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(RESEARCH ARTICLE)

Physico-chemical characterization of the soils of the watersheds of Boukombe in North-West Benin

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Abstract

This study addresses the specificities of soils in low-income countries. These infertile soils are characterized by low levels of agricultural productivity and the disappearance of long-term fallow, which is gradually giving way to shorter-term fallow and sedentary agriculture. The overall objective was to assess the physico-chemical characteristics of the soils of the Boukombe watersheds in the north-west of Atacora in Benin. Soil studies of 15 farm sites from which soils were sampled at the [0-20] cm horizon with 30 composite samples and statistical analyzes were performed. The results of particle size analysis showed predominance (68%) of a textural dimorphism with a sandy loam character and a relatively stable structure. The soils are generally acidic (pH ≤ 5), sodium in places and poor in Organic Matter (0.3%), particularly in the plateau. Mountain lands have soils richer in OM (4%), but poor in nitrogen with a content of between [0.02-0.14%], the C / N ratio at 3% lower than 12. The contents nutrients and minerals are accumulated at the bottom of slopes (2.23% carbon, 0.14% nitrogen) and at the top of slopes (14ppm of phosphorus) under *Fonio*. These soils remain in a fragile state, subjecting them to the process of intense erosion. The degradation, silting up and progressive acidification of soils constitute the main constraints of agricultural production, the solution of which is based on restoring their fertility by rehabilitating dikes and removing silt.

Keywords: Soils; Catchment basins; Physico-chemical characteristics; Erosion and degradation

1. Introduction

The world's population is expected to grow by more than 2 billion to reach 9.6 billion in 2050 [58]. Most of this growth will take place in cities in low-income countries, with infertile soils and low levels of agricultural productivity. Population growth in sub-Saharan Africa has led to increased demand for food. However, the practice of long-term fallow tends to disappear, giving way to short-term fallow and sedentary agriculture [70, 36]. In most countries of sub-Saharan Africa, soils have low fertility, and exported nutrients are not adequately replaced. Intensive agriculture and the search for new fertile land put pressure on the ecosystem, which in turn leads to reduced soil fertility [54, 22]. In addition, yields are relatively low and land productivity decreases accordingly [74, 70]. In Ziguinchor in Senegal, for example, agriculture contributes to the fight against poverty and remains a guarantee of food security. The rare agro-environmental studies carried out in this city [37, 16, 75, 17, and 20].

In Benin, agriculture contributes around 36% to the formation of the Gross Domestic Product (GDP), more than 85% to the country's official export earnings and employs nearly 75% of the population [50]. Despite this, it remains traditional with the use of archaic techniques and methods [72]. It gradually becomes mining and causes almost irreversible degradation of land and ecosystems [30]. Most of the cropping systems used result in soil degradation [6]. Farmers in the watersheds of the commune of Boukombe use agricultural methods and practices that contribute to this transformation, which varies depending on the locality [41, 43]. The physical properties of soils naturally depend on the relative proportions of the constituent elements, but also on the way in which these elements are associated with

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each other to form structural units ... plant and animal debris which falls on the ground constitutes the essential source of organic matter which, gradually transformed, gives rise by mineralization of soluble or gaseous elements, assimilable and by humification, to humic colloidal complexes [3]. On the other hand, several handicaps would limit the sustainable development of agriculture, (i) farming techniques dominated by extensive and shifting slash-and-burn agriculture; (ii) climate change with these perceptible effects, through a strong disruption of the seasonal cycle and resulting in low agricultural productivity; (iii) decline in soil fertility and agricultural production; and finally (iv) the inability to use mineral fertilizers because of their high cost and the lack of a stable market [60, 49 and 56]. It is with this in mind that the study was set up to find solutions for integrated management of soil fertility and improvement of land productivity in Boukombe. The general objective was to assess the physico-chemical characteristics of the soils of the watersheds of the commune of Boukombe in the north-west of the department of Atacora in Benin. It is a contribution to a better sustainable management of soil fertility for the improvement of the productivity and income of producers in the Boukombe watersheds. More specifically, it involves: (i) characterizing the physicochemical properties of soils, through farmers' fields, and (ii) determining soil fertility indicators with a view to proposing an integrated management strategy for soil fertility for improved crop production.

2. Material and methods

2.1. Study environment

The study was carried out in five (05) villages in the watersheds of the commune of Boukombe in the north-west of the department of Atacora in Benin. These are the villages of: Koumagou A, Koumagou B, Okouaro, Koukouatiengou and Koussoucoingou (figure 1). The town is located between 10 ° and 10 ° 40 'North latitude and 0 ° 75' and 1 ° 30 'East longitude. It brings together the physical and socio-economic features of mountainous northwest Benin. The relief is very rugged, dominated by mountains. The climate is Sudanese, characterized by a rainy season from April to October and a dry season from November to March. The local economy is based on agriculture, animal husbandry and crafts. A diversity of socio-cultural groups is found there, the most of which are the Bètammaribè, the Beberibe and the Lamba. The number of this population is 83,147 inhabitants with an increase of 2.86% [35].

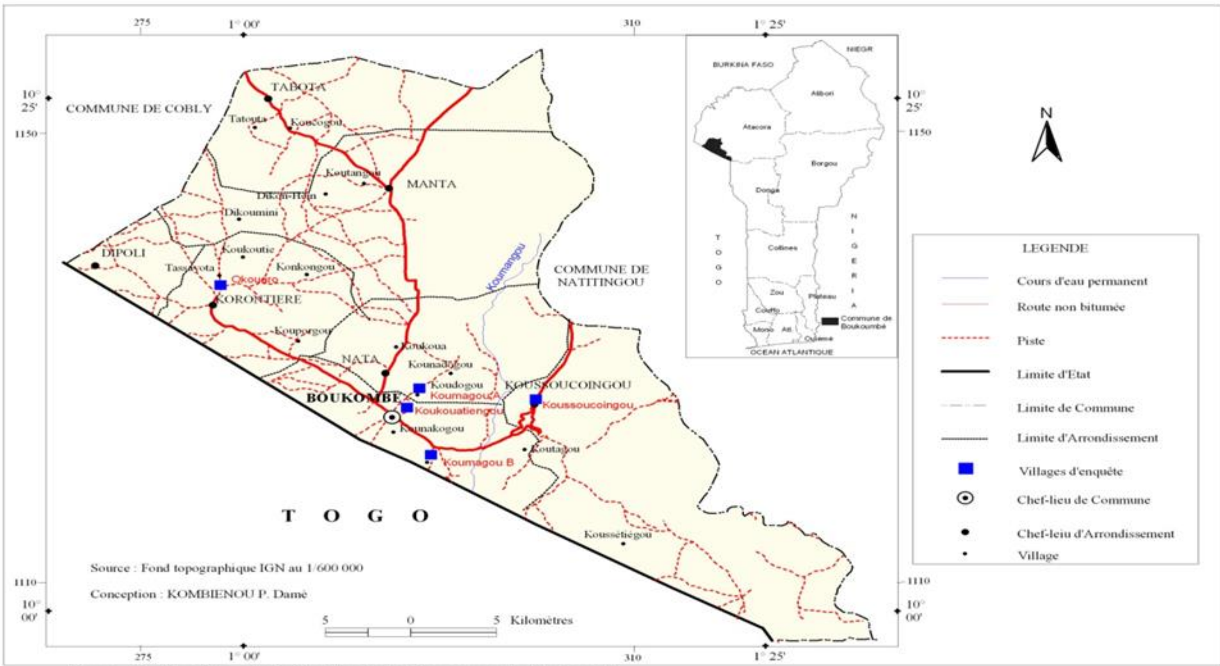

Figure 1 Location of the study area

2.2. Data collection tools

The preparatory phase consisted in collecting with the help of a GPS (Global Positioning System) the geographical coordinates of the points which constitute the territorial limits of the study area. The constitution of the sample required the mobilization of impact assessment approaches. The assessment of the impact of these exogenous technologies can be done using experimental (random) approaches [15].The following data collection tools in chronological order of use have been selected: a notebook, card holders, pencil, ballpoint pen; a camera for possible illustrations; a Garmin GPS

(Global Positioning System) receiver to record the geographic coordinates of the villages; a questionnaire to conduct surveys of producers and other actors involved in the agricultural sector of the Study Municipality.

2.3. Sampling and analysis

The sampling mainly concerned the mountain sides which are the areas that are increasingly cultivated. In the fields, soil samples were taken from the surface horizon (0 to 20 cm) of the mountain along a pedological topo-sequence in the upper slope (Hv) and in the lower slope (Bv). In total, thirty (5x3x2) samples were taken at the rate of two (02) samples per site, three (03) sites per village and five (05) villages in the commune.

2.4 Method of processing and analyzing the samples taken particle size

Analysis of these samples allowed soil texture to be determined and the rates of particle size fractions such as sands, silts and clay to be determined. The chemical analysis focused on the chemical parameters of the studied soils: pH, Cation Exchange Capacity (CEC), total nitrogen Nt, organic carbon (Corg) and available phosphorus (Pass.).

2.5. Preparation of samples

The soil samples taken during the production of the soil profiles were analyzed in the Laboratory. The analyzes focused on particle size, organic carbon content (C), pH, cation exchange capacity (CEC), total nitrogen (N), assimilable phosphorus (P), potassium (K) , exchangeable calcium (Ca) and magnesium (Mg). These soil samples were first dried. Drying was done in the shade (out of direct sunlight to prevent loss of volatile elements) for about a week. Then the soil is weighed, crumbled, sieved at 2 mm for fine earth kept in a suitable cloth. The residue or gritty charge remaining in the sieve is weighed and its content calculated before being stored.

2.6. Physico-chemical composition of cultivated soils

The physico-chemical composition of the soils under cultivation is known. Thus, the physico-chemical analysis of soil constituents at all sites was carried out. A typology (the sampling was done in such a way as to include elements of the typology of the farms present in the commune of Boukombe, such as the age, the sex of the farm managers, the ethnicity, etc.) of the farms was done at the study area level.

The soils that housed the study sites (farmers' farms) were characterized by a laboratory analysis of these soil samples with determination of the following elements:

Texture by grain size;

Organic carbon content (C);

Rate of organic matter (Cx1, 724);

Total nitrogen content (Nt);

Rate of assimilable phosphorus (Pass);

Content of exchangeable bases (S): Mg, Ca, Na, K;

CEC (Cationic Exchange Capacity);

Water pH.

2.7. Granulometry

The determination of the particle size comprises the following three phases:- a phase of destruction of organic matter by treatment with oxygenated water;- a dispersion phase which involves the removal of flocculants ions, the addition of sodium hexametaphosphate and mechanical agitation by inversion;- a phase of separation and sorting of particles by sedimentation and sampling with a Robinson's pipette for the clay, silt and sand fractions. Particle size is used to determine the percentage of sand, silt, clay and organic matter in a soil sample.

2.8. pH

The pH is determined using the pH meter and the different interpretations are presented in Table 1.

Table 1 Interpretation grid for pH values

pH values	Qualification
< 4,5	Extremely acidic
[4,5 – 5,0]	Very strongly acidic
[5,1 – 5,5]	Strongly acidic
[5,6 – 6,0]	Moderately acidic
[6,1 – 6,5]	Weakly acidic
[6,6 – 7,3]	Neutral
[7,4 – 7,6]	Slightly alkaline
[7,7 - 8,4]	Moderately alkaline
[8,5 - 9,0]	Strongly alkaline
> 9,1	Very strongly alkaline

Source: [59]

2.9. Organic material

The organic matter content is determined by the product of the percentage of soil carbon and the conversion factor and the constant 1.724 using the following formula: (% C x 1.724 = MO)For the interpretation of the organic matter content, the grouping was done in three classes distributed as follows:

High organic matter content (> 1.5%);

Average organic matter content (between 1 and 1.5%);

Low organic matter content (<1%).

2.10. Total nitrogen

Total nitrogen is determined by distillation in the presence of sodium hydroxide (NaOH) and determination of ammoniacal nitrogen with 1N H2SO4 after mineralization with sulfuric acid (H2SO4). The interpretation grid for the nitrogen content is presented in Table 2.

Table 2 Interpretation grid of nitrogen content

N values	Interpretations
+ 3 ‰	Very rich in nitrogen
2– 3 ‰	Rich in nitrogen
1-2 ‰	Moderately rich in nitrogen
-1 ‰	Low in nitrogen

Source: [59]

2.11. Assimilable phosphorus

The assimilable phosphorus is determined by the BrayI method which involves the extraction after stirring of the sol-BrayI solution mixture and finally assayed with a colorimeter in the presence of ascorbic acid and ammonium moly date after a slight heating in a water bath at 80 ° C. The phosphorus interpretation grid adopted is presented in Table 3.

Table 3 Interpretation grid for soil phosphorus

P Values of	Interpretations
>20 ppm	High phosphorus value
10 à 20 ppm	Average phosphorus value
≤ 10 ppm	Low phosphorus value

Source: [59]

2.12. Cationic Exchange Capacity (C.E.C or T), saturation rate (V) and sum of exchangeable bases (S)

The CEC is the maximum amount of exchangeable cations that colloids can retain and which can easily pass into the soil solution. It indicates the filling of a reservoir of nutrients capable of being released to nourish the plant. It generally varies from 8 (sandy soils, poor in M.O) to more than 20 meq / 100g (clay soils, rich in M.O). It is determined in the same way as in the case of nitrogen after displacement of NH4 fixed on the absorbent complex. This displacement is made by a solution of KCl. The saturation rate is determined by the product of the S / T ratio and a real 100:

$$V = (S / T) \times 100, \text{ where}$$

S is the sum of the exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and T the cation exchange capacity in meq / 100g of soil. The values of CEC and the degree of saturation are presented in Table 4.

Table 4 Interpretation grid of the CEC and the saturation rate

Interpretation	Very weak	Weak	Medium	Strong	Very strong
CEC	< 5	5 à 10	10 à 25	25 à 40	> 40
Interpretation	Reserve Very weak	Weak	Medium	Strong	Very strong
S	< 2	2 à 5	5 à 10	10 à 15	>15
%V = S/T*100	< 15	15 à 40	40 à 60	60 à 90	90 à 100

Source: [59]

After presenting the interpretation grid of the CEC and the saturation rate, the grid of the degree of leaching of a soil in bases is presented in Table 5.

Table 5 Interpretation grid of soil base saturation

Interpretations	Values
Very weakly leached	V = 70 – 100 %
Slightly washed out	V = 50 – 70 %
Moderately leached	V = 30 – 50 %
Heavily leached	V = 15 – 30 %
Very heavily leached	V = 0 – 15 %

Source: [59]

2.13. Determination of soil texture

The evaluation of textural classes is done following the principles of classification and evaluation of land [26].

Six classes are selected for classification and presented in Table 6:

- A: very fine texture, corresponding to the clayey and clayey-silty textures;

- E: fine texture, corresponding to clay-sandy, silty-clay and fine silt-clay textures;

- M: medium texture, corresponding to the silty-clayey-sandy, silt, fine silt and very fine silt classes;

- N: medium to coarse texture, corresponding to the silty-sandy class;

- S: coarse texture, corresponding to the sandy loam class;

- Z: very coarse texture, corresponding to the sand class.

The textural classes and indices of the different soils are presented in Table 6.

Table 6 Interpretation grid of soil textural indices

N°	Texture	Indice	Texture fine
1	A et AL	A	Very fine texture
2	AS, LA et LAf	E	Fine texture
3	LAS, L et Lf	M	Medium texture
4	LS et Lf	N	Coarse medium texture
5	SL	S	Coarse texture
6	S	Z	Very coarse medium texture

Source: [59]

First, the percentage of clay, silt and sand is determined in the different horizons. The percentage of these three elements (clay, silt and sand) is determined and allows the textural degree of the soil to be assessed (Table 7).

Table 7 Interpretation grid for the clay, silt and sand content

Diameter	Determined elements	Somme
0 – 2 µ (microns) %	Clay	Clay %
2 – 20 µ (microns) %	Coarse silt	∑ Coarse %
20 – 5 µ (microns) %	Fine silt	
50 – 200 µ (microns) %	Fine sand	∑ Sand %
200 – 2000 µ (microns) %	Coarse	

Source: [59]

The texture of the soil is determined by the weight average of the rates of each element (clay, silt and sand) by the formula:

$$X = \frac{Q \times Hz}{Pfr}$$, with:

X the rate of the element;

Q the amount of the element (clay, silt or sand);

Hz the thickness of the Horizon;

Pfr the total depth of the profile.

After calculating the weight average of the different elements (clay, silt and sand), the textural class is determined using the textural triangle or textural diagram.

After explaining the determination of the textural class, the interpretation grid for the suitability of soils is made [27] and presented in Table 8.

Table 8 Interpretation grid of soil suitability for cultivation

Orders	**Class**
S1	Apt
S2	**Moderately fit**
S3	Marginal fit
V1	Currently unfit
V2	Unfit

Source: [59] S: Apt; V: Unfit

The aptitude classes are divided into five classes defined according to soil limitations or constraints.

S1: Fit; class S1 floors are suitable for the type of use; they have no or only slight limitations.

S2: Moderately able; S2 soils are suitable but require adapted cultivation techniques, controlled plowing, light drainage, etc. They have no more than 3 moderate limitations possibly associated with low limitations.

S3: Marginally fit; the yield of these soils is questioned; they have more than 3 moderate limitations and no more than one severe limitation which however does not prevent cultivation absolutely.

V1: Currently unfit; potentially fit. Soils with more than one severe limitation which can however be corrected under current economic conditions.

V2: Unsuitable, soils with severe or very severe limitations that cannot be corrected under current economic conditions.

It is also about distinguishing the current valuation from the potential valuation. The current assessment refers to the value of the land under current conditions. The potential appraisal considers the value after completion of development work. So a floor belonging to class S3 after development can pass to class S2 or S1. Its current aptitude is S3, the potential is S1 or S2. A V1 soil can be classified as potentially suitable.

2.14. Cationic balance

There is cationic equilibrium in a soil when the ratios of calcium (Ca) and magnesium (Mg) give a value greater than 1 or less than or equal to 10 and or when the ratios of magnesium (Mg) and potassium (K) give a value greater than 3 or less than or equal to 20 [77]. The equation is as follows:

$1 < Ca / Mg < 10$ and $3 < Mg / K < 20$

2.15. Statistical analyzes

The analysis of variance was performed using Tukey's test (Tukey Simultaneous Tests).

3. Results

3.1. Physical characteristics of the soils of the Boukombe watersheds

3.1.1. Grain size and texture of soils

The analysis of the granulometric results in Figure 2 of the soil samples taken revealed that the silt content of the soils varied from 14 to 37%, that of clay from 10 to 43% and that of sand from 31 to 67%. However, the textural analysis revealed, overall, a predominance (68%) of a textural dimorphism with a silty-sandy character in the lands of the Boukombe watersheds. They are followed by silts (18%), loamy-clayey-sandy (12%) and silty-clay soils (2%). Consequently, by comparing the clay rates at the level of the different study villages, it must be remembered that this rate was higher at the top of the slope under Fonio in Koukouatiengou and lower at the top of the slope under *Fonio* in Koumagou A This showed that this rate was not a function of altitude. The dominance of coarse elements (sand) indicated that the soils in Boukombe were poor reservoirs of water within the reach of plants. Hence the high risk of erosion. The results showed the highest and lowest clay proportions in height in the *Fonio* system, but in 2 different villages. However, further studies were necessary to identify the active part of the relief in the degradation and the chemical poverty of the grounds. In short, the analysis of figure 2 relating to the content of the different granulometric fractions and the texture of the soils showed that there is no significant difference between the average contents of the soil fractions of the different soils (p> 0.05).

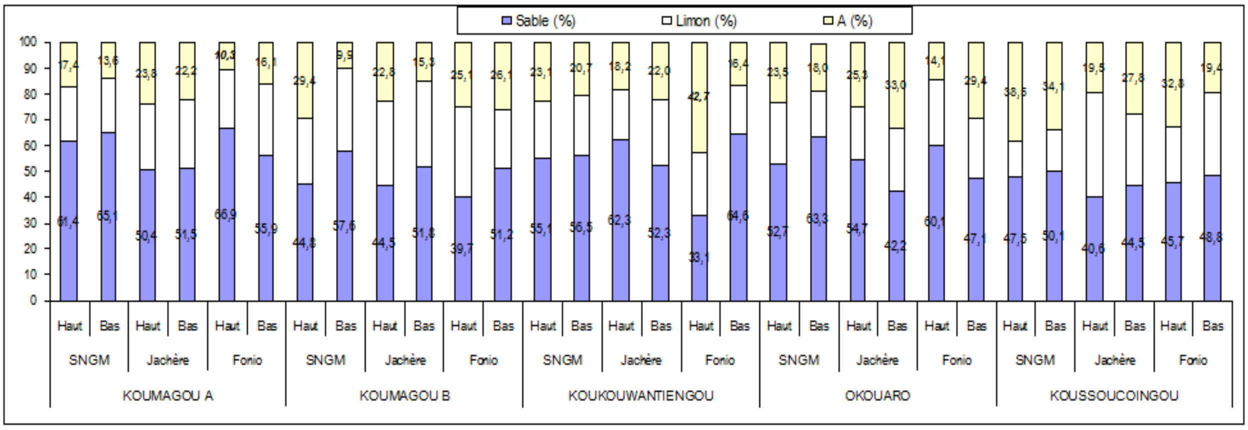

Figure 2 Dynamics of coarse elements in soils at study sites

3.2. Chemical characteristics of the soil in the Boukombe watersheds

3.2.1. Acid-base properties of watershed soils

The analysis of Table 9 showed that the pH and Cation Exchange Capacity (CEC) of the analyzed soils show slight variability depending on the village and the topo-sequence. The soils of the watersheds of the villages of Koussoucoingou, Koumagou A, Koumagou B and Okouaro in Boukombe had the lowest pH (4.1 to 5.9) and are considered potentially acidic. In these villages, the soils are moderately acidic with a pH = 4.9 and 5.9 respectively at the top of the slope and very acidic with a pH = 4.6 and pH = 5.0 and moderately acidic with a pH = 5, 8 at the bottom of the slope. From the point of view of the topo-sequence, the soils of the Koukouatiengou watersheds have a relatively neutral pH (pH = [6.6-6.8]) and moderately acidic in their upper parts at the top of the slopes with a pH = 5.6 at site I and at site II at the bottom of the slope. In the Koukouatiengou watersheds, the soils have a pH varying from (pH = [6.2-6.6]) at the top of the slope respectively at sites II and I, therefore weakly acidic and slightly alkaline (pH = [7.4-7.5]) at sites III and I at the bottom of the slope. The cation exchange capacity, base saturation and sum of bases were generally low in the soils studied in all the villages of the watersheds of the Commune of Boukombe. The Cationic Exchange Capacity (CEC) content observed at the bottom of the slope is approximately almost double that noted in its upper part at the top of the slope. It is, on average, estimated between 6.94 meq / 100g and 7.68 meq / 100g in the villages of Koumagou A and Koukouatiengou.

Table 9 Variation of the pH and CEC of the soils of the Boukombe watersheds

Commune	Villages	Part / Sites	pH eau			pH kcl			%TS	CEC		
			I	II	III	I	II	III		I	II	III
Boukombe	Koussoucoingou	H-v	4.60	4.88	5.01	3.97	4.41	4.08	28.21	16.88	17.75	14.44
		B-v	5.80	5.45	5.80	4.90	4.76	4.96	33.06	20.25	18.94	19.25
		Average	5.20	5.16	5.41	4 .44	4.60	4.52	30.61	18.57	18.35	16.85
	Koukouatiengou	H-v	6.64	6.20	6.30	3.92	5.85	3.81	49.40	12.00	15.13	14.33
		B-v	7.53	6.60	7.38	4.36	3.85	4.08	49.68	20.25	16.00	18.00
		Average	7.09	6.40	6.84	4.14	4.85	3.95	49.54	16.13	15.56	16.17
	Koumagou A	H-v	4.93	5.85	5.24	7.35	5.09	5.23	18.18	17.69	17.06	15.50
		B-v	5.18	5.78	5.04	5.20	5.03	5.41	21.62	20.50	21.44	32.25
		Average	5.06	5.82	5.14	6.28	5.06	5.32	19.90	19.10	19.25	23.88
	Koumagou B	H-v	5.51	5.41	5.45	6.08	4.68	5.79	23.13	19.32	27.69	20.81
		B-v	5.26	5.32	5.29	4.68	4.77	7.05	19.28	32.69	32.88	29.25
		Average	5.39	5.37	5.74	5.38	4.73	6.42	21.21	26.01	30.29	25.03
	Okouaro	H-v	5.94	5.44	5.23	5.43	5.79	4.89	11.17	40.81	38.31	33.31
		B-v	5.49	4.12	5.46	4.71	4.35	5.04	16.34	42.69	60.19	41.44
		Average	5.72	4.78	5.35	5.07	5.07	4.97	13.76	41.75	49.25	37.38

Source: Laboratory analysis results in June 2019

Legend: pH water = water; pH kcl = potassium; I = site1; II = site2; III = site3 H-v = top of the slope; B-v = low-slope; CEC = Cationic Exchange Capacity.

In the village of Koumagou B, the average Ca content is higher (6.37 meq / 100g). Like the element nitrogen, the soils analyzed are very poor in phosphorus. None of the watersheds reached the average phosphorus content of 5 ppm which is estimated to be low. The highest phosphorus content is estimated at 13.90 ppm and was not noted at the top of the slope of the village of Kousoucoingou.

The comparative analysis showed a significant difference in the variation of the average content of Na (0.29 to 1.93meq / 100g) and K (0.12 to 1.28meq / 100g) depending on the slope. However, it is not significant for the variation of the average contents of Ca, Mg and CEC. Most soils had low organic matter and medium nitrogen content. On the other hand, these soils were deficient in phosphorus with the exception of hydromorphic and mountain soils. The explanation here could be that the Atacora Range was teeming with many shallows. The soils of the village of Koumagou A have the lowest average Ca content (1.00 meq / 100g) at the third site. However, the village of Koumagou B has the highest average Ca content (5.82 meq / 100g). Overall, the average Ca contents in all of the watersheds studied are above 0.2 meq / 100g. The average Mg element content is very high ([Mg]> 0.5 meq / 100g) in the soils of the watersheds of the villages of Koukouatiengou and Koumagou A and only in one site respectively at the site in Koussoucoingou (site III), Okouaro (site I) and in Koumagou B at sites II and III. However, the highest Mg content (1.88 meq / 100g) is recorded at the bottom of the slope at site II in the village of Koukouatiengou.

The analysis of Table 10 showed that in the majority of soil samples analyzed 73.33%, the Ca2 + / Mg2 + ratio is greater than 1% and less than 10% and in 36.67% the rate of the Mg2 + / K + ratio is greater than 3% and less than 20%. On the other hand, only in 03.33% the rate of the Ca2 + / Mg2 + ratio is less than 1% and in only 23.33% the rate of this ratio is greater than 10, that of the Mg2 + / K + ratio is at 63.33% less than 3 %. There is a relatively cationic balance in the soils of the Boukombe watersheds.

The potassium content of only 26.67% of the soil samples studied at Boukombe was greater than 0.4 meq / 100g of soil. This can induce a good content and without limitation for the cultures. This potassium content varied between 0.12 and

0.98méq / 100g of soil for 100% of the soil samples studied. The majority of soils were poorly provided with potassium (73.33%), except mountain soils (26.67%) which still had a good potassium content varying respectively between 0.5 and 1.0 meq / 100g remaining relatively close in the mean (1 to 1.5). It should be noted that these results are only for mountain soils (Table 10).

Table 10: Exchangeable base (S) content in the soils of the Boukombe watersheds

Commune	**Villages**	**Part**	**Na^+(meq/100g)**			**K^+ (meq/100g)**			**Mg^{2+}(meq/100g)**			**Ca^{2+}(meq/100g)**		
		Sites	I	II	III	I	II	III	I	II	III	I	II	III
Boukombe		H-v	0.35	0.25	0.54	0.12	0.13	0.82	0.29	0.30	0.50	2.21	4.91	3.03
		B-v	0.55	0.33	0.79	0.24	0.21	0.46	0.60	0.35	0.58	5.21	5.14	4.96
	Koussoucoingou	Average	0.45	0.29	0.66	0.18	0.17	1.28	0.44	0.32	1.08	3.71	5.02	3.99
		H-v	1.61	1.90	1.81	0.28	0.30	0.29	1.73	1.48	1.59	2.84	3.84	2.33
		B-v	1.67	1.97	1.91	0.62	0.46	0.33	1.79	1.88	1.30	5.03	5.52	4.58
	Koukouatiengou	Average	1.64	1.93	1.86	0.45	0.38	0.31	1.76	1.68	1.44	3.93	4.68	4.45
		H-v	0.36	0.33	0.54	0.22	0.18	0.30	0.64	0.44	0.86	4.28	5.24	0.65
		B-v	0.73	0.89	0.60	0.34	0.18	0.53	0.76	0.91	0.93	5.58	6.40	1.35
	Koumagou A	Average	0.54	0.61	0.54	0.28	0.18	0.41	0.70	0.67	0.89	4.93	5.82	1.00
		H-v	0.47	0.29	0.85	0.10	0.11	0.80	0.23	0.58	1.08	3.27	3.91	3.65
		B-v	0.56	0.80	0.59	0.14	0.14	0.98	0.51	0.65	1.22	5.21	6.28	4.03
	Koumagou B	Average	0.51	0.54	0.72	0.12	0.12	0.89	0.37	0.61	1.15	6.37	5.09	3.84
		H-v	0.61	0.24	0.40	0.12	0.18	0.17	0.63	0.58	0.24	2.91	2.91	3.47
		B-v,	0.86	0.60	1.90	0.16	0.18	0.15	0.95	0.07	0.32	5.10	5.58	6.65
	Okouaro	Average	0.73	0.42	1.15	0.14	0.18	0.16	0.79	0.32	0.14	4.00	4.24	5.06

Source: Laboratory analysis results in June 2019

Legend: Ca = Calcium, Mg = Magnesium, Na = Sodium, K = Potassium, meq = milliequivalent, g = gram

Analysis of the sodium (Na) content showed that in general, only 23.33% of the sloping soils of the villages are sodium ([Na]> 1meq / 100g). However, the majority (76.67%) are not. These contents varied from 0.24meq / 100g and 1.97meq / 100g. The Na content is therefore not almost evenly distributed along the topo-sequence gradient in the watersheds of all the study villages. The greatest concentration of Na is recorded at the bottom of the slope at Koukouatiengou at site II (1.97 meq / 100g).

Overall, the soils of the Boukombe watersheds show a probable response to potassium fertilizers ([K] <0.5 meq / 100g). However, at the top of the slope of the Koukouatiengou village and at the bottom of the slope, the response to potassium fertilizers is not probable. This study village has a K content that varies from 1.61 meq / 100g to 1.97 meq / 100g. The average value of the soil CEC in all the watersheds is 7.50 meq / 100g at the top of the slope at site III in Koussoucoingou and (62.19 meq / 100g) at the bottom of the slope at site II in Okouaro and is considered high. The percentage of nutrient cations (TS) among exchangeable bases is estimated to be average in the villages of Koumagou A (19.90%), Koumagou B (21.21%) and that of Koussoucoingou (30.61%), low in Okouaro (13.76%). It is, however, high in the village of Koukouatiengou (49.54%).

3.2.2.Fertilizing element content of watershed soils

Figures 3, 4, 5 and 6 show the contents obtained in assimilable phosphorus, in C / N ratio, in carbon and total nitrogen in the soils of the Boukombé watersheds.

The analysis of figure 3 showed that, the content of Phosphorus (P) was higher in altitude under Fonio in Koussoucoingou (14%), Koukouatiengou (7%) and under fallow (7%) in Koumagou B to compare the results of the villages between them and the farming system

practiced in the environment. Fonio and fallow certainly had a strong capacity to retain or regenerate Phosphorus. This was certainly what had led producers to practice fallow cultivated in the area. The level of assimilable phosphorus varied from 1% to 13% (figure 3).

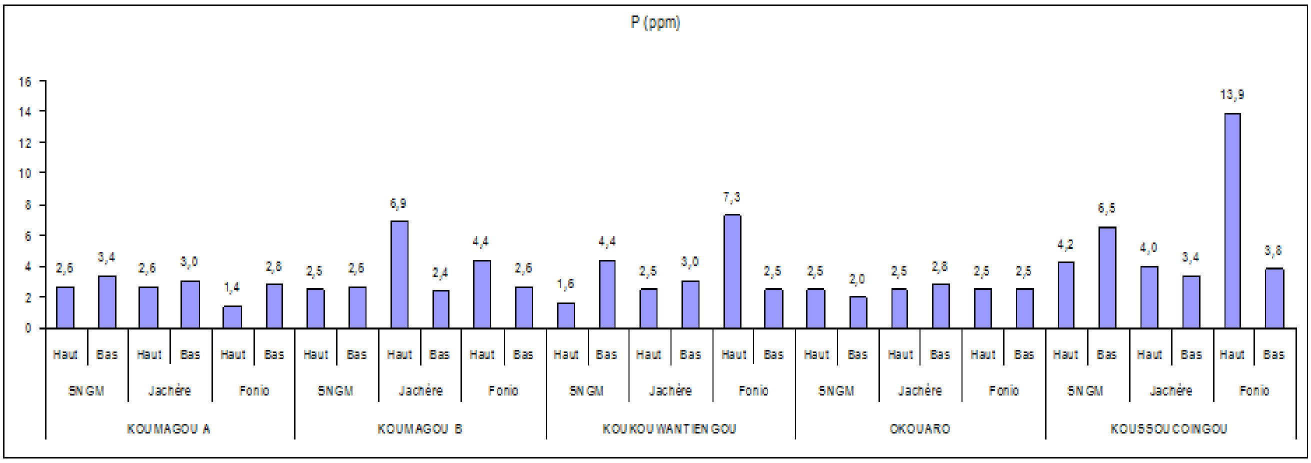

Figure 3 Assimilable Phosphorus content in the soils of the study sites

From the analysis of figure 4, it was found that 97% (29/30 samples analyzed) of the results, the C / Nt ratio> 12% and 3% (1/30 samples analyzed), the C / Nt ratio <12%. Overall, organic matter (OM) rates ranged from 0.3% to 4%. C / Nt ratios were good at the bottom of the fallow (13%) and *Fonio* (17%) at Koumagou A, Koumagou B, Koukouatiengou, Okouaro and Koussoucoingou. These soil types represented only 33% (5/15 study sites) of all study sites. If the humification was only good when C / N was around 9 [7], only 6% (1/15 study sites) of the soils showed a C / N ratio close to 11. This is the soil under fallow in Koumagou B (figure 4). The state of the physico-chemical properties of the soils and the relief were dependent on socio-economic features relating to agricultural production in Boukombe.

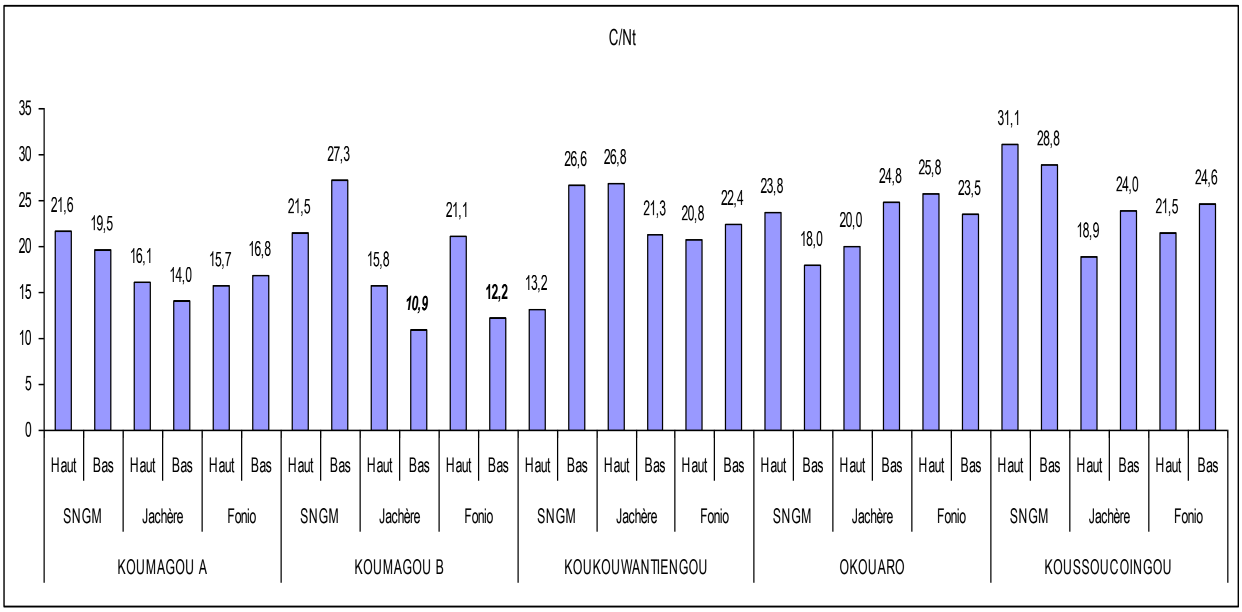

Figure 4 Evolution of the C / Ntotal ratio in the soil of the study sites

From the analysis of Figure 5, it was found that the carbon content varied from 0.40 to 2.28%. This drop in the carbon content in the environment was due to anthropogenic activities, the non-supply of nutrients and confirmed the level of soil degradation observed. The carbon content being low along the profile, the clay had had a significant part revealing that the soils were very leached. Likewise the variations in the carbon content which decreased were evidence of leaching of soils which were exposed to erosion of all kinds. The soils at the bottom of the slopes which have an organic carbon content greater than 2% received organic matter from the summits by runoff. All of the soils analyzed are chemically poor and degraded, due to agricultural systems.

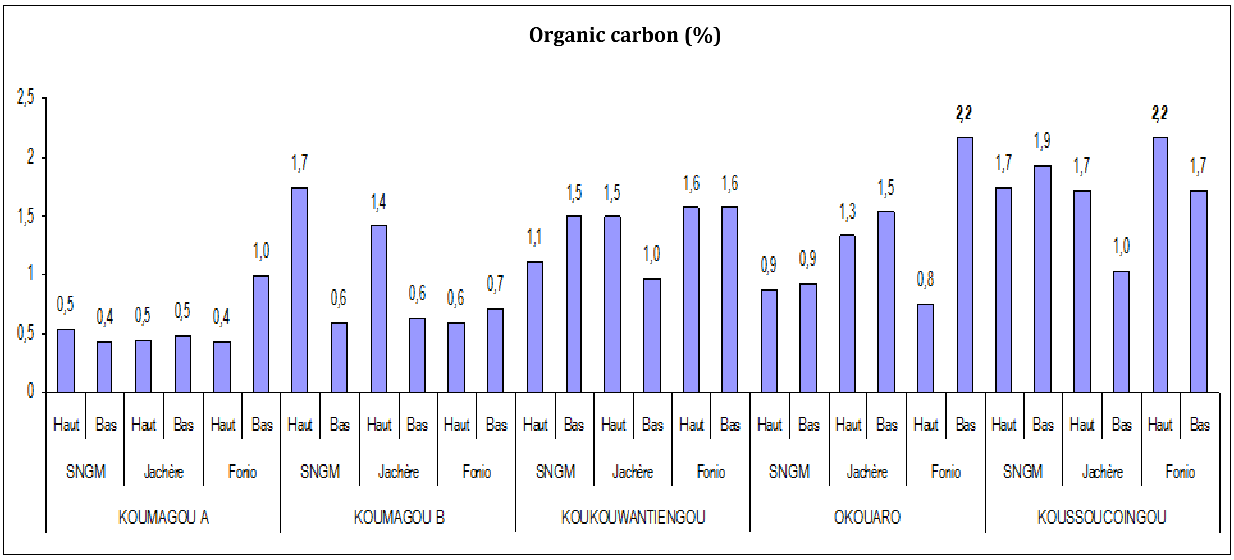

Figure 5 Organic carbon content in the soils of the study sites

Analysis of Figure 6 revealed that the nitrogen levels ranged from 0.02 to 0.14. The decrease in these nitrogen levels in the environment was due to human activities, the lack of nutrients and confirmed the level of soil degradation observed. Likewise the variation of the nitrogen content which decreased was the proof of leaching of soils which were exposed to erosion of all kinds. All agricultural land has an N content in the range [0.02-0.14%]. Thus, agricultural land is considered very poor in nitrogen regardless of the topo-sequence level. However, the C / N ratio is, in 3%, less than 12 in all the lands studied; with the exception of the vast 97% of the land in the Commune. The study noted that the soils of agricultural land in Boukombé are relatively poor in nitrogen (N) which results from the biodegradation of OM

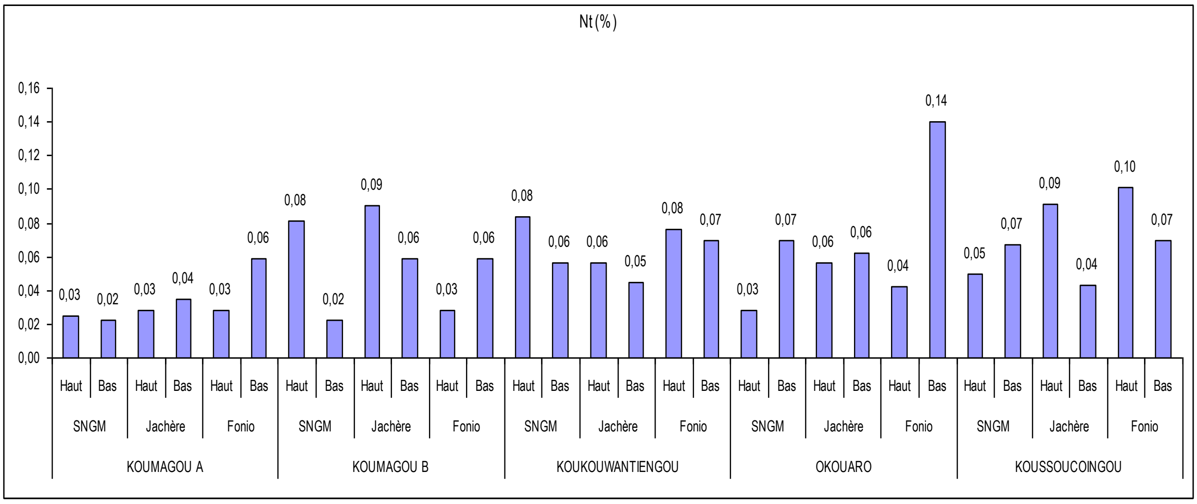

Figure 6 Total nitrogen content in the soils of the study sites

3.2.3. Effects of operating sites on the levels of phosphorus, carbon and nitrogen

Table 11 contains the results of the statistical analysis of the effects of operating sites on the levels of phosphorus, organic carbon and nitrogen. total nitrogen.

The analysis of Table 11 showed that the levels of phosphorus, carbon and nitrogen in these soils varied very significantly from one site to another, in other words from mountain to plateau (P <0.0001) . However, they did not vary significantly within an operating site (P> 0.05). This meant that the levels of these organic and mineral elements in mountain soils differed significantly from those in plateau soils.

Table 11 Analysis of variance of the effects of operating sites on the levels of phosphorus, carbon and nitrogen

Factors		Level of phosphorus	Level of carbon	Level of nitrogen
Inter-site variation	Ddl	F	F	F
	1	111.33***	102.41***	39.04***
Intra-plateau variation	1	0.09ns	0.00ns	0.11ns
Intra-mountain variation	1	0.64ns	0.06ns	0.00ns

Source: Analysis results, October 2019

*** significant inter-site difference at the 0.1% threshold; ns; not significant: intra-site difference.

4. Discussion

4.1. Physicochemical characteristics of the soils of the Boukombe watersheds

The discussion of the results focuses in particular on the physicochemical characteristics of the soils of the watersheds. It also concerns the agronomic potential of these soils and their major constraints on agricultural production linked to the sandy texture and the acid-alkaline character of certain parts.

4.1.1. Textural and granulometric characteristics of watershed soils

The results of the granulometric analysis of the studied soils showed overall a predominance (68%) of a textural dimorphism with a sandy loam character in the lands of the watersheds. These results show that the soils in the study area are suitable for cereal cultivation. A good yield could therefore be obtained if the mineral elements provide the essential and important quantities for the good development of crops. Studies by [31, 11 and 62] have reported that a sandy loam texture or medium coarse texture is excellent and suitable for most crops. However, the soil resources of the shallow horizon (0-20 cm) of land in the catchment areas of the commune of Boukombé present, from the point of view of their physical properties, an unbalanced texture, mainly silty-sandy in nature. They have a relatively stable structure with a hydromorphic character, due to their good water retention capacity. Indeed, all three size fractions are generally well represented. This gives them good agronomic potential, especially for cereal production. These types of soils composed of 31 to 67% sand, 14 to 37% silt and 10 to 43% clay have already been noted by [78] in the agricultural valleys of the Abomey – Bohicon conurbation in Benin. However, some parts of these lands are, from a granulometric point of view, predominated by the sand fraction. This state of affairs could be explained, in part, by the water erosion observed at the level of the plateau and the progressive silting up of the rice-growing lands of Koumagou A and Koumagou B. This phenomenon is much more accentuated in the watersheds of Koumagou A and Okouaro which have the highest sand content downstream, respectively estimated at 70% and 50%. Indeed, according to a study carried out in Senegal, the silting process is modifying the state of the soil structure of the agricultural valleys of the city of Ziguinchor, which from a general point of view, was almost stable, fragmentary and conducive to agricultural production [19]. Consequently, crop yields and the smooth running of human agropastoral activities are compromised. Soil leaching and the phenomena of drought, rainfall disturbances, shifting and shortening of the rainy season alone weaken the structure and physicochemical composition of soils [20]. Because coarse elements (sand) are dominant in these soils, they are poor reservoirs of water that can be used by plants. Indeed, the coarse elements can be considered as devoid of a usable reservoir for water [7]. In addition, soil erosion can lead to changes in the physical properties of the soil such as changes in bulk density, water infiltration and water holding capacity or structure [46, 1]. However, the profound change in the physical properties of the soil can significantly negatively affect soil productivity and hence crop yields. The studies by [20] in the city of Ziguinchor in Senegal, have shown that the splash effect of the intense rains often recorded favors the stripping of the soil, the transport of sandy particles by runoff and silting up of rice fields. A good structure of the topsoil layers is essential in agricultural activities. Because it ensures a balance between the different fractions of the soil (solid, liquid and gas) and allows crops to have at their disposal all the nutrients necessary for optimal growth [13]. Organic matter is one of the compounds that bind together soil particles [64]. Moreover, the continued use of the land without the use of suitable restoration and conservation techniques undoubtedly leads to total soil degradation [45, 3]. This explains the current state of the soil plateaus north-west of the Atacora Department in Boukombe, the chemical characteristics of which are very low whatever the localities considered. This phenomenon is also explained by the fact that the pressure on the soils of the plateaus is much greater and lasts much longer with unsuitable practices (slash-and-burn or crops with total export of harvest residues) which have caused physical, chemical and biological damage [39].

4.1.2. Acid-alkali character, factors limiting agricultural production

The acidic character of the watershed soils is one of the main factors limiting agricultural production in the Municipality of Boukombe. It is much more remarkable in the upper part of the slopes of the villages of Koussoucoingou, Koumagou A, Koumagou B and Okouaro. The Koukouatiengou watersheds have the best chemical characteristics due to its relatively neutral pH both at the top of the slope and at the bottom of the slope and which is well suited to most crops [24]. However, the studies conducted by [17] in the commune of Ziguinchor in Senegal, found that the combined effect of acidity and salinity made 8.73% of the 838.9 ha rice crops unusable. This state of affairs was much more noted in the villages of Okouaro and Koussoucoingou which recorded the highest Na soil concentrations, respectively estimated at 4.90 meq / 100g and 5.60 meq / 100g at the bottom of slopes at site III. Indeed, the peculiarity of the sodium character of the soils of these two villages results from the influence of strong erosion. In addition, the mangrove strip that protected the dikes has deteriorated due to the combined effect of anthropogenic pressure and climatic deteriorations noted by various authors [53, 55, and 78].

4.1.3. Soil nutrient content

The results of the soil analysis revealed a relative poverty of the watersheds of the commune of Boukombe in organic matter. This is partly justified by the fact that the majority of producers (80%) do not spread organic manure in their fields and do not bury crop residues during the plowing of the soil either [42]. These cultural practices have a double objective. They aim to maintain the level of soil fertility and to fight against their acidification [18]. The absence of woody vegetation in the watersheds has also contributed to the degradation of soil fertility. More than 40% of agricultural households in the study villages of the commune of Boukombe declared, in this regard, that the function of improving soil fertility would be one of the main reasons justifying the deliberate choice to leave woody vegetation in the shallows [17]. This vegetation makes a very important contribution to the supply of OM from the decomposition of the litter. Moreover, the OM richness of the village of Koukouatiengou would have positively influenced the increase in the pH of these soils. This is relatively neutral over the entire topo-sequence of the village. This confirms the work of [21] who showed that the decomposition of plant litter contributes to the increase of the pH value and to the improvement of soil fertility. The soils of this village have a saturation rate of exchangeable bases estimated, on average, at 68.34%. This gives them the character of silty-sandy-clay soils saturated with nutrients available for crops. We can deduce, from this result, that the calcium reserves of this village are sufficient and that the physicochemical and biological functioning of its soil is optimal.

Although the soils analyzed are relatively poor in OM, it should be noted that nitrogen and phosphorus were estimated to be very poor in all of these slopes. Their respective average content varies between 0.056% and 3.490 ppm. Yet the C / N ratio gave 3% of values less than 12, thus demonstrating an intense biological activity in certain parts of these soils, a good mineralization process of OM and consequently a good liberalization of the quantity of nitrogen in the soil. However, in the majority (97%) the C / N ratio gave values greater than 12. This study has, moreover, made it possible to observe that the nitrogen content of the soils is linked, at 99.5%, to that. of OM. This shows that the nitrogen concentration of soils is highly dependent on their OM richness and their biological activities. This supports the hypothesis that the nitrogen required for crop growth is due to the biodegradation of soil OM. This dichotomy of OM and nitrogen content, as well as the poverty of soils in phosphorus could be explained by the fact that these nutrients are taken up by crops or by the low abundance of bio-reducers in the environment [20]. Moreover, the fact that the watersheds of the commune of Boukombé are permanently exploited all the rainy seasons is the fundamental reason that the soil samples are taken during the period during which, the crops would have already taken the significant quantity. nitrogen, necessary for their growth. The same is true for phosphorus, which ensures cell multiplication, photosynthetic respiration and the growth of the root system as indicated by [80, 81]. It is also necessary to mention that this study made it possible to observe that the proportion of the sandy fraction is negatively correlated with the potassium content of the soils. This result shows that the more sandy the soil, the less potassium (K) it has. This confirms that silting contributes to the decline in soil fertility in potassium, which is useful for fruiting and ripening of crops, as demonstrated by [47]. Moreover, this translates that the CEC of the soil is inversely proportional to its pH and its content of nutrient cations (K +, Ca2 +, Mg2 +, Na +). Total nitrogen associated with the determination of organic carbon is used to characterize organic matter and chemical fertility of soils by calculating the C / N ratio. Thus, in agricultural soils, the C / N ratios of plowed surface horizons are of the order of 9 when humification is good. Under cultures, a C / N ratio equal to or greater than 12 indicates that the mineralization is encountering difficulties [7]. This is also justified by the low content of total nitrogen and the low level of organic matter, indicating poor biological activity such as the biological cycle of nitrogen and carbon [39]. Most soils have a low organic carbon rate (less than 2%), except for 2 cases which have an organic carbon rate greater than 2% under fonio. This can be explained by the input of organic matter by fonio and downwards peaks by runoff and the effect of accumulation, at the bottom of slopes. Likewise, the total nitrogen contents are much lower and vary from 0.02 to 0.10%. However, there is only one case of a low slope where the soil has a nitrogen content of 0.14%; which is relatively high and shows good chemical nitrogen fertility. Of all the soils studied 98% are poor in terms of chemical fertility and 2% of them are rich. Consequently, almost all of the soil in the watersheds of the Municipality of Boukombé is degraded, and therefore poor. In this Commune, more than 40 years ago [84] or more than 30 years [26] in the surface horizon of the soils, the organic carbon rate was 2.44% and the rate of 0.14% total nitrogen. Thus, formerly the soils of this Commune had good chemical fertility originally. This explains the immigration of many populations in this locality in the 1960s. Consequently, the current degradation noted is explained by the integrated action of agricultural systems and the relief of the environment [44].

The levels of assimilable phosphorus in Boukombé soils vary from 1.40 to 7.48 ppm. These levels are very low according to the fertility scale for available phosphorus BRAY-I defined by [33]. Indeed, when the available phosphorus content is less than 40 ppm, the fertility of the soil is very low in this fertility scale. This confirms the state of soil degradation in the Municipality. It is therefore important to resort to soil conservation and restoration techniques before cultivation. Slash-and-burn slash-and-burn agriculture linked mainly to yam and cotton cultivation is the main cause of clearing over large areas [40]. In addition, non-compliance with the doses of chemical fertilizers or the non-use of fertilizers leads to a prolonged impoverishment of the land due to the lack of nutrients [9, 5, 57, 2 and 38]. As soon as the clearing and the disappearance of litter, one observes a rapid decrease of the organic matter of the soil (SOM) and the beginning of chemical, biological and physical degradation of the surface horizons. The fire suddenly mineralizes the litter, temporarily raises the pH, but releases CO2 and ash which are blown by the wind or washed away during the first storms. Plowing in turn introduces oxygen into the soil, accelerates the mineralization of SOMs and mixes the underlying humus and mineral horizons: in the short term, tillage reduces the activities of fauna (earthworms in particular). Cultivated sandy soils lose 50% of their SOM in 4 years and clay soils in 10-15 years. All in all, cultivated soils become both less productive and less resistant to rainfall energy [66]. There is also fallow land to restore the productivity of soils degraded by cultivation [29] and traditional techniques for rehabilitating eroded soils such as mulching, agroforestry, organic and mineral manure (ash) or even zaï, a complex technique involving the storage of water in the soil, termites and tillage in the Sudano-Sahelian zone [67, 71].

pH is a key component of soil chemistry and determines the availability of nutrients for plants and soil microorganisms [24, 10]. The water pH of the moderately acidic soils studied is a favorable element for the cultivation of cassava [31]. More than 80% (86.67%) of the soil samples studied have an Mg 2 + / K + equilibrium ratio within the range of the normative value. Too high a Mg 2 + / K + ratio in light soil causes potassium deficiency and therefore lowers yields, while in clay soils a too low Mg 2 + / K + ratio slows down the absorption rate of magnesium, thus limiting yields [32, 62]. These results could be explained by the fact that the soils studied have an insufficiently good organic matter content. The latter allows the immobilization of phosphorus in soils. These results disagree with those obtained by [8, 48]. The exchangeable bases have shown that there is not a marked deficiency in calcium (Ca2 +) and magnesium (Mg2 +).

The values of the sum of exchangeable cations of certain signs of the soil or its surface [23]. This indicator value is based on principles also recognized in ecology [14]. This is how Nigerien peasants in the Say and Ouallam regions recognize that fallow land has become fertile again thanks to biological indicators familiar to their environment[61] setting up a new agricultural plot.

In view of all the above, it becomes urgent to put in place a new strategy of good integrated management of soil fertility to ensure the rational and sustainable use of agricultural land in the Boukombé watersheds. According to the law enunciated by Liebig, a German chemist that one can successively correct all modifiable limiting factors, until obtaining the potential return which depends only on non modifiable, for example water (in rainfed cultivation), light, CO2 content, etc. According to the same author, it is the weakest element in relation to the needs of plants that determines the yield of a crop [83]. Studies carried out by [34] on soil fertilization and the importance of organic matter have shown that mineral elements are present in the soil and, when properly maintained, they will be available from these elements for the plant. Therefore, this study proposes as a solution to the integrated management of soil fertility by, the use of mineral and organic fertilizers, the association of cassava cultivation with legumes and green manures. The solutions proposed will make it possible to (i) correct any soil deficiencies in one or more important or essential elements; (ii) strengthen and restore soil fertility through nitrogen nutrition when its mobilizable reserves (iii) stimulate implantation at the time of emergence [82, 65].

5. Conclusion

The study of the physicochemical characterization of the soils of the watersheds of the Commune of Boukombe in the North-West of Benin, which focused on 5 villages, made it possible to note, in general, a predominance of sandy soils with a silty texture-sandy, characterized by a relatively stable structure. These physical characteristics give them great agronomic potential, especially for cereal production. In addition, the absence of fertilization practices consisting of the spreading of manure in the fields among farmers, the burying of crop residues, gives these soils a relative poverty in organic matter and, consequently, in nutrients not available for crops. To this must be added the developments linked to the establishment of bunds and hydro-agricultural dikes. These practices help maintain soil fertility and improve agricultural yields. The main factors that are altering soil quality and hampering agricultural production in these watersheds are, among others, acidification, combined with gradual silting up. There is also the galloping demographic growth of the population which results in the anarchic and progressive occupation of the watersheds by the built environment. This suggests a problem with the viability of agriculture in the municipality. However, the rehabilitation of anti-erosion dikes in the Koumagou A and Koumagou B watersheds should help mitigate the effects of acidification. The problem of the silting up of watersheds could be solved by establishing canals and sewers to evacuate runoff water in the villages located in the plateau areas of these basins. Among other constraints, the occupation of these watersheds must be resolved on the basis of a ban promoted and known to all stakeholders in the development of the municipality. The study also made it clear that erosion, accelerated degradation, impoverishment of soils as well as the shortage of arable land under unprecedented high demographic pressure are the major agricultural problems, the most mentioned. . However, it appears that taking into account the current state of the physico-chemical characteristics of soils is not sufficient to measure the impact of agricultural systems. It is necessary to have a measure of yields and the level of soil degradation. The nutrient balance reveals deficiencies in mineral elements, the most marked of which concern exchangeable calcium and magnesium, following the increase in the potassium concentration in the studied soils. Then, the content of organic matter and major elements (nitrogen, phosphorus and potassium) are not sufficient to optimize optimal crop yields, despite the disparate use of mineral fertilizer on certain crops in Boukombe. There is a correlation between the indicators of fertility and the physico-chemical parameters of the soil samples studied.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest in the manuscript, as no associate author has contributed to the manuscript.

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