3	17,0	10,8	60,5	10,5	7,0	4,3	2,7

Types of soils	Organic matter (%)				Exchangeable cations (méq/100g)						
	OM	**OC**	**NT**	**C/N**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Na^+**	**S**	**CEC**	**S/T**
Colluv soil B11	1,43	0,83	0,05	16,6	5,76	0,58	0,42	0,10	6,86	8,20	84
Vertisol B12	2,49	1,45	0,04	36,2	7,12	2,04	0,55	0,10	9,81	11,56	85
Alluv soil B13	2,89	1,68	0,02	84	5,87	2,84	1,42	0,58	10,71	11,20	96
Alluv soil B14	2,17	1,26	0,03	42	7,56	1,84	0,82	0,28	10,80	11,20	94
Alluv soil B15	0,74	0,43	0,00	-	4,56	0,80	0,62	0,42	6,40	8,08	79
Vertic soil B16	0,76	0,44	0,00	-	9,56	0,64	0,54	0,47	11,21	12,8	88

Colluv soil: **colluvial soil**, alluv soil : **alluvial soil**, vertiq soil : vertic alluvial soil. **FS**: fine silt. **CS**: coarse silt. **FS**: fine sand. **CS**: coarse sand. **OM**: organic matter **OC**: organic carbon **NT**: nitrogenize total.

Following the NNE-SSW direction, the physicochemical analysis of the soils of Boboyo, shows that: colluvial soils (or arenosols, regosols) are neutral, sandy-clay and are characterized by strong proportions in exchangeable bases; the ferruginous indurate soils (luvisols) are acid, sandy, and present average proportions in exchangeable bases and alluvial soils (entisols, fluvisols) are acid, sandy and characterized by average proportions in exchangeable bases. These soils are saturated, low in organic matter and nitrogen.

Table III: Physicochemical characters of the surface horizons of NNE-SSW direction.

	Granulometric analysis with dispersant (%)					Granulometric analysis without dispersant (%)					pH		
	Clay	**FS**	**CS**	**FS**	**CS**	**Clay**	**FS**	**CS**	**FS**	**CS**	**H_2O**	**KCl**	**ΔpH**
Colluv soil B21	20,0	5,5	4,9	20,1	48,8	0,5	22,3	5,9	24,2	46,8	7,0	6,1	0,9
Fer ind soil B22	11,2	0,8	5,9	26,1	55,2	1,8	7,0	6,6	28,1	56,1	5,2	4,1	1,1
Alluv soil B23	12,2	7,0	2,3	39,8	38,2	8,8	7,8	3,5	42,8	37,1	5,5	4,3	1,2
Alluv soil B24	13,0	7,5	2,1	35,4	42,4	10,0	8,5	6,8	32,5	42,8	5,6	4,4	1,5

	Organic matter (%)				Exchangeable cations (méq/100g)						
	OM	**OC**	**NT**	**C/N**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Na^+**	**S**	**CEC**	**S/T**
Colluv soil B21	1,00	0,58	0,04	14,5	11,21	1,84	0,72	0,38	14,15	15,86	89
Fer ind soil B22	1,79	1,04	0,03	34,6	3,12	1,20	0,54	0,18	5,04	5,12	98
Alluv soil B23	0,72	0,42	0,03	14	3,76	0,32	0,42	0,47	4,97	6,4	78
Alluv soil B24	1,36	0,79	0,04	19,7	5,04	0,36	0,85	0,47	6,72	7,64	88

Colluv soil : colluvial soil, **Alluv soil**: alluvial soil, **Fer ind soil** : ferruginous indurate soils. **FS**: fine silt. **LG**: coarse silt. **SF**: fine sand. **SG**: coarse sand. **OM**: organic matter **OC**: organic carbon. **NT**: nitrogenize total.

Erodibility of soils

Erodibility of the soil is defined as the vulnerability or susceptibility of the soil to erosion (Igwe, 2003). Erodibility of soils can be still defined like the evaluation of the susceptibility of the soils to the detachment of its particles and their transport by the agents of erosion (Cerdan, 2001).

Erodibilty of soils to W-E direction

Table IV: Erodibility indices of the surface horizons of the soils of Boboyo following W-E direction

Types of soils	WDC (%)	WDS(%)	TC (%)	TS(%)	CDR (%)	DR	CA	ESR	ESP
Colluv soil B11	2,8	14,4	11,5	8,9	0,24	0,84	8,7	0,01	1,22
Vertisol B12	5,5	12,8	12,8	6,8	0,42	0,93	7,3	0,01	0,86

Alluv soil B13	1,3	16,6	12,5	7,1	0,1	0,91	11,2	0,05	5,17
Alluv soil B14	10,5	9,2	12,8	9,1	0,82	0,89	2,3	0,02	2,50
Alluv soil B15	10,5	8,1	12,8	11	0,82	0,78	2,3	0,07	5,19
Vertic soil B16	3,5	27,8	18,3	15,9	0,18	0,9	15	0,04	3,67

The total clay of Boboyo soils varies from 11,5% for colluvial soil (arenosols, regosols) B11 to 18,3% for the alluvial soil (entisols, fluvisols) B16. It is noted that the alluvial soil (entisols, fluvisols) B16 located at 2200m of the granitic solid mass, is more clay than colluvial soil (arenosols, regosols) B11. Water dispersible clay or the WDC varies from 1,3 % for the alluvial soil (entisols, fluvisols) B13 with 10,5% for the alluvial soil (entisols, fluvisols) B14 and B15. Water dispersible clay present of the values raised for the profiles B14, B15 and of the weak values for other soils. Igwe (2003) and Brubaker and *al* (1992) show that the soils having a high value of WDC erode more easily than those having a low value. It thus appears that the alluvial soils (entisols, fluvisols) B14, B15 are most susceptibility soils at erosion. The various studied soils can be classified according to their increasing degree of erodibility: colluvial soil (arenosols, regosols) – vertic alluvial soil (alfisol, ultisol) –vertisols – alluvial soil (entisols, fluvisols). All things considered, the soils susceptible to erosion are alluvial soil (entisols, fluvisols) B13 and B12 which are located at a few meters of the granitic solid mass. The most soils who susceptible to erosion are the alluvial soils (entisols, fluvisols) B14, B15 respectively located at 1500 and 1900m of the granitic solid mass.

Dispersion ratio or DR of the studied soils varies between 0,78 for alluvial soil (entisols, fluvisols) B15 and 0,93 for the vertisol B12. These values of DR show that the alluvial soil B12 is most susceptibility at erosion whereas the alluvial soil (entisols, fluvisols) B15 is the least susceptible to erosion; indeed, more the value of DR is raised, more the soil has the potentiality to erode (Middleton 1930; Brubaker and *al*, 1992). While basing oneself on the values of DR, it can also classify the soils of Boboyo, energy of the soils having the potentiality to erode on the soils not having this potentiality: alluvial soil (entisols, fluvisols) –colluvial soil (arenosols, regosols) –vertic alluvial soil (alfisol, ultisol) – vertisol.

Clay Dispersion Ratio (CDR) presents proportions ranging between 0,10 for the alluvial soil (entisols, fluvisols) B13 and 0,82 for the alluvial soils (entisols, fluvisols) B14 and B15. According to Igwe (2004), the soils having a high CDR indicate a severe dispersion, whereas those with weak CDR reveal a weak dispersion. Alluvial soils (entisols, fluvisols) B14 and B15 is dispersed whereas the alluvial soil (entisols, fluvisols) B13 is dispersed the least. The classification of the soils according to their dispersion (CDR), gives the following order of the soils most dispersed towards the least dispersed: Alluvial soils (entisols, fluvisols, alfisol, ultisol) – vertisols – colluvial soils (or arenosols, regosols).

Clay Aggregation (CA) indicates the class of stability of the soils. The soils richest in aggregates erode more slowly than the soils low in aggregates (Igwe, 2003). The clay rate incorporated for the various studied soils varies between 2,3 for the alluvial soils (entisols, fluvisols) (B14, B15) and 15 for the vertic alluvial soil (alfisol, ultisol) (B16) (tableau IV). The soils B13 and B16 have the CA values higher than 10; the soils B11, B12 have the CA values ranging between 5 and 10 and the soils B14, B15 have values lower than 5. The soil B16 aggregate than all the others is followed of B13, B11, B12, B14 and B15. It results from it that the alluvial soils B13 and B16 are most stable and thus the least vulnerable; and the alluvial soils (entisols, fluvisols) B14, B15 most unstable and most likely with erosion. Soils of Boboyo are classified more stable with most unstable according to decreasing CA: vertic alluvial soils (alfisol, ultisol) – colluvial soils (arenosols, regosols) – vertisol – alluvial soils (entisols, fluvisols).

The values of the exchangeable sodium rate or Exchangeable Sodium Ratio (ESR) are overall moderate for the whole of the studied soils. They are: ranging between 0,07 for the alluvial soils B15 and 0,01 for the colluvial soil (arenosols, regosols) B11 and the vertisol B12 (tableau IV).

The values of the percentage of exchangeable sodium (ESP) lie between 5,19 (B15) and 0,86 (B12). The values of ESP are average for the soils B13, B14, B15 and B16 and weak for the soils B11 and B12 (Mémento de l'agronome, 1984; Beernaert and Bitondo, 1992). At the end of this study, it is noted that the alluvial soils (entisols, fluvisols) are the most susceptible to erosion.

All things considered, the study of the erodibility of the soils of the W-E direction shows that: the vertic alluvial soil (alfisol, ultisol) (B16) is most clay, the others being sandy; the soils most vulnerable to erosion are the alluvial soils (B14, B15); the colluvial soils (arenosols, regosols) are less susceptible to erosion; alluvial soil (entisols, fluvisols) is more vulnerable to dispersion because showing the most raised value of DR. It arises from the values of CDR that clays of the alluvial soils (entisols, fluvisols) B14 and B15 are strongly dispersed then in the alluvial soil (entisols, fluvisols) B13 is not it less. There is a positive correlation between the WDC and the CDR: soil having the strongest value of WDC to also the highest value of CDR. Aggregate clay rate or CA, it arises that the alluvial soils (entisols, fluvisols) B14, B15 are most unstable and most vulnerable to erosion, whereas the soils B13 and B16 are more stable and little susceptibility to erosion.

Erodibilté of soils to NNE-SSW direction

Table V: Indices of erodibility of the surface horizons of soils following NNE-SSW direction.

	WDC (%)	WDS (%)	TC (%)	TS (%)	CDR (%)	DR	CA	ESR	ESP
Colluv soil B21	0,5	28,2	20	10,4	0,02	0,94	19,5	0,027	2,39
Fer ind soil B22	1,5	13,6	11,2	6,7	0,16	0,86	9,4	0,037	3,51
Alluv soil B23	8,8	11,3	12,2	9,3	0,72	0,93	3,4	0,104	7,34
Alluv soil B24	10	15,3	13	9,6	0,76	1,11	3	0,075	6,15

Total clay (TC) varies from 11, 20% for the ferruginous indurate soils B22 to 20% for colluvial soil (arenosols, regosols) B21 (table IV). It is noted that ferruginous indurate soils B22 has low TC content while the colluvial soil (arenosols, regosols) B21 has strong proportion of TC (20%). It results from it that the soil B21 is more clayey than the soil B22.

Soils having a high value of Water Dispersible Clay (WDC) erode more easily than those having a low value (Bajracharya and al., 1992; Brubaker and al., 1992 ; Igwe, 2003). Water clay dispersed varies from 0, 5 % for colluvial soil (arenosols, regosols) B21 to 10,0% for alluvial soil (entisols, fluvisols) B24. WDC or water clay dispersed presents a strong value for the B24 profile. It thus appears that the alluvial soil (entisols, fluvisols) B24 is most susceptibly soil to erosion. Soils studied can be classified according to their increasing degree of erodibility: colluvial soil (arenosols, regosols) – ferruginous indurate soil (luvisols) - alluvial soil (entisols, fluvisols). All things considered, the least likely soil to erosion is the colluvial soil (arenosols, regosols) B21; who is located at the foot of the granitic solid mass. The most vulnerably soil to erosion is the alluvial soil (entisols, fluvisols) B24 located 1700m of the granitic solid mass.

DR or dispersion ratio varies between 0, 86 for ferruginous indurate soil (luvisols) B22 and 1, 11 for alluvial soil B24. These values of DR enable us to say that the alluvial soil (entisols, fluvisols) B24 is most vulnerable,whereas ferruginous indurate soil (luvisols) B22 is less vulnerable; because more the value of DR is raised, more soil has the potentiality to erode (Middleton, 1930 ; Igwe, 2003 ; Brubaker and al, 1992). While basing itself on the values of DR, we can classify the soils of Boboyo, to soils having the greatest potentiality to erode on soils having the smallest potentiality to erode: alluvial soil – colluvial soil (arenosols, regosols) – ferruginous indurate soil (luvisols).

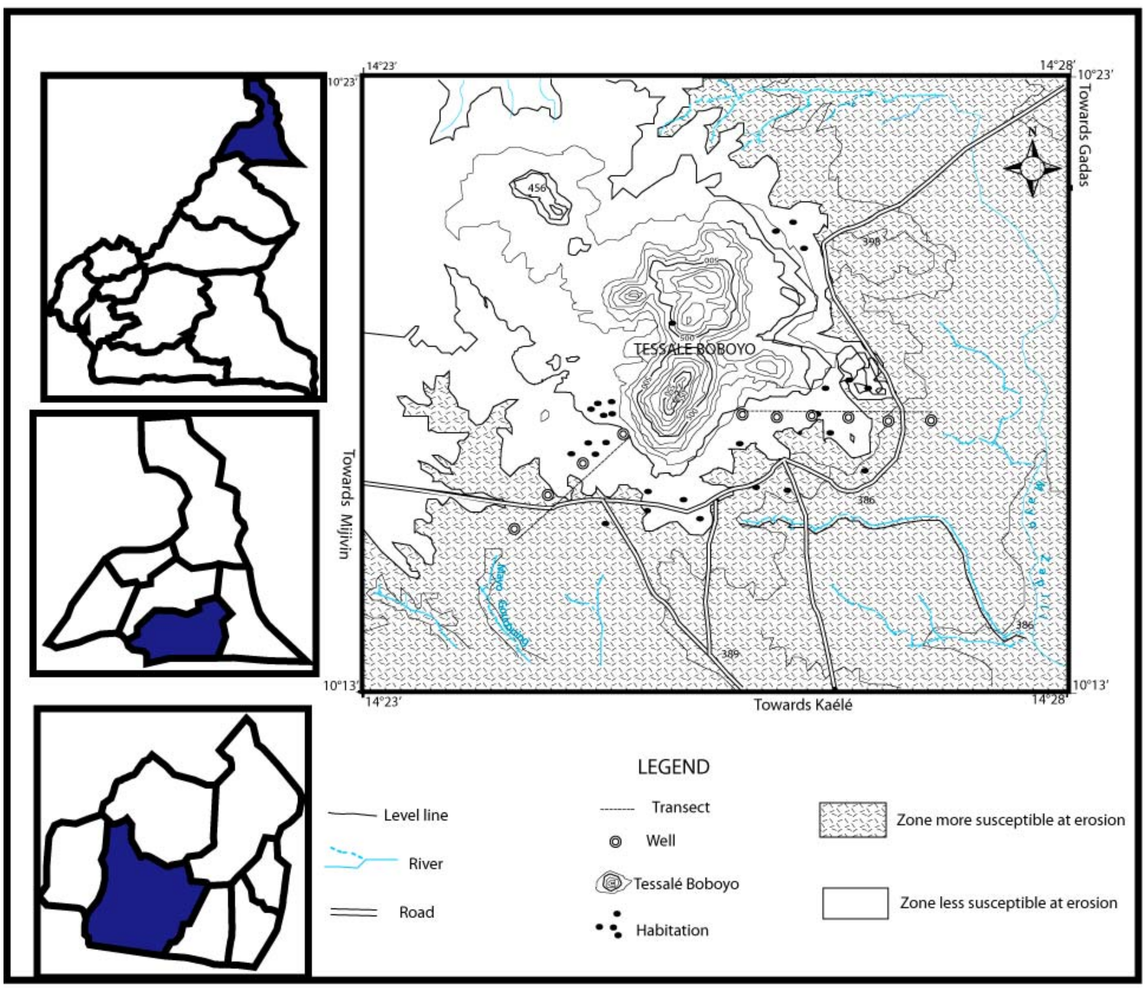
Clay Dispersion Ratio or CDR presents proportions ranging between 0, 02 for the alluvial soil B24 (table IV). The soils having a high CDR indicate a severe dispersion, whereas those with weak CDR have a weak dispersion (Igwe (2005). It arises from the values of CDR which the alluvial soil B24 is more dispersed than the colluvial soil (arenosols, regosols) B21. By using the values of CDR, we can classify the soils according to their degree of decreasing dispersion: alluvial soil (entisols, fluvisols) – ferruginous indurate soil (luvisols) – colluvial soil (arenosols, regosols).

Clay Aggregation or CA varies between 3 for the alluvial soil B24 and 19, 5 for colluvial soil (arenosols, regosols) B21 (table V). So B21 is more clayey, whereas B24 is the least clayey. The soil B21 has higher value of CA of 10 ; the ferruginous indurate soil (luvisols) B22 has a CA value ranging between 5 and 10 and soils B23, B24 have values lower than 5. Results of CA, it results from it that the alluvial soils (entisols, fluvisols) B23, B24 are most unstable and most likely with erosion that the colluvial soil (arenosols, regosols) B21 and ferruginous indurate soil (luvisols) B22. According to Igwe (2003, 2005), CA indicates the class of stability of the soil. The soils richest in aggregates erode more slowly than the grounds low in aggregates. This can classify the grounds of Boboyo of most stable to most unstable according to decreasing CA: colluvial soil (arenosols, regosols) – ferruginous indurate soil (luvisols) - alluvial soil (entisols, fluvisols).

The values of the exchangeable sodium ratio or (ESR) varied between 0, 1 for alluvial soil (entisols, fluvisols) B23 to 0,027 for colluvial soil (arenosols, regosols) B21 (table V). The values of sodium are overall high for B23 profile. The values of exchangeable of sodium ratio (ESP) varied between 2, 39 for colluvial soil (arenosols, regosols) B21 to 7, 34 for the alluvial soil (entisols, fluvisols) B23. The values of ESP are average according to this direction (Mémento de l'agronome, 1984; Beernaert and Bitondo, 1992).

Estimate of the erodibility of the soil according to NNE-SSW direction, it results that: the colluvial soil (arenosols, regosols) B21 is most clayey, the others are sandy; of the study of water dispersed clay or WDC, it results that the colluvial soil (arenosols, regosols) B21 and ferruginous indurate soil (luvisols) B22 are least susceptible to erosion and alluvial soils (entisols, fluvisols) B23 and B24 are most susceptible to erosion; the values of dispersion ratio or DR, shows that the alluvial soil (entisols, fluvisols) B24 is the least vulnerable. It arises from the values of clay dispersion ratio or CDR which the alluvial soil B24 is the most dispersed whereas the colluvial soil (arenosols, regosols) B21 is low dispersed; of results of clay aggregate or CA, it results that the alluvial soil are aggregate, more stable and more susceptible of erosion than colluvial soil (arenosols, regosols) B21 and ferruginous indurate soil B22

In conclusion, the erodibility index permitted to identify the soils more vulnerable to erosion. Following two direction, the soils being able to erode easily are the alluvial soils. With the index obtained, a map of erodibility of soils was established.



Source: Institut géographique nationale-Paris, 1966

Figure 3: Map of erodibility of soils of the study areas.

DISCUSSION AND INTERPRETATION

Morphology of Boboyo soils

There are six types of soils in Boboyo: lithosols, colluvial soil (arenosols, regosols), alluvial soil, vertisols, vertic alluvial soil and ferruginous indurate soils. The lithosols are characterized by a dull color with predominance of gray (Martin, 1963). These soils are very gravelly and would be very sensitive to erosion. They were not analyzed within the framework of this study. The colluvial soils (arenosols, regosols) of Boboyo are structured little, brown to brown dark, sandy, and presented many types of gravel of quartz and feldspar. They are in situation of Piedmont and profit from material contribution transported along the slopes (Duchaufour, 2001). The vertisols of Boboyo have brown gray color with sandy-clayey texture. Indeed, it is recognized that the vertisols have a dark gray to black color and are clayey to clay-sandy (Dudal, 1967), vertisols of our study zone clearly do not show the characteristics of a vertisol. However, Bühmann and Schoeman (1995) indicate that for some authors, the different colors would be had is with the topographic position (vertisol black in bottoms melt, vertisol reddish on the slopes), maybe with the small proportion of montmorillonite and stronger quantity of iron in relation to a better drainage. Vertisols of Boboyo, located on the slopes in position of good drainage, recognize themselves by their slits of withdrawal and a prismatic macrostructure. According to Martin and Ségalen (1966) and Brabant and Gavaud (1985), prismatic macrostructure and well marked slits of withdrawal are the principal morphological characteristics of these soils. Alluvial soils (entisols, fluvisols) are recent deposits of the valleys, they are localised in the major bed of the rivers (Duchaufour, 2001). They have a brown to yellow color, not very clayey; they have a polyhedric structure and a good permeability. The morphology of the vertic alluvial soil (alfisol, ultisol) can be summarized thus: under a surface horizon, it is a typical horizon vertisolic of 66cm thickness, with prismatic structure, slits of withdrawal and strong cohesion. The soils met are similar to those described by Martin and Ségalen (1966), and Brabant and Gavaud (1985).

Physicochemical characters of the soils

Analysis of the physicochemical parameters related to five types of soils: colluvial soils (arenosols, regosols), vertisols, alluvial soils (entisols, fluvisols), vertic alluvial soil (alfisol, ultisol) and ferruginous indurate soils (luvisols). The colluvial soils met with Boboyo are acid to slightly acid, sandy, the total nitrogen poor and present a small proportion in exchangeable bases and organic matter. According to Martin (1963), Martin and Ségalen (1966) and Duchaufour (2001), the colluvial soils (arenosols, regosols) are characterized by a variable granulometry but always with sandy predominance (about 40 to 60%), the pH is slightly acid and oscillate between 5,5 and 6,5, the organic matter is about 0,8 to 1,3%, the cation exchange capacity varies between 3 and 15méq/100g soil, but the rate of saturation is high (between 60 and 90%). Colluvial soils (arenosols, regosols) meet to Boboyo present the same characters that those described by these authors. Vertisols of Boboyo is slightly acid, saturated, the total nitrogen poor and present an average proportion of organic matter and exchangeable bases. According to Dudal (1967), Martin (1963), Martin and Ségalen (1966) vertisols are characterized by an clayey to clay-sandy texture, the pH varied between 7 and 8 only the samples of surface can have a pH lower than 7, the contents of organic matter are average (0,8 to 1,5%), ratio C/N included between 10 and 14, the cation exchange capacity is always high (25 to 35méq/100) and is saturated with more than 80% even 100%, the nodules limestones are present in all the profile. In the vertisols of Boboyo, low content of clay (12,80%) would be cause to the granitic nature of the rock and in addition with a lessivage of clays. According to the Brabant and Gavaud (1985), the vertisols met in this area are little developed vertisols, on gneiss and embréchite. Alluvial soils (entisols, fluvisols) meet to Boboyo are neutral, sandy, rich an exchangeable bases and present an average content of organic matter. In a general way, the alluvial soils (entisols, fluvisols) are characterized by a sandy to sand-clayey texture (10 to 20% clay), the cation exchange capacity included between

8 and 12méq/100, and is saturated between 60 and 80%, the pH is acid (5,5 to 6,5), the contents of organic matter are average (1,1 to 1,6%) and the report C/N ranging between 9 and 12 indicate a good biological activity of the soil (Martin and Ségalen, 1966). These characters are rather similar to those of the soils of Boboyo with the only difference which report C/N is higher than 12 this would indicate a worse biological activity in the alluvial soils of Boboyo.

Indices of erodibility in relation to the physicochemical characters of the soils

Indices of erodibility (total clay, water dispersed clay, ratio of dispersion, aggregate clay and Na^+ exchangeable) calculated can be put in relation to the physicochemical properties. Indeed, the soils most vulnerable to erosion (alluvial soils: entisols, fluvisols) show more or less low contents of organic matter. It is recognized that the organic matter plays a role of binder, it can maintain together the particles clayey subjected to the osmotic pressure induced by absorptive sodium; it acts on the aggregation and the structure of the soils and can also make hydrophobic surfaces of the mineral particles; what causes to slow down the speed of moistening of the aggregates and thus to reduce the processes of bursting. In other words, the organic matter can control the flocculation and the deflocculation of the clayey particles (Emerson, 1977; Mullins, 1990;; Kretzchmar et *al*., 1998 ; Cerdan, 2001 ; Chenu et *al*., 2000 Igwe, 2005).

Thus, strong erodibility of the alluvial soils (entisols, fluvisols) of Boboyo would be to cause by the low content of organic matter; it would be insufficient to maintain the clay particles forming with the latter a stable complex argilo humic. Igwe (2005) and Curtin and *al* (2006) showed that a low percentage of organic carbon in the soil cause a severe dispersion of clay in water from same the soils having a strong proportion of organic carbon show a weak dispersion in water. The results obtained (table IV and V) show that the soils vulnerable to erosion are the alluvial soils (entisols, fluvisols) (B14, B15 and B23) characterized by low percentages of organic carbon; whereas the soils least vulnerable to erosion (colluvial soil (arenosols, regosols) B21) have a strong percentage of organic carbon. Magnesium is in positive correlation (r = 0,800) with the organic matter.

The sodium which is a monovalent cation is recognized as being a dispersing agent and the smallest proportion of all the cations. Indeed, the presence of Na^+ in the soil causes the dispersion of the particles clayey. According to Seta and *al.* (1996), Igwe and *al.* (1999), Kjaergaard and *al.* (2004), the soils more erodibles present the strongest proportions of sodium. The soils identified like most vulnerable to erosion present the highest proportions of sodium. In addition, sodium, in the situations of supersaturation, could act like flocculating agent with the negative influences on the structure of the soils (Igwe, and *al*., 1999). In Boboyo, the influence of sodium in the studied soils is not clearly established. Indeed, according to the transect W-E, alluvial soil (entisols, fluvisols) B13 who is less susceptible to erosion, curiously present a significant proportion of Na^+. Its notable presence does not seem to cause the dispersion of the clay particles. Colluvial soil (arenosols, regosols) who is less susceptible to erosion following the transect NNE-SSW, present a small proportion of Na^+; the presence of Na^+ in small quantity do not cause the dispersion of the clay particles. Too, the presence of Na^+ in great quantity cause the dispersion of the clayey particles in alluvial soils (entisols, fluvisols) who are more susceptible to erosion following the transect NNE-SSW. Exchangeable sodium is in positive correlation with the degree of exchangeable sodium (r = 0,711) and percentage of exchangeable sodium (r = 0,791).

Calcium plays a dominating role in the physics soil behavior. By its capacity flocculating toward to clays and its role stabilizing for the humic compound, it strongly contributes to the organization of the structure of the soil and to the stability of this structure (Bonneau and Souchier, 1994). Calcium is used as cation of connection between clay and humic precursors thus contributing to the formation of the complex argilo humic of the soil (Oliveira and *al*, 2004). In Boboyo, according to the transect NNE-SSW; colluvial soil (arenosols, regosols) containing more aggregate clay was identified as being less susceptible to erosion. It would have the most stable structure; Calcium contents (11, 21) raised in this soil thus contents of total clay seem to confirm it. Following the transect W-E, alluvial soil (entisols, fluvisols) B15 present the low calcium content (4, 56); this would explain its unstable character. Alluvial soils (entisols, fluvisols) B14, B15, B23, B24 present a low Ca^{2+} content, they are unstable. Exchangeable calcium is in positive correlation with total clay (dispersed clay in the sodium hexametaphosphate) (r = 0,884), the clay aggregate (r = 0,696) and with the cation exchange capacity (r = 0,961). The aggregation of clay is in negative correlation with the water dispersible clay (r = -0,880) and the degree of dispersion of clays (r = -0,909); it is in positive correlation with total clay (r = 0,756). There is a positive correlation (r = 0,996) between water dispersible clay and the degree of dispersion of clays. The cation exchange capacity is in positive correlation with total clay (r = 0,814) and the aggregation of clay (r = 0,668). Le Bissonnais (1995) consider that from 10% of CEC, the soils are very sensitive to erosion. In short, the indices of erodibility are in positive correlation with the cation exchange capacity, exchangeable calcium.

CONCLUSION

The macromorphologic data made it possible to identify six types of soils : the lithosol who occupies the high zones of the landscape and thus the profile is reduced to a surface horizon surmounting the granitic arena; the colluvial soils (arenosols, regosols) who are located high on piedmont, of sandy texture and including three horizons ; the alluvial soils (entisols, fluvisols) who are widest and deep, of sandy texture, and four to eight horizons include; the vertic alluvial soils (alfisol, ultisol), of sand-clay texture, including four horizons and located completely in bottom of slope in the alluvial plain. The vertisols who are situated between colluvial soils (arenosols, regosols) and alluvial soils (following the transect W-E), of sandy texture and present three horizons having a genetic bond between them. The ferruginous indurate soils, of the sandy texture, located between the colluvial soil (arenosols, regosols) and alluvial soil (following the transect NNE-SSW). Physicochemical characterization of the soils of Boboyo, shows that: (1) the colluvial soil (arenosols, regosols) are slightly acid to neutrals, sandy to sand-clay; (2) the vertisols are slightly acid, sandy; (3) the ferruginous indurate soils (luvisols) are acid, sandy; (4) the alluvial soil (entisols, fluvisols) are acid to neutrals, sandy; (5) the vertic alluvial soil is neutral, sand-clay. All these soils are saturated, low in nitrogen and organic matter and are characterized by average proportions in exchangeable bases.

The whole of the indices of erodiblity (WDC, CA, CDR and DR) used shows that, following the two transects, the alluvial soils (entisols, fluvisols) are more susceptibles to erosion whereas the colluvial soils (arenosols, regosols) are less vulnerable. These indices of erodibility are in positive correlation with cation exchange capacity and exchangeable calcium.

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