
*Journal of Agriculture and Ecology Research International*

***Volume 24, Issue 5, Page 142-161, 2023; Article no.JAERI.103475***
***ISSN: 2394-1073***

# Physicochemical Properties and Fertility Level of the Vertisols Surface Horizons for *muskuwaari* [*Sorghum bicolor* (L.) Moench] Cultivation in the Sudano-Sahelian zone of Cameroon

**Rapmo Kononer Serge [a*], Abdou Bouba Armand [a], Tobolbaï Richard [b], Goudoum Augustin [a] and Ngakou Albert [c]**

*[a] Department of Agriculture, Livestock and By Products, National Advanced School of Engineering of Maroua, University of Maroua, P.O. Box 46, Maroua, Cameroon.*
*[b] Department of Microbiology, Faculty of Science, University of Yaounde I, P.O. Box 812, Yaounde, Cameroon.*
*[c] Department of Biological Sciences, Faculty of Science, University of Ngaoundere, P.O. Box 454, Ngaoundere, Cameroon.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

***Article Information***

DOI: 10.9734/JAERI/2023/v24i5552

**Open Peer Review History:**
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/103475

***Original Research Article***

***Received: 20/05/2023***
***Accepted: 26/07/2023***
***Published: 07/08/2023***

**Corresponding author: E-mail: sergerapmo9@gmail.com, serge.rapmo@yahoo.com;*

## ABSTRACT

Poor agricultural practices coupled with climatic aberrations have led to the degradation of vertisols intended for *muskuwaari* cultivation and consequently result in a drastic drop in crop yield. Faced with this situation, the knowledge of the state of their physicochemical properties and fertility level becomes a priority to develop strategies to restore their fertility. In this perpective, this work is inscribed to contribute to the knowledge of the state of the physicochemical properties of vertisols and the evaluation of the associated fertility level. To do this, 6 samples of cultivated vertisols associated with the rhizosphere were surveyed and collected in the surface horizon (0-30 cm) including, three samples in each administrative region of the North (Houla, Bangli, Pitoa) and the Far North (Dargala, Ibba, Moutourwa) respectively. Physical characterisation revealed that almost all of these vertisols have rather a silty texture with a very small proportion of the clay fraction (25.66-28.66%) compared to normal (40-80%). Chemically, acidity is spatially variable with generally low proportions (pH= 5.50-7.16) compared to normal (7-7.5). These vertisols also have very low proportions of nitrogen (0.03-0.08 %), organic carbon (0.95-1.9%), organic matter (1.63-3.39%), C/N ratio (19.45-49.14%), assimilable phosphorus (5.92-45.31 mg/kg), the sum of exchangeable cations (4.10-7.56 meq/100 g), cation exchange capacity (16.51-18.49 meq/100 g) and saturation of the exchangeable complex (23.33-43.14%) compared to normal especially for organic matter (2-4%), the sum of exchangeable cations (25-40 meq/100 g), the cation exchange capacity (20-45 meq/100 g) and the saturation of the exchangeable complex (80-100%). Therefore, the fertility level associated with these vertisols was very low with at least one limiting parameter. One fertility rehabilitation strategy for these vertisols is based on the use of inputs such as mycorrhizae and/or compost.

*Keywords: Physicochemical properties; fertility level; vertisol; muskuwaari; mycorrhizae; compost.*

## 1. INTRODUCTION

The agricultural sector is the mainstay of many countries'socioeconomic development around the world [1]. In Africa, it is a strategic development pathway because of the diverse socio-economic and environmental services it provides, particularly to cities in developing countries [2]. In Cameroon, the subsistence, industrial and export agriculture sector is the largest provider of employment and contributes 22.9 % of the gross domestic product [3]. Among agricultural products, cereals are also the most important food resource for both human and animal consumption [4,5]. In the Sudano-Sahelian zone, the cultivation of flood sorghum commonly known as *muskuwaari* occupies, a prominent place in this sector of activity and represents a major part of cereal production by regularly supplying urban markets in northern Cameroon, a large part of southern Chad and part of Northwestern Nigeria [6]. This type of sorghum is used in food and feed as seed and fodder, respectively [7]. The seed has a high energy value, because it is high in carbohydrates (starch) and also contains fats, proteins, fiber, minerals and vitamins [8]. However, the cultivation of this speculation depends on a drastic reduction in yields due to the degradation of the quality of soils on which it is grown [9]. At the same time, the cereal deficit has increased in recent years due to a combination of several factors, including land saturation [10], inflation in the price of cereal commodities on the market [11], population growth [12], the cotton crisis [13], diseases and pests [14], armed conflicts [15], the phenomenon of climate change and disruption [16], the Covid-19 pandemic [17], vegetation loss [18] and more recently, economic repression between and within Western countries [19]. According to the 2017 World Food Programme (WFP) report, in Northern Cameroon, the problem of food insecurity is chronic and recurrent, and nearly 40% of the population is affected by this calamity. Faced with this situation, the implementation of agricultural strategies, aimed at increasing agricultural production with respect to ecological functionalities is necessary [20]. For this purpose, the screening of appropriate fertilisers must take into account the properties of the soil and the requirements of the plant [21]. This work is therefore to enhance the knowledge on the physicochemical properties and fertility level of vertisols surface horizons intended for *muskuwaari* cultivation in the Sudano-Sahelian zone of Cameroon.

## 2. MATERIALS AND METHODS

### 2.1 Study Area Description

The study was conducted in the Sudano-Sahelian zone of Cameroon covering both the administrative regions of the North and the Far North. It is still called agro-ecological zone 1 and extends from the Benue floodplain (9° N) to the current shores of Lake Chad (13° N) with an area of 100,353 km² representing about 21.15% of Cameroon's territory [22].

In the Far North region, the study was carried out in the Diamare floodplain, while in the North region it focused on the Benue floodplain.

Diamare floodplain is located between 10°0' and 10°48' North latitude and between 14°0' and 14°48' East longitude. In this station, the selected sampled substations included Ibba (14.41672°E; 10.68982°N; 227 m), Dargala (14.57194°E; 10.55634°N; 345 m) and Moutourwa (14.19117°E; 10.25772°N; 468 m).

Benue floodplain is located between 6°43' and 10°45' North latitude and 11°41' and 15°40' East longitude. In this station, the selected sampled substations included Pitoa (13.50966°E; 10.25772°N ; 171 m), Houla (13.71094°E; 9.29718°N; 200 m) and Bangli (13.21518°E; 9.22819°N; 171 m).

### 2.2 Collection and Conditioning of Soil Samples

Soil samples were collected at the end of the 2020/2021 crop year, at a depth of 0-30 cm from the soil and using a planter based on Huang et al. method [23]. This method consisted in constructing two concentric circles of 3 and 6 meters radius delimited by 2 perpendicular lines around a central sampling point (Fig. 1).

The points of intersection of the first circle with the two perpendicular lines represent the first elementary sampling points. The other sampling points were distributed equidistant 6 meters in radius. The GPS coordinates of each field were taken at the same time. In each station (Diamare floodplain or Benue floodplain), 3 sites with an average distance of 500 meters were selected and for each site, 3 fields of at least 2 hectares were chosen for collection [24]. In each field, 12 rhizospheres were surveyed and collected (Fig. 2). All 12 soil samples collected per field (500 g per sample) were homogenized to form a composite soil sample from each site.

### 2.3 Physicochemical Characterization and Fertility Level Assessment of Soil Samples in the Study Area

Each composite sample was physically and chemically analyzed according to the methods described by [25], at the Soil Science Laboratory of the University of Dschang.

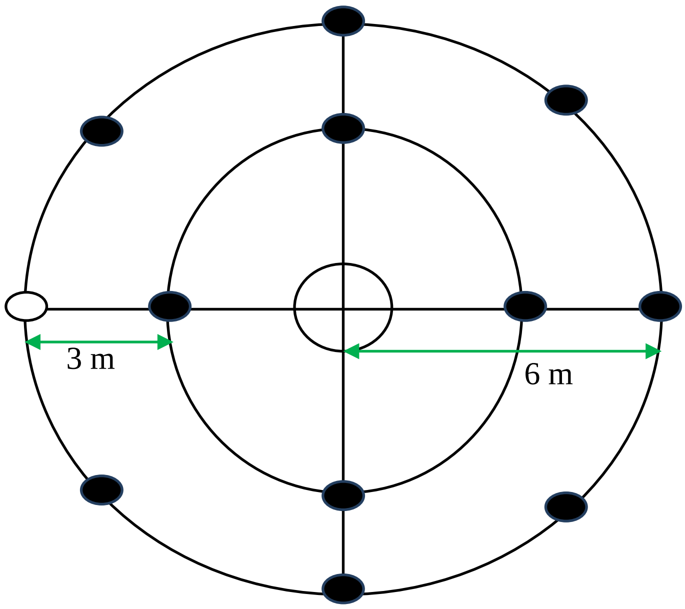


**Fig. 1. Experimental soil collection device [23]**

⊕*Central sampling point;* ⬤ *Elementary sampling point*


**Fig. 2. Prospecting (A) and collecting (B) soil samples from the *muskuwaari* rhizosphere**

#### 2.3.1 Soil texture

The soil texture was determined by the Robinson Pipette method [26]. The sandy fraction was obtained by dry sieving. This consisted of drying at 105 °C for 24 hours, 500 g of soil sample. A series of sieves was previously mounted from bottom to top following this toposequence of meshes: 45 µm, 63 µm, 106 µm, 150 µm, 180 µm, 500 µm, 2 mm and 2.36 mm. A mass of 100 g of previously dried soil sample was taken and passed through the sieves. The whole was agitated until a rejected mass was obtained and accumulated on each sieve. Each mass was then weighed whereas silt and clay samples were taken with a pipette. The soil structure was read according to the triangle of soil textures.

#### 2.3.2 pH ($pH_{water}$ ; $pH_{KCL}$)

The pH measurement was done using the method of [27]. The $pH_{water}$ was determined by an electrode in a soil-water solution suspension (1/2.5) and the $pH_{KCl}$ in a soil-KCl suspension (1/2.5) 1N. 20 g of dried and sieved soil (2 mm) was placed in a beaker and 50 ml of sterilized distilled water was added. After stirring at intervals of 15 minutes for 2 hours, the pH was measured with a glass electrode pH meter after calibration for $pH_{water}$. The same process was carried out for $pH_{KCl}$ except that the 50 ml of distilled water was replaced by 50 ml of a of Potassium Chloride solution (KCl).

#### 2.3.3 Total organic matter

The total organic carbon (OC) proportion was determined using the method of Walkley and Black [28]. This method consisted in oxidizing the soil organic carbon with a solution of Potassium Dichromate ($K_2Cr_2O_7$) in excess in an acidic medium. The excess of Dichromate not reduced by Organic Carbon was then titrated by a solution of ferrous sulfate ($FeSO_4H_2O$) in the presence of Diphenylalamine which turns from purple to green at the point of equivalence. The result was converted and the organic matter (OM) proportion was then determined by the formula:

$$OM\ (\%) = OC\ (\%) \times 1.724$$

With OM: Organic Matter ; OC: Organic Carbon and 1.724 the division factor.

#### 2.3.4 Total nitrogen

The total nitrogen proportion was determined by the Kjeldahl method [29], which consisted in hot attacking the organic matter with concentrated Sulfuric Acid in the presence of a catalyst and then distilling the extraction solution with excess soda and titrated with $H_2SO_4$ (1N).

#### 2.3.5.= Assimilable phosphorus

The assimilable phosphorus proportion was obtained using the Bray 2 method [30]. It consisted in combining the extraction of phosphorus in an acidic medium with complexation, ammonium fluoride and aluminum.

#### 2.3.6 Exchangeable cations

The proportions of exchangeable cations were determined by the "Aqua-Regia extraction" method [31]. For this purpose, 3 g of soil was weighed in a quartz bowl and perfectly mixed with hydrogen chloride diluted with distilled water and 2 ml of diluted $HNO_3^-$ (1/2 $HNO_3^-$/diluted water). The mixture was then covered for more than 8 hours of the night and the day after, which it was heated in a sand bath for 2 hours. 2 ml of diluted hydrogen chloride (HCl) and 2 ml of $HNO_3^-$ were added respectively in 2 steps (T1 and T2). Subsequently, the samples were transferred to a 50 ml vial filled with distilled and filtered water. The concentration of the different ions was measured using an ICP-OES spectrophotometer.

#### 2.3.7 Cation Exchange Capacity (CEC)

The CEC was determined using the Duchaufour method [32]. For this, the sample was first saturated with ammonium ions ($NH_4^+$) by successive percolations of an ammonium acetate solution ($CH_3CO_2NH_4$) at 1 mol/l. The buffering capacity of the latter made it possible to reduce the pH of the medium to around 7 which is one of the essential properties of this method. After removing the excess ammonium ions by percolation of ethyl alcohol, their exchange was then carried out with a solution of sodium chloride (NaCl) at 1 mol/l. The displaced ammonium ions were determined by spectrocoloriometry on the previous solution once filtered. The concentrations found were converted to meq/100 g.

#### 2.3.8 The sum of exchangeable cations (SEC)

The proportion of the Sum of Exchangeable Cations (SEC) was determined by spectrophotometry and their relative proportions were determined and compared to the optimal cationic ratio (76/18/6) [33].

#### 2.3.9 The saturation of the exchangeable complex (V)

The saturation of exchangeable complex (V) was obtained by the following formula [31]:

$$V (\%) = SEC \times 100/CEC$$

With SEC: Sum of Exchangeable Cations and CEC: Cationic Exchange Capacity.

### 2.4 Fertility Level

The fertility level of the different soil samples was determined according to the criteria for evaluating fertility classes (table 1) reported by [34] with the following classes:

- Class I, high fertility level : Soils are of this class when the properties do not present or have only slight limitations ;
- Class II, average fertility level : Soils are of this class when the properties do not have more than 3 moderate limitations possibly associated with small limitations ;
- Class III, low fertility level : Soils are of this class when their properties have more than 3 moderate limitations associated with a single severe limitation ;
- Class IV, very low fertility level : Soils are of this class when their properties have more than one severe limitation.

The reference cut-off values (Table 2) for tropical soils typical of vertisol made it possible to assess the current state of vertisol properties in the study area.

**Table 1. Criteria for assessing soil fertility classes**

| Parameters | Fertility level | | | | |
|---|---|---|---|---|---|
| | Very high (Without limitation) | High (Low limitation) | Medium (Medium limitation) | Low (Severe limitations) | Very low (Very severe limitations) |
| | Degree 0 | Degree 1 | Degree 2 | Degree 3 | Degree 4 |
| **OM (%)** | > 2 | 2-2.15 | 1.5-1 | 1-0.5 | < 0.5 |
| **N (%)** | > 0.08 | 0.08-0.06 | 0.06-0.045 | 0.045-0.03 | < 0.03 |
| **AP (Cmol/kg)** | > 20 | 20-15 | 15-10 | 10-5 | < 5 |
| **$K^+$ (Cmol/kg)** | > 0.4 | 0.4-0.3 | 0.3-0.2 | 0.2-0.1 | < 0.1 |
| **SEC (Cmol/kg)** | > 10 | 10-7.5 | 7.5-5 | 5-2 | < 2 |
| **V (%)** | > 60 | 60-50 | 50-30 | 30-15 | < 15 |
| **CEC (Cmol/kg)** | > 25 | 25-15 | 15-10 | 10-5 | < 5 |
| **pH** | 5.5-6.5 | 5.5-6.0 | 5.5-5.3 | 5.3-5.2 | < 5.2 |
| | 6.5-8.2 | 6.5-7.8 | 7.8-8.3 | 8.3-8.5 | > 8.5 |

*OM: Organic Matter; N: Nitrogen; AP: Assimilable phosphorus; $K^+$: Potassium; SEC: Sum of Exchangeable Cations; V: Saturation of the exchangeable complex; CEC: Cation Exchange Capacity; pH: potential of Hydrogen*

**Table 2. Reference cut-off values [35]**

| Parameter | Clay (%) | pH | OM (%) | SEC (meq/100 g) | V (%) | CEC (meq/100 g) |
|---|---|---|---|---|---|---|
| **Thresholds** | 40-80 | 7-7.5 | 2-4 | 25-70 | 80-100 | 20-45 |

*pH: potential of Hydrogen; OM: Organic matter; SEC: Sum of Exchangeable Cations; V: Saturation of the exchangeable complex; CEC: Cationic Exchange Capacity*

## 2.5 Statistical Analysis

The results obtained were statistically analysed using StatGraphics Centurion 16.0 software. When the analysis would have revealed significant differences, Duncan's test was used to judge the difference between the proportion means of the different parameters at the 5 % level. A Principal Component Analysis (PCA) highlighted the relationships between the proportion means of the different parameters through a multivariate approach using XLStat 2007 8.04 software. The projection of all individuals on the planes of axes 1 and 2 made it possible to assess the dispersion of individuals and to better compare their variability in space on the physical and chemical levels.

# 3. RESULTS

## 3.1 Physical Properties of Soil Samples

Table 3 shows the particle size composition of the different soil samples by site. The analysis of variance (ANOVA) performed shows that the mean proportions of coarse elements vary very significantly ($p$ <0.0001) between study areas for elements such as silt and sand except for clay ($p$ = 0.889). At the same time, the mean proportion of these elements shows significant differences ($p$ <0.0001) in almost all areas of interest except the Dargala site ($p$ = 0.1260). However, the proportion of clay was lower at all sites compared to other coarse elements.

It emerges from this table that the Ibba site is richer in sand (42%) compared to the sites of Moutourwa (40.81%), Dargala (36.66%), Houla (38.08%), Pitoa (43.25%) and Bangli (39.08%) which are rather rich in silt respectively. The proportion of clay was lower at all sites compared to other coarse elements. By projecting different proportions of the particle size fraction for each site onto the [36] soil texture triangle, it can be seen that the texture of the soils studied varies from one site to another with Pitoa, Houla, Ibba and Moutourwa having a loamy texture. On the other hand, that of Bangli and Dargala is silancy (Fig. 3).

Based on all the physical soil fractions, the analysis of the three crude fractions (Fig. 3) revealed dissimilarities between the texture of the different soil samples ($p$ <0.0001). The dendrogram in Fig. 4 makes it possible to distinguish probably 4 homogeneous classes of soils with a 4.79% physical similarity index.

It is noted in this classification that the first class consists of soil samples from Bangli, Dargala and Houla. The second class, on the other hand, is essentially characterized by the soil sample from the Ibba site. The third class is mainly characterized by the soil sample from the Moutourwa site. The fourth class is characterised by the soil samples from Pitoa.

## 3.2 Chemical Properties

### 3.2.1 pH

Table 4 shows the average pH proportions ($H_2O$; KCl) of the different soil samples by site. The analysis of variance performed shows a

**Table 3. Average proportion (%) of physical elements at different sites**

| Sites | Clay | Silt | Sand | p-value |
|---|---|---|---|---|
| **Ibba** | $28.66\pm3.21^{A}_{a}$ | $29.33\pm0.58^{A}_{a}$ | $42.00\pm0.2^{B}_{b}$ | 0.0008 |
| **Moutourwa** | $28.00\pm3.00^{A}_{a}$ | $40.81\pm0.16^{B}_{bc}$ | $31.18\pm2.85^{A}_{a}$ | 0.0010 |
| **Dargala** | $28.33\pm5.77^{A}_{a}$ | $36.66\pm1.56^{A}_{b}$ | $35.00\pm1.00^{A}_{a}$ | 0.1260 |
| **Houla** | $28.00\pm2.00^{A}_{a}$ | $38.08\pm1.01^{C}_{bc}$ | $33.91\pm1.01^{B}_{a}$ | 0.0003 |
| **Pitoa** | $25.66\pm3.21^{A}_{a}$ | $43.25\pm2.38^{B}_{c}$ | $31.08\pm0.88^{A}_{a}$ | 0.0002 |
| **Bangli** | $27.58\pm0.52^{A}_{a}$ | $39.08\pm0.88^{C}_{bc}$ | $33.33\pm1.15^{B}_{a}$ | 0.0001 |
| **p-value** | 0.8890 | 0.0001 | 0.0001 | |

*Uppercase letters on the same row and lowercase letters in the same column are not significantly different at the 5% threshold* significant difference between the mean pH proportions in the different study sites (*p* <0.0001). At the same time, this proportion varies very significantly (*p* <0.0001) for the potential of hydrogen in the Ibba, Moutourwa, Dargala and Houla sites, unlike the Pitoa (*p* = 0.1018) and Bangli (*p* = 0.0849) sites.

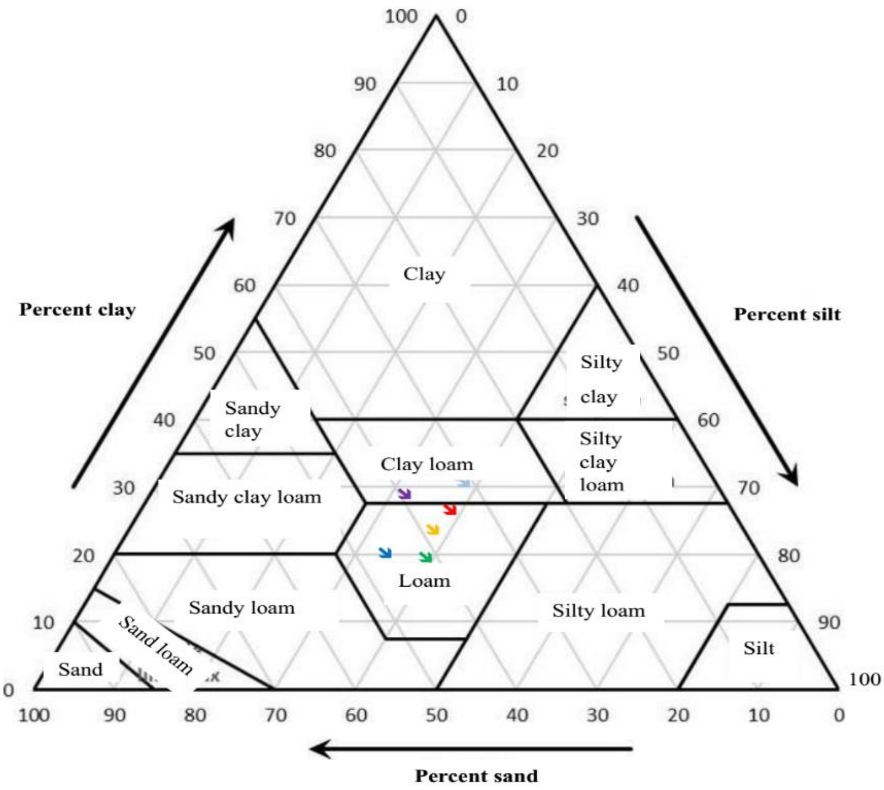


**Fig. 3. Soil texture reading triangle according to [36]**

*Dargala* *Bangli* *Pitoa* *Houla* *Moutourwa* *Ibba*

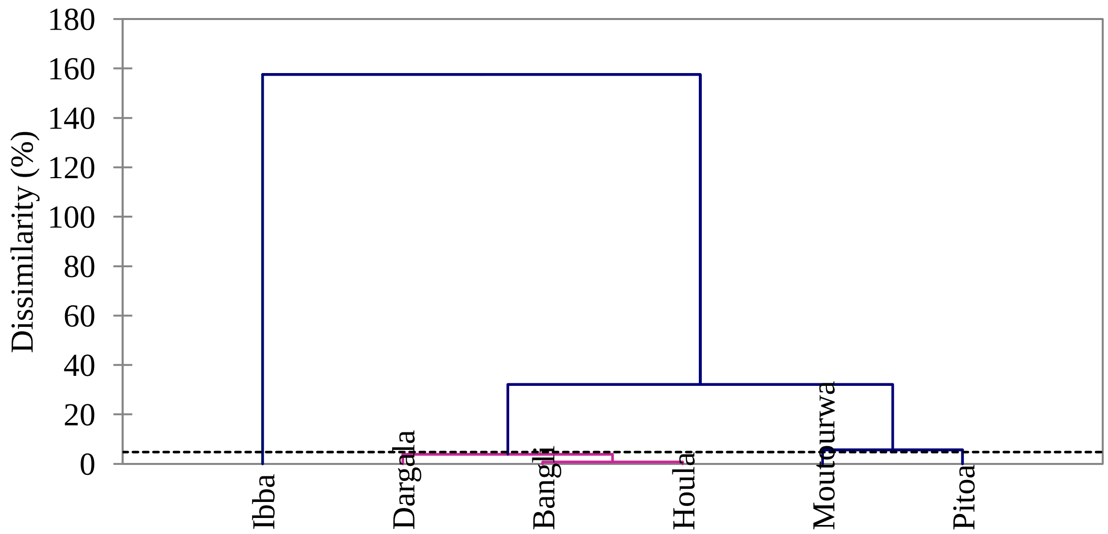


**Fig. 4. Classification dendrogram of all soil samples according to the similarity of the proportion of coarse elements**

**Table 4. Average proportion (%) of the potential of hydrogen at different sites**

| Sites | pH | | |
|---|---|---|---|
| | $H_2O$ | KCl | p-value |
| **Ibba** | $6.16\pm0.06^{A}_{ab}$ | $5.36\pm0.38^{A}_{ab}$ | 0.0600 |
| **Moutourwa** | $6.11\pm0.09^{B}_{ab}$ | $5.59\pm0.10^{A}_{abc}$ | 0.0020 |
| **Dargala** | $6.60\pm0.10^{B}_{bc}$ | $6.03\pm0.23^{A}_{bc}$ | 0.0300 |
| **Houla** | $5.50\pm0.20^{B}_{a}$ | $4.91\pm0.05^{A}_{a}$ | 0.0300 |
| **Pitoa** | $7.16\pm0.50^{A}_{c}$ | $6.3\pm0.50^{A}_{c}$ | 0.1018 |
| **Bangli** | $5.63\pm0.42^{A}_{a}$ | $4.96\pm0.29^{A}_{a}$ | 0.0849 |
| **p-value** | 0.0001 | 0.0003 | |

*pH: potential of Hydrogen; $H_2O$: Water; KCl: Potassium Chloride; Uppercase letters on the same row and lowercase letters in the same column are not significantly different at the 5% threshold*

It is noted from this table that all soil samples from the sites studied have a generally acidic pH except for the sample from the Pitoa site which is close to neutrality (pH= 7.16). In addition, the acidity of the soils of Ibba, Moutourwa and Dargala is light. That of the Houla and Bangli sites is moderate while that of the Pitoa site is moderately alkaline.

### 3.2.2 Total nitrogen, organic carbon, organic matter and C/N ratio

Table 5 shows the average proportions of total nitrogen (N), total organic carbon (OC), total organic matter (OM) and the ratio of total carbon/nitrogen (C/N) of the different soil samples by site. The analysis of variance performed shows a very significant difference between the mean proportions of each of these chemical elements in the different study sites (*p* <0.0001). Relatively, there is also a very significant difference between the proportions of these different elements for all sites (*p* <0.0001).

Table 5 shows that the average proportion of total nitrogen is low for all soils at the sites studied (0.03-0.08%) that of a high organic carbon (0.93-1.89%). Relatively, the total organic matter is low for the sites of Moutourwa (1.63%) and Dargala (1.74%) but rather average for the sites of Ibba (2.96%), Houla (3.25%), Pitoa (3.26 %) and Bangli (3.39%). The ratio of carbon to total nitrogen remains very low (19.45-49.14%).

### 3.2.3 Assimilable phosphorus

Fig. 5 shows the average proportion of phosphorus available at the different study sites. The analysis of variance performed reveals a very significant difference (*p* <0.0001) between the mean proportions in this element for all the different study sites.

From this Fig. 5, it can be observed that the average proportion of assimilable phosphorus of the sites of Ibba (16.57 mg/kg), Houla (35.66 mg/kg), Pitoa (45.31 mg/kg) and Bangli

(21.53 mg/kg) remains average compared to the sites of Moutourwa (5.92 mg/kg) and Dargala (6.77 mg/kg) whose proportions of assimilable phosphorus are very low.

### 3.2.4 Exchangeable cations, Sum of Exchangeable Cations (SEC), Cation Exchange Capacity (CEC) and saturation of the exchangeable complex (V%)

Table 6 shows the average proportions of exchangeable cations, the sum of exchangeable cations, the cation exchange capacity and the saturation of the exchangeable complex of the different soil samples by site. The analysis of variance performed shows a very significant difference between the mean proportions of each of these chemical elements in the different study sites (*p* <0.0001). Relatively, there is also a very significant difference between the proportions of these different elements for all sites (*p* <0.0001).

On Table 6, we note that the average proportion of the $Ca^{2+}$ ion remains low for the sites of Ibba (3.26 meq/100 g), Moutourwa (2.25 meq/100 g), Houla (2.16 meq/100 g), Pitoa (3.20 meq/100 g) and Bangli (4.20 meq/100 g). On the other hand, it is very low for the Dargala site (1.85 meq/100 g). That of the $Mg^{2+}$ ion remains low for all sites. That of the $Na^{+}$ ion also remains low for the sites of Ibba (0.15 meq/100 g), Dargala (0.26 meq/100 g) and Houla (0.16 meq/100 g). However, it remains high for the Moutourwa site (0.98 meq/100 g), medium for the Pitoa site (0.39 meq/100 g) and very low for the Bangli site (0.07 meq/100 g). The $K^{+}$ ion proportion on the other hand, is very high for the sites of Ibba (1.59

meq/100g), Moutourwa (1.59 meq/100 g), Dargala (1.59 meq/100 g) and Pitoa (3.09 meq/100 g) unlike the sites of Houla (1.09 meq/100 g) and Bangli (0.84 meq/100 g) whose proportions are rather high. In addition, the sum of exchangeable cations, cation exchange capacity and saturation of the exchangeable complex remain very poor by reference standards.

Based on all the chemical constituents of different soil samples, the analysis of variance (Fig. 6) revealed significant differences between the proportion in chemical properties from different soil samples ($p$ <0.0001). The dendrogram of Fig. 6 made it possible to distinguish all the samples into 3 dissimilar classes, according to their chemical constituent proportion with 254.5 % similarity index.

This classification shows that the first class is mainly made up of soil samples from the IbbaDargala and Bangli sites. The second class is made up of soil samples from the Houla and Pitoa site. The third class is the soil sample from the Moutourwa site.

#### 3.2.5 Identification of limiting physicochemical parameters and estimation of soil fertility levels

Tables 7 and 8 present respectively the limiting physicochemical parameters and of fertility level associated with the different soil samples. The analysis of Table 7 shows that for each site, at least one physicochemical parameter is limiting.

However, the focus is on the parameters of severe limitations that would be at the origin of the low fertility of the soil. In Ibba, the severe limiting parameters are nitrogen, potassium and cation exchange capacity. In Moutourwa, the severe limiting parameters are assimilable phosphorus, potassium and cation exchange

**Table 5. Average proportion (%) of nitrogen, organic carbon, total organic matter and C/N ratio**

| Sites | N | OC | OM | C/N | p-value |
|---|---|---|---|---|---|
| **Ibba** | $0.04\pm0.01^{A}_{a}$ | $1.72\pm0.05^{B}_{b}$ | $2.96\pm0.02^{C}_{b}$ | $49.14\pm0.19^{D}_{e}$ | 0.0000 |
| **Moutourwa** | $0.05\pm0.00^{A}_{ab}$ | $0.95\pm0.01^{A}_{a}$ | $1.63\pm0.03^{A}_{a}$ | $19.45\pm1.50^{B}_{a}$ | 0.0000 |
| **Dargala** | $0.03\pm0.005^{A}_{a}$ | $1.01\pm0.01^{B}_{a}$ | $1.74\pm0.01^{C}_{a}$ | $35.98\pm0.44^{D}_{d}$ | 0.0000 |
| **Houla** | $0.08\pm0.01^{A}_{c}$ | $1.89\pm0.18^{B}_{c}$ | $3.25\pm0.26^{C}_{bc}$ | $24.62\pm0.01^{D}_{b}$ | 0.0000 |
| **Pitoa** | $0.06\pm0.005^{A}_{bc}$ | $0.93\pm0.05^{B}_{c}$ | $3.26\pm0.02^{C}_{bc}$ | $30.67\pm0.45^{D}_{c}$ | 0.0000 |
| **Bangli** | $0.05\pm0.00^{A}_{ab}$ | $1.9\pm0.05^{B}_{c}$ | $3.39\pm0.11^{C}_{c}$ | $34.64\pm0.56^{D}_{d}$ | 0.0000 |
| ***p*-value** | 0.0001 | 0.0000 | 0.0000 | 0.0000 | |

*N: Nitrogen; OC: Organic Carbon; MO: Organic Matter; C/N: Carbon/Nitrogen ratio; Uppercase letters on the same row and lowercase letters in the same column are not significantly different at the 5% threshold*

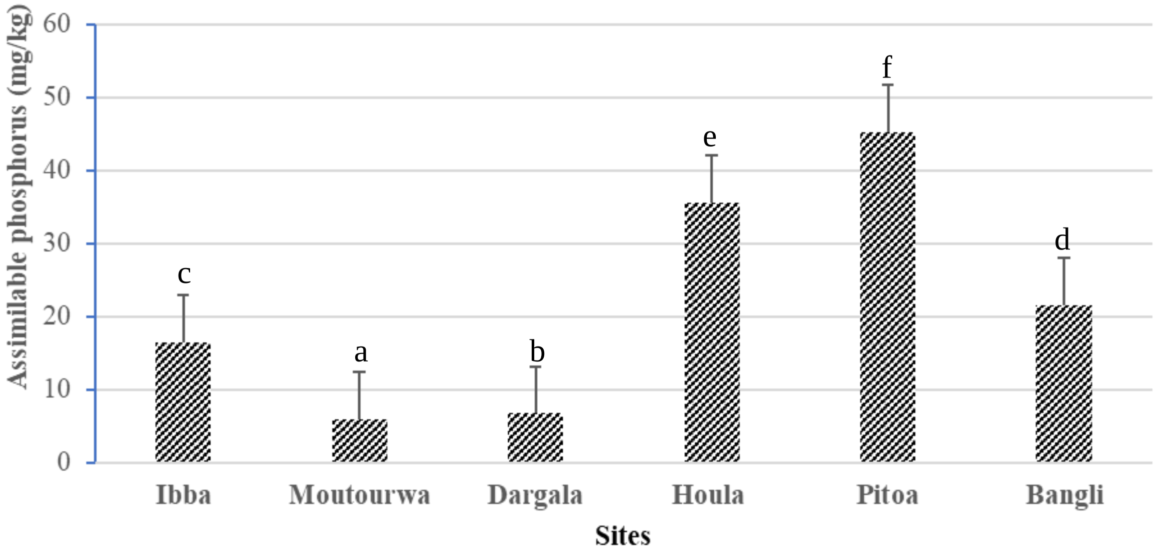


**Fig. 5. Phosphorus proportion available in soils at different sites (mg/kg)**
*Values with the same letters are not significantly different at the 5% threshold*

capacity. At Dargala, the severe limiting parameters are assimilable phosphorus, potassium, sum of exchangeable cations, cation exchange capacity and potential of hydrogen. At Houla, the severe limiting parameters are potassium, Sum of exchangeable cations and Saturation in exchangeable complex. In Pitoa, the severe limiting parameters are potassium and cation exchange capacity. On the other hand, in Bangli, the severe limiting parameters are potassium and saturation in exchangeable complex.

Referring to the fertility classes to which each site soil sample belongs (Table 8), it can be seen that all the soil samples studied belong to degree 4 characterized by a very low fertility level.

#### 3.2.6 Correlation between physicochemical propertiess and overall soil classification

A summary of the correlation matrix between the proportions of physical and chemical elements at all sites is presented in Table 9. The analysis of this table shows several levels of correlation between the different variables.

Overall, silt is strongly and negatively correlated with sand (r = -0.998 ; $p$ <0.05) and C/N ratio (r = -0.896 ; $p$ <0.05). Sand is strongly and positively correlated with the C/N ratio (r = 0.909; $p$ <0.05). Organic matter is strongly and positively correlated with organic carbon (r = 0.998; $p$ <0.05) and inversely with cation exchange capacity (r = -0.948 ; $p$ <0.05) and $pH_{KCl}$ (r = -0.896 ; $p$ <0.05). Organic carbon is strongly and negatively correlated with cation exchange capacity (r = -0.948 ; $p$ <0.05) and $pH_{KCl}$ (r = -0.895 ; $p$ <0.05). Magnesium is strongly and positively correlated with the sum of exchangeable cations (r = 0.910 ; $p$ <0.05) and the saturation of the exchangeable complex (r = 0.943; $p$ <0.05). The sum of the exchangeable cations is strongly positively correlated with the saturation of the exchangeable complex (r = 0.962; $p$ <0.05). $pH_{water}$ eau is strongly and positively correlated with $pH_{KCl}$.

Fig. 7A subdivided into two axes made it possible to verify the existence of the relationship of similarity of proportions between physical and chemical elements in all sites.

In this model, axes F1 and F2 contribute for variations of 47.59 % and 25.42 % respectively affinity between the proportions of the characteristic elements of the soils, for a total of 73.01 %. Most of the analysis is concentrated in Table 10.

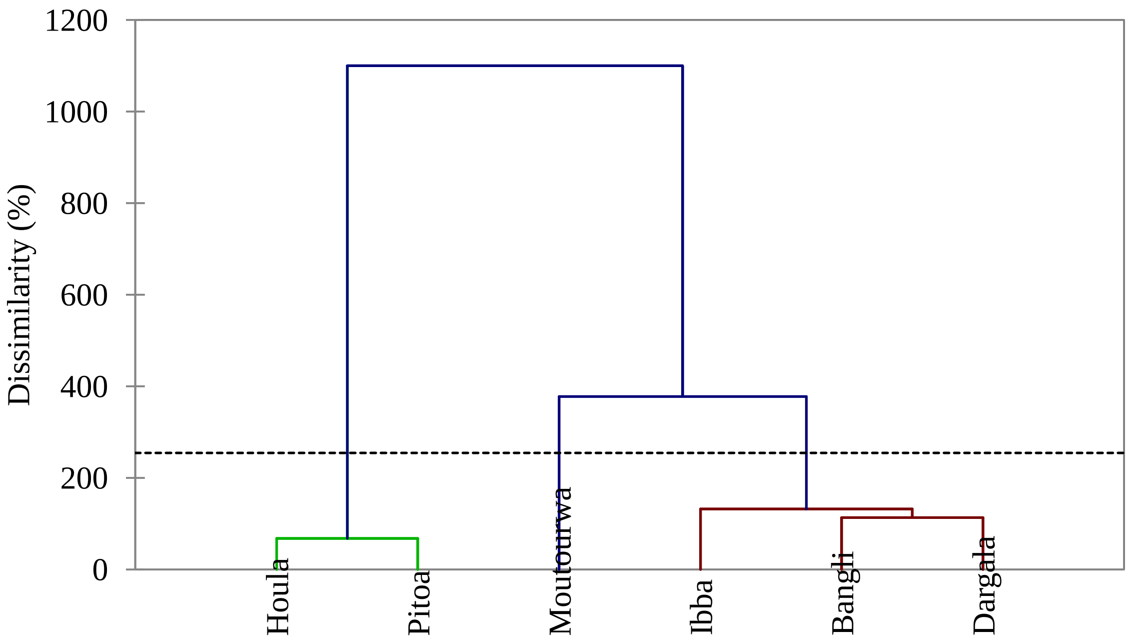


**Fig. 6. Dendrogram for classifying all soil samples according to similarity in chemical property proportion**

**Table 6. Average proportion of exchangeable cations, sum of exchangeable cations, cation exchange capacity and saturation of the exchangeable complex of the different sites**

| Sites | Exchangeable cations (méq/100g) | | | | SEC | CEC | V | p-value |
|---|---|---|---|---|---|---|---|---|
| | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | méq/100g | méq/100 g | % | |
| **Ibba** | $3.26\pm0.12^{B}_{c}$ | $1.23\pm0.09^{A}_{c}$ | $0.15\pm0.00^{A}_{b}$ | $1.59\pm0.04^{AB}_{c}$ | $6.17\pm0.06^{C}_{b}$ | $17.25\pm1.04^{D}_{ab}$ | $34.57\pm1.44^{E}_{d}$ | 0.0000 |
| **Moutourwa** | $2.25\pm0.05^{B}_{b}$ | $1.26\pm0.05^{A}_{c}$ | $0.98\pm0.01^{A}_{e}$ | $1.59\pm0.01^{AB}_{c}$ | $6.08\pm0.02^{C}_{b}$ | $18.49\pm0.50^{D}_{b}$ | $32.59\pm0.59^{E}_{c}$ | 0.0000 |
| **Dargala** | $1.85\pm0.03^{B}_{a}$ | $0.56\pm0.05^{A}_{a}$ | $0.26\pm0.01^{A}_{c}$ | $1.59\pm0.04^{B}_{c}$ | $4.40\pm0.40^{C}_{a}$ | $18.25\pm0.04^{D}_{b}$ | $23.33\pm0.65^{E}_{a}$ | 0.0000 |
| **Houla** | $2.16\pm0.02^{C}_{b}$ | $0.84\pm0.14^{AB}_{b}$ | $0.16\pm0.01^{A}_{b}$ | $1,09\pm0.08^{B}_{b}$ | $4.10\pm0.31^{D}_{a}$ | $16.51\pm0.61^{E}_{a}$ | $25.35\pm0.07^{F}_{b}$ | 0.0000 |
| **Pitoa** | $3.20\pm0.23^{C}_{c}$ | $0.96\pm0.03^{B}_{b}$ | $0.39\pm0.06^{A}_{d}$ | $3.09\pm0.12^{C}_{d}$ | $7.56\pm0.02^{D}_{c}$ | $17.47\pm0.06^{E}_{ab}$ | $43.14\pm0.30^{F}_{f}$ | 0.0000 |
| **Bangli** | $4.20\pm0.03^{C}_{d}$ | $1.16\pm0.02^{B}_{c}$ | $0.07\pm0.02^{A}_{a}$ | $0.84\pm0.11^{B}_{a}$ | $6.42\pm0.13^{D}_{b}$ | $17.2\pm0.31^{E}_{ab}$ | $37.32\pm0.25^{F}_{e}$ | 0.0000 |
| **p-value** | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | |

*$Ca^{2+}$: Calcium ion; $Mg^{2+}$: Magnesium ion; $Na^{+}$: Sodium ion; $K^{+}$: Potassium ion; SEC: Sum of Exchangeable Cations; CEC: Cation Exchange Capacity; V: saturation of the exchangeable complex; Uppercase letters on the same row and lowercase letters in the same column are not significantly different at the 5 % threshold*

**Table 7. Identification of limiting physicochemical parameters**

| | Ibba | Moutourwa | Dargala | Houla | Pitoa | Bangli |
|---|---|---|---|---|---|---|
| **OM (%)** | 2.96 | 1.66 | 1.74 | 3.25 | 3.26 | 3.39 |
| **N (%)** | 0.04 | 0.05 | 0.03 | 0.08 | 0.06 | 0.05 |
| **AP (Cmol/kg)** | 16.50 | 5.92 | 6.77 | 35.66 | 45.31 | 21.53 |
| **$K^{+}$ (Cmol/kg)** | 1.59 | 1.50 | 1.59 | 1.09 | 3.09 | 0.84 |
| **SEC (Cmol/kg)** | 6.17 | 6.08 | 4.40 | 4.10 | 7.56 | 6.42 |
| **CEC (Cmol/kg)** | 17.25 | 32.59 | 23.33 | 25.35 | 43.14 | 37.32 |
| **V (%)** | 3.45 | 18.49 | 18.25 | 16.51 | 17.47 | 17.20 |
| **pH** | 6.16 | 6.11 | 6.60 | 5.5 | 7.16 | 5.63 |
| **Limiting factors** | N, AP, $K^{+}$, SEC, CEC, V, pH | OM, N, AP, $K^{+}$, SEC, CEC, V, pH | OM, N, AP, $K^{+}$, SCE, CEC, V, pH | N, $K^{+}$, SEC, CEC, V, pH | N, AP, $K^{+}$, SEC, CEC, V, pH | N, $K^{+}$, SEC, CEC, V, pH |

*OM: Total Organic Matter; N: total Nitrogen; AP: Assimilable Phosphorus; $K^{+}$: Potassium ion; SEC: Sum of Exchangeable Cations; CEC: Cationic Exchange Capacity; V: Saturation of the exchangeable complex; pH: potential of Hydrogen*

**Table 8. Degree of limitation of physicochemical parameter and associated fertility level**

| | Ibba | Moutourwa | Dargala | Houla | Pitoa | Bangli |
|---|---|---|---|---|---|---|
| **OM (%)** | Without limitation | Low throttling | Low throttling | Without limitation | Without limitation | Without limitation |
| **N (%)** | Severe limitation | Average limitation | Average limitation | Low throttling | Average limitation | Average limitation |
| **AP ($cmol^+/kg$)** | Low throttling | Severe limitation | Severe limitation | Without limitation | Without limitation | Without limitation |
| **$K^+$ ($cmol^+/kg$)** | Severe limitation | Severe limitation | Severe limitation | Severe limitation | Severe limitation | Severe limitation |
| **SEC ($cmol^+/kg$)** | Average limitation | Average limitation | Severe limitation | Severe limitation | Low throttling | Average limitation |
| **CEC ($cmol^+/kg$)** | Severe limitation | Severe limitation | Severe limitation | Low throttling | Severe limitation | Low throttling |
| **V (%)** | Low throttling | Low throttling | Low throttling | Severe limitation | Low throttling | Severe limitation |
| **pH** | Low throttling | Low throttling | Severe limitation | Average limitation | Low throttling | Low throttling |
| **Soil class** | IV | IV | IV | IV | IV | IV |
| **Fertility level** | Very low | Very low | Very low | Very low | Very low | Very low |

*OM: Organic matter; N: Total Nitrogen; AP: Assimilable Phosphorus; $K^+$: Potassium ion; SEC: Sum of Exchangeable Cations; CEC: Cationic Exchange Capacity; V: Saturation of the exchangeable complex; pH: Potential of Hydrogen*

**Table 9. Correlation matrix between proportions of physical and chemical properties for all sites**

| Variables | Clay | Silt | Sand | OM | OC | N | C/N | AP | CEC | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | SEC | V | $pH_{Water}$ | $pH_{KCl}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Clay** | **1** | | | | | | | | | | | | | | | | |
| **Silt** | -0.828 | **1** | | | | | | | | | | | | | | | |
| **Sand** | 0.795 | **-0.998** | **1** | | | | | | | | | | | | | | |
| **OM** | -0.271 | -0.255 | 0.303 | **1** | | | | | | | | | | | | | |
| **OC** | -0.233 | -0.281 | 0.327 | **0.998** | **1** | | | | | | | | | | | | |
| **N** | -0.438 | 0.349 | -0.333 | 0.523 | 0.543 | **1** | | | | | | | | | | | |
| **C/N** | 0.601 | **-0.896** | **0.909** | 0.316 | 0.318 | -0.551 | **1** | | | | | | | | | | |
| **AP** | -0.290 | -0.026 | 0.057 | 0.851 | 0.867 | 0.842 | -0.064 | **1** | | | | | | | | | |
| **CEC** | 0.139 | 0.261 | -0.296 | **-0.933** | **-0.948** | -0.691 | -0.197 | **-0.964** | **1** | | | | | | | | |
| **$Ca^{2+}$** | -0.355 | -0.182 | 0.232 | 0.672 | 0.638 | -0.066 | 0.441 | 0.213 | -0.362 | **1** | | | | | | | |
| **$Mg^{2+}$** | -0.231 | -0.040 | 0.066 | 0.290 | 0.275 | 0.072 | 0.047 | -0.021 | -0.054 | 0.694 | **1** | | | | | | |
| **$Na^{+}$** | -0.052 | 0.476 | -0.509 | -0.755 | -0.753 | -0.068 | -0.639 | -0.591 | 0.725 | -0.436 | 0.251 | **1** | | | | | |
| **$K^{+}$** | 0.797 | -0.376 | 0.327 | -0.774 | -0.748 | -0.567 | 0.165 | -0.716 | 0.667 | -0.583 | -0.173 | 0.517 | **1** | | | | |
| **SEC** | -0.149 | -0.115 | 0.139 | 0.119 | 0.090 | -0.326 | 0.256 | -0.325 | 0.197 | 0.754 | **0.910** | 0.203 | -0.047 | **1** | | | |
| **V** | -0.265 | -0.113 | 0.148 | 0.375 | 0.348 | -0.115 | 0.255 | -0.058 | -0.066 | 0.872 | **0.943** | 0.026 | -0.279 | **0.962** | **1** | | |
| **$pH_{Water}$** | 0.640 | -0.295 | 0.255 | -0.790 | -0.787 | -0.863 | 0.318 | -0.852 | 0.778 | -0.439 | -0.382 | 0.275 | 0.842 | -0.067 | -0.316 | **1** | |
| **$pH_{KCl}$** | 0.508 | -0.080 | 0.036 | **-0.896** | **-0.895** | -0.774 | 0.094 | -0.865 | 0.852 | -0.572 | -0.455 | 0.409 | 0.818 | -0.166 | -0.423 | **0.972** | **1** |

*OM: Organic Matter; OC: Organic Carbon; N: Nitrogen; C/N: carbon/nitrogen ratio; AP: Assimilable Phosphorus; CEC: Cationic Exchange Capacity; $Ca^{2+}$: Calcium ion; $Mg^{2+}$: Magnesium ion; $Na^{+}$: sodium ion; $K^{+}$: Potassium ion; SEC: Sum of Exchangeable Cations; V: Saturation of the exchangeable complex ; $pH_{Water}$: potential Hydrogen of water; $pH_{KCl}$: potential Hydrogen of KCl; The values in bold are significantly different at the 5% threshold*

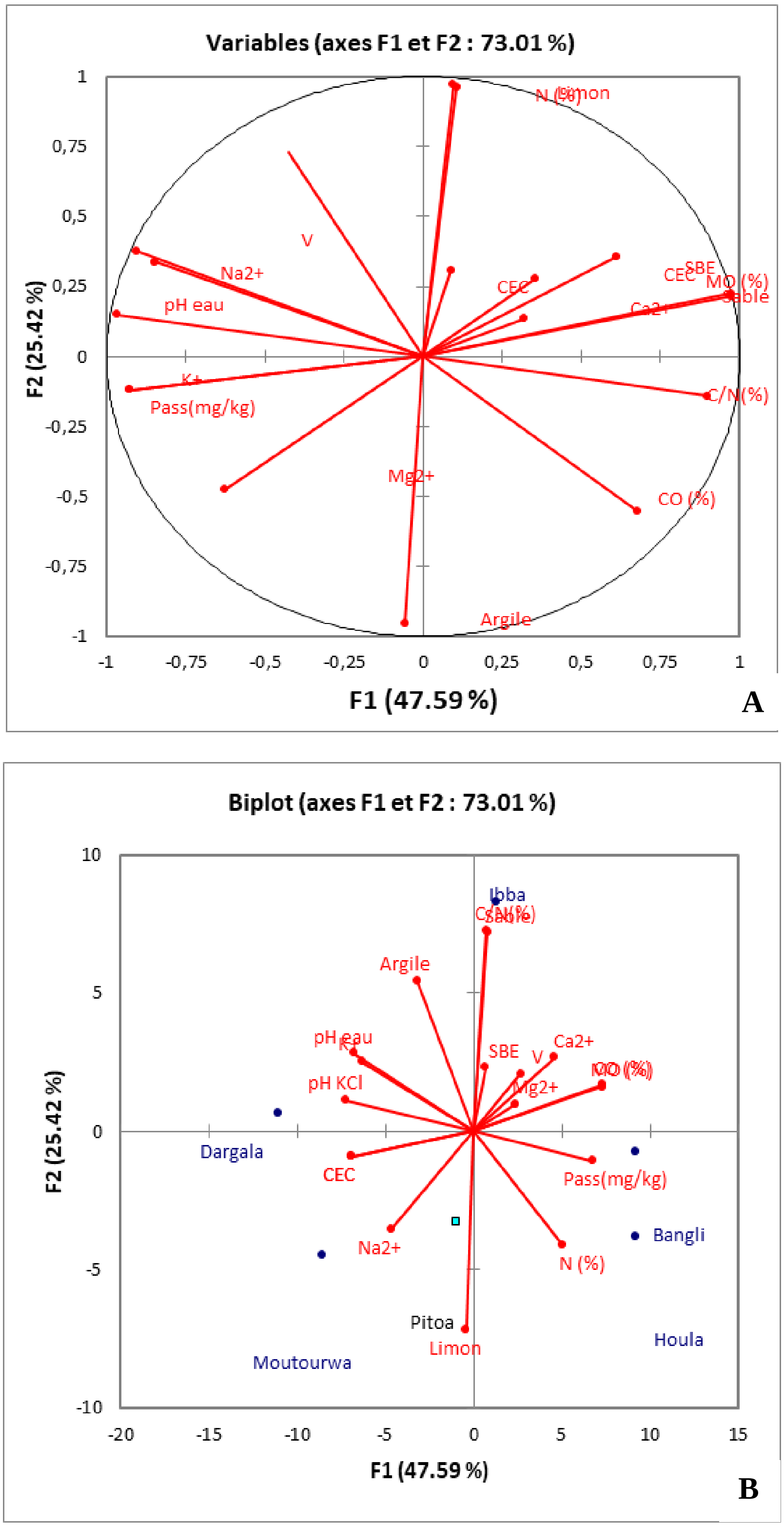


**Fig. 7. Principal component analysis of parameters (A) and scatter plot in the factorial plane (B)**

**Table 10. Eigenvalue and percentage variance of the first four axes of the CPA**

| | F1 | F2 | F3 | F4 |
|---|---|---|---|---|
| **Eigenvalue** | 8.566 | 4.576 | 3.722 | 3.722 |
| **Variability (%)** | 47.590 | 25.424 | 20.679 | 6.306 |
| **Cumulative percentage** | 47.590 | 73.015 | 93.694 | 100.000 |

According to the correlation circle (Fig. 7A), the first axis (F1) makes it possible to discriminate soils rich in CEC, $Na^+$, $pH_{KCl}$, $pH_{water}$, Limon, $K^+$, in the negative abscissa of soils rich in SEC, V, AP, $Ca^{2+}$, N, $Mg^{2+}$, OM and OC in the positive abscissa (Fig. 7B). The F2 axis makes it possible to oppose the rich soils with the proportions of clay, C/N and sands on the negative ordinates of soils rich in CEC, $Na^+$, $pH_{KCl}$, $pH_{water}$, Limon, $K^+$ on the positive ordinates. Fig. 8B representing the distribution of sites according to the proportion of physical and chemical elements in the factorial design (F1 and F2) makes it possible to distinguish 4 groups of vertisols studied with a strong heterogeneity in the composition of physical and chemical elements. The F1 axis makes it possible to oppose the soils of group one (G1) which is lower in proportion to CEC, $Na^+$, $pH_{KCl}$, $pH_{water}$, Limon and $K^+$ of the soils of group 2, 3 and 4 (G2, G3 and G4) rather provided in the proportions of sand, C/N, $Mg^{2+}$, N, $Ca^{2+}$, OM, OC, AP, SEC and V.

To better appreciate the similarity of the physicochemical composition of the different sites, a hierarchical ascending classification (CAH) made it possible to obtain a dendrogram that groups the different sites with proportions of physical and chemical elements statistically dissimilar by three classes (Fig. 8) with 366.6% similarity index.

The analysis of this classification makes clear distinction of three main classes of soils with similar physicochemical characteristics. The first class is composed of soil samples from Houla and Pitoa; the second class consists of the soil samples of Dargala and Moutourwa and the last class consists of the soil samples of Bangli and Ibba.

## 4. DISCUSSION

The different samples study soils belong to the class of vertisols but have quite different physical and chemical properties. Particle size analysis showed that the proportions of silt and sand largely dominate that of clay in almost all the sites studied except for the Ibba site where the proportion of sand is much more dominant. This

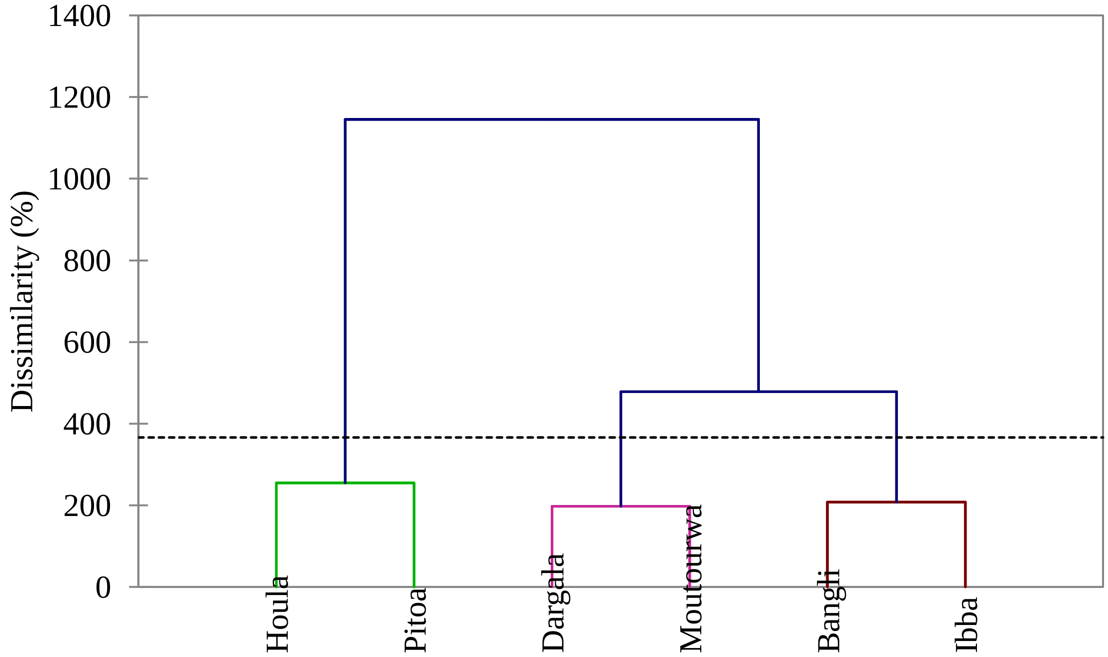


**Fig. 8. Dendrogram for classifying all soil samples according to similarity in proportion in physical and chemical elements**

high proportion of sand could be explained by water erosion [37]. Indeed, this erosion would come from the splash effects of intense rains accompanied by floods that strip the soil, transport fine particles through runoff water and silt up the agricultural plot. Therefore, this erosion makes the soil of this site filter and light subsequently gives it low structural stability and high susceptibility to physical and chemical degradation. The silty and silty texture of the other sites testifies to the adaptability of these soils to muskuwaari cultivation [38] except that clay proportions are minimal at almost all sites and therefore hinder their quality cultural suitability [39]. Indeed, clay is the element that conditions the retention of water and nutrients on the adsorbent complex [34] and in the case of this study, its low proportion could also be explained by the long-lasting acid rain that would lead to the drainage of surface horizons [40].

The pH proportions of the soil determine the type of activity existing or predominant in these same soils [39]. The proportion values obtained at the different sites are between 5 and 7, which would mean that nutrient bioavailability is not uniform across sites [41]. In addition, the results show that at all sites, the $pH_{water}$ is higher than the $pH_{KCl}$ indicating the presence of negatively charged colloids in the soils of the different sites studied [42]. This would be explained by the immobilization of anions and cations that would have led to soil acidification [43]. Indeed, when karés are flooded before the establishment of the culture, there would be an increase in the solubility of $Al^{3+}$ ions, a decrease in the assimilability of phosphorus following the release of cations and most likely a disturbance of biological activity. As the pH increases, the hydrogen would dissociate and the bound $Al^{3+}$ ions would be released to precipitate into the amorphous form $Al(OH)_3$. These changes release negative cation exchange sites and thus increase soil pH.

Chemical analyses results facilited the recording of a variation in the proportions of very low nitrogen, high organic carbon, organic matter from low to medium. In the same vein, the C/N ratio was very low for all sites. In fact, organic matter is the source of nutrients (N, S, P, etc.) in highly altered tropical soils with low mineral reserves [44]. The low proportion of nitrogen, organic carbon, organic matter and associated C/N ratio could be explained on the one hand by the pedoclimatic conditions of variable temperature and humidity depending on the sites and crop methods and which would have an influence on the decomposition of soil organic matter [21]. On the other hand, the low proportions found in organic or even average matter could be explained by the salinity of the soils, which would exert an action inhibiting the activity of telluric microorganisms involved in the decomposition of organic matter [45]. In addition, in the *muskuwaari* cropping system, crop residues (straw and ear tops) typically consumed by animals and dried cow dung remaining on the plots would be transported by women and children to be used as an energy source for cooking. However, crop residues positively affect soil properties such as moisture content, aggregate formation, density and porosity [46].

These poor cultural practices would expose these soil types to several agronomic problems, in particular the sensitivity to leaching of elements to the deep layers or erosion (water and/or wind) because organic matter could no longer exert its biological activity and stabilizer of soil structure [21]. Statistical analyses also showed significant differences ($p$ <0.0001) in the different sites for the proportion of assimilable phosphorus. This change in proportion was moderate to very small and could be explained by the low proportion of clay, pH and organic matter in the associated soils. Indeed, the availability of phosphorus in soils would be controlled by the organic matter content of the soil, which would play a role of immobilizing phosphorus in the soil [47].

The analysis of exchangeable cations in the different sites showed that there is a low proportion of calcium, magnesium and sodium compared to the proportion of exchangeable potassium, which would be very high in all sites. This could be attributed to the fact that the proportion of organic matter would be acceptable but quite low. Indeed, organic matter in the soil would play a major role both agronomically and environmentally, namely the adsorption and retention of water, exchangeable bases, phosphorus, nitrogen and metallic trace elements [48]. That of potassium, on the other hand, very high, would be explained by the decrease in the proportion of calcium and magnesium in the soil solution during flood periods [47].

Relative to the low proportion of exchangeable cations, the low proportion of cation exchange capacity (CEC) would be related to the low proportion of organic matter and clay observed at various locations. This linear relationship would indicate that cation exchange capacity would become less important as soil organic matter content increased [49]. Indeed, soils with a high CEC could contain more cations and have a high capacity to exchange them than soils with a low CEC [50].

The saturation proportion of the exchangeable complex is two to three times lower in all soils of the areas studied. Indeed, the saturation rate is a valuable pedological and agronomic indicator of the chemical richness of the soil, which determines the biological activity, the quality of the structure and the quantity of nutrient reserves [39]. The low proportion of this parameter in the different soils of the sites of this study would lead to the conclusion that the soils studied are of a very low fertility level. This would be related to the nature of the clay-humic complex, which would be very poor in soil nutrient reserves [34]. Indeed, in acidic soils, the clay-humic complex would fix many more $H^+$ ions and few other ions ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $NH_4^+$, $Na^+$, etc.) and consequently would have generated the low CEC [51].

On the other hand, the assessment of the level of soil fertility by the detection of limiting physicochemical parameters would also have made it possible to conclude that all the sites studied are of a very low fertility level with at least one limiting physical and/or chemical parameter. This, is explained on the one hand by the low proportion of clay, organic matter and low CECE and on the other hand, by the negative correlations observed on both sides between physical and chemical elements.

## 5. CONCLUSION

This study aimed at evaluating the physical and chemical properties variation of some sample of vertisols associated with *muskuwaari* cultivation, as well as the fertility level for sustainable management. It revealed that most of these samples have poor physicochemical properties and very low fertility levels. The analysis of the particle size fraction showed significant differences ($p$ <0.0001) between the proportions of silt and sand except for the proportion of clay in the different sites, which makes them have a low retention capacity of the essential chemical elements for goodhost plant productivity. The measurement of chemical parameters has also shown that these soils have potentials of hydrogen ranging from very acidic to neutral (5.5 < pH < 7.16) and therefore a very low proportion of nitrogen, organic carbon, organic matter, C/N ratio, assimilable phosphorus, exchangeable cations, sum of exchangeable cations, cation exchange capacity and saturation of the exchangeable complex. In order to achieve productivity, sustainable development and food security, it would be interesting to rehabilitate the physical and chemical properties of these vertisols to an optimal level of biofertilizers.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Sanouna A, Soumana B, Hassane M, Toudou A, Mahamadou I S, Determinants of production on farms in the river valley in the commune of Kourtheye in Niger. African Agronomy. 2020;32(4):463-474.
2. Ba, A., Cantoreggi, N., Simos, J., Duchemin, E. Health impacts of urban farmers' practices in Dakar (Senegal) » VertigO - The electronic journal in environmental sciences [Online]. 2016; 16(1).
   Published online on 09 May 2016.
   Accessed July 02, 2017.
   Available:http://vertigo.revues.org/17030 ; DOI : 10.4000/vertigo.17030
3. ADB, 2022. Evaluation report of the DRC/AHAI department on the support program for the strengthening of agricultural production in Cameroon (PARPAC). 2022;38.
4. Hill H, Lee LS, Henry R, Variation in Sorghum Starch Synthesis Genes Associated with Differences in Starch Phenotype. Food Chem., 2012;131(1):175-183.
   DOI: 10.1016/j.foodchem.2011.08.057
5. García AC, Hernández VM, Bonet J, Coma J, Andrés ML, Effects of inclusion of Sorghum distillers dried grains with solubles (DDGS) in diets for growing and finishing pigs. Span. J. Agric. Res. 2012;4:1016-1024.
6. Saïdou A-A, Christine R, Clelia S, Tuong-Vi CH, Kenga R, History of a recent agricultural innovation at the regional level: Selection and circulation of transplanted sorghum in the Chadian basin. Les Cahiers d'Outre-Mer. 2014;66:141-168.

7. Watts-Williams SJ, Emmett BD, Levesque-Tremblay V, MacLean AM, Sun X, Satterlee JW, Fei Z, Harrison MJ, Diverse Sorghum bicolor accessions show marked variation in growth and transcriptionnal responses to arbuscular mycorhizal fungi. Plant Cell Environ. 2018;42:1758-1774.
8. Li J, Chen Z, Guan X, Liu J, Zhang M, Xu B, Optimization of germination conditions to enhance hydroxyl radical inhibition by water-soluble protein from stress millet. J. Cereal Sci. 2008;48:619-624.
9. Masse D, Donfack P, Floret C, Pontanier R, Seiny-Boukar L, Rehabilitation of degraded vertisols (hardened soils) in Northern Cameroon. John Libbey Eurotext, Paris. 1995;127-137.
10. Seignobos C, Iyebi-Mandjeck O, Abdourahman N, Land saturation and muskuwaari: Terroir of Balaza-Domayo. DPGT Report. 1995;62.
11. Koussoumna LN, The instability of the cereal market (millet, sorghum, maize) in the Far North Province of Cameroon. Master's thesis in Geography. University of Ngaoundere. 2001;98.
12. Temple L, Fofiri NE, Ndame JP, Ndjouenkeu R, Impacts of urban growth on innovation in food supply chains in Northern Cameroon. In : African Savannahs in Development : Innovating to Last, Garoua-Cameroon. 2009;14.
13. Folefack DP, Bakwowi JN, Kpade PC, The crisis of the cotton sector and food security in Northern Cameroon. Journal of Applied Biosciences. 2014;75:6221-6231.
14. Ngatanko I, Ngamo TL, Mapongmetsem PM, Diversity and spatial distribution of stem borers and their natural enemies on off season sorghum, *Sorghum bicolour* (L.) Moench (Poaceae), in the Sudano-sahelian zone of Cameroon. Int. J. Agri. & Agri. R. 2015;7(5):51-58.
15. UN. Annual report. 2016;16p.
16. Yakouba O, Saidou A, Madi A, Zieba FW, Yemeta OF, Peasant perception of rainfall disturbances and adaptation strategies in sorghum cropping systems in the Sudano-Sahelian zone of Cameroon. Afrique Science, 2017;13(4):50-65.
17. FAO, IFAD, WHO, WFP, UNICEF, Summary of the State of Food Security and Nutrition in the World : Transforming Food Systems to Make Food Security, Better Nutrition and Healthy and Affordable Food a Reality for All. 2021;44.
Available:https://doi.org/10.4060/cb5409fr
18. Pa aï VN, Dongock ND, Tchobsala X, Ibrahima A, Influence of anthropization on the diversity of woody vegetation in muskuwaari transplanted sorghum field in the Sudano-sahelian zone of Cameroon. International Journal of Plant and Soil Science. 2022;34(22):559-571.
19. FAO, IFAD, WHO, WFP, UNICEF, Summary of The State of Food Security and Nutrition in the World 2022. Reorient food and agricultural policies to make healthy eating more affordable. Rome. FAO.
Available:https://2022;doi.org/10.4060/cc0640fr
20. Vanlauwe B, Diels J, Sanginga N, Merckx R, Long-term integrated soil fertility management in South-western Nigeria: Crop performance and impact on the soil fertility status. Plant and Soil. 2005;273(1-2):337-354.
21. Sekou SG, Abba SM, Boubacar T, Souleymane D, Bandiougou D, Hamara D, Oumarou G, Spatial variability of the physical and chemical characteristics of the soils of the village irrigated rice and wheat perimeters of the commune to say in Mali. Revue Malienne de Science et de Technologie, Série A. 2019;22:13.
22. Fofiri NEJ, Temple L, Ndamè J-P. Agricultural storage infrastructures (ISAC) in the Sudano-Sahelian zone of Cameroon: conditions of governance of a common good for food security. In Revue D'Économie du Développement. 2016;22.
23. Huang J, Wong VNL, Triantafilis J, Mapping Soil Salinity and pH across an Estuarine and Alluvial Plain Using Electromagnetic and Digital Elevation Model Data. Soil Use and Management. 2014;30(3):394-402.
24. Séry DJ-M, Kouadjo ZGC, Voko BRR, Zézé A, Selecting native arbuscular mycorrhizal fungi to promote cassava growth and increase yield under field conditions. Front. Microbiol. 2016;7:20-63.
DOI: 10.3389/fmicb.2016.02063
25. Pauwels JM, Van Ranst E, Verloo M, Mvendo ZEA, Laboratory Manual of pedology. Analysis methods of soils and plants, equipments, stocks management glasses and chemical products. Bruxelles : General Administration of Cooperation to Development (AGCD). 1992;265.
26. AFNOR. Soil quality: Determination of particle size distribution of soil particles -

Pipette method. Theme: Physical Properties of Soils; 2003.
27. McLean EO, Soil pH and lime requirement, in Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, D. R. Buxton, Ed. Madison : American Society of Agronomy Inc. and Soil Science Society of America Inc. 1982;199-224.
28. Walkley A, Black IA, An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sciences. 1934;37:29-38.
29. MacDonald DC, Methods of soil and tissue analysis used in the analytical laboratory. Ottawa, Canada : Canadian Forestry Service Information Report MM-X-78; 1977.
30. Olsen SR, Sommers LE, Phosphorus. In Methods of soil analysis. Ed Page et al. Madison, Wisc. : ASA and SSSA: 1982;403-430.
31. Thomas GW, Exchangeable cations, in Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, A. L. Page, R. H. Buxton, D. R. Miller Keeney, Eds., Madison: American Society of Agronomy Inc. and Soil Science Society of America Inc. 1982;159-165.
32. Duchaufour PH, Pedogenesis and pedological classification (II). Masson Paris. 1977;477.
33. Beernaert F, Bitondo D, Simple and practical methods to evaluate analytical data of soil profiles. University of Dschang, Cameroon : Belgian Cooperation; 1992.
34. Amonmide I, Dagbenonbakin G, Agbangba CE, Akponikpe P, Contribution to the assessment of soil fertility levels in cotton-based cropping systems in Benin. Int. J. Biol. Chem. Sci. 2019;13(3):1846-1860. DOI: https://dx.doi.org/10.4314/ijbcs.v13i3.52
35. Azinwi TP, Djoufac WE, Bitom D, Njopwouo D, Petrological, physico-chemical and mechanical study of the topomorphic vertisol of the sudano-sahelian region of north Cameroon. The Bentham Open Geology Journal. 2011;5: 33-55.
36. USDA. Soil classification: A comprehensive system [prepared by] soil survey staff. 7th approximation. Washington, D.C., USA; 1960.
37. Dasylva M, Ndour N, Mamadou AAD, Sambou B, Physico-Chemical Characterization of Soils of Agricultural Valleys of the Commune of Ziguinchor in Senegal. European Scientific Journal. 2019;15(15):185-7881.
38. Basga DS, Temga JP, Tsozué D, Danbé N, Nguetnkam JP, Morphological, mineralogical and geochemical features of topomorphic vertisols used for sorghum production in North Cameroon. Eurasian J. Soil Sci. 2018;7(4):346-354.
39. N'goran KE, N'guessan E, Tehia KE, Zohouri GP, Ochou OG, Valorization of organic manure in cotton-based cropping systems and food security in Côte d'Ivoire, In M, Fok N, Ousmane and K Siaka (Eds.), AGRAR-2013: 1st African Research Conference on Agriculture, Food and Nutrition, Yamoussoukro: Agriculture and the Challenges of Food and Nutrition in Africa: What Contributions from Research in Cotton Countries. 2016;187-195.
40. Koulibaly B, Traoré O, Dakuo D, Lalsaga R, Lompo F, Zombré PN, Acidification of ferruginous and ferralitic soils in cotton production in Burkina Faso. Int. J. Biol. Chem. Sci. 2014;8(6):2879-2890.
41. Borah KK, Bhuyan B, Sarma, PH, Lead, arsenic, fluoride, and iron contamination of drinking water in the tea garden belt of Darrang district, Assam, India. Environmental Monitoring and Assessment. 2010;169:347-352.
42. Koy, Improvement of the quality of sandy soils in the Bateke plateau (DR Congo) by applying geological material and local industrial organic waste. PhD thesis, Faculty of Science, University of Gent, Belgium. 2009;323.
43. Huang SP, Cares JE, Nematodes. In : Anonyme (eds) Échantillonnage (Méthodes), Restitution du séminaire d'Embu, 23-27 février, Kenya. 2004;7.
44. Mulaji C, Disa-Disa P, Kibal I, Culot M, Diagnosis of the agro-pedological state of acidic soils in the province of Kinshasa in the Democratic Republic of Congo (DRC). Chemistry Proceedings. 2016;19:820-826. Available:http://dx.doi.org/10.1016/j.crci.2015.08.010
45. Fruit L, Recous S, Richard G, Plant residue decomposition: effect of soil porosity and particle size. In effect of mineral-organic microorganism interactions on soil and freshwater environments, Ed Berthelin et al. 1999;189-196.
46. Koulibay B, Traoré O, Dakuo D, Zombré PN, Bondé D, Effects of crop residue management on yields and crop balances

of a cotton-corn-sorghum rotation in Burkina Faso. Tropicultura. 2010;28(3): 184-189.

47. Ballot CSA, Mawussi G, Atakpama W, Moita-Nassy M, Yangakola TM, Zinga I, Sillas S, Kpérkouma W, Dercon G, Komlan B, Koffi A, Physico-chemical characterization of soils to improve cassava productivity (*Manihot esculenta* Crantz) in the Damara region of south-central central Africa. African Agronomy, 2016;28(1):9-23.
48. Baize D, Guide to soil analysis, 2nd Ed. France, INRA Editions. 2000; 257.
49. Tahirou S, Zerbo P, Ouattara S, Sanou Y, Ado MN, Characterization of the physicochemical parameters of the soil of the Saga rice zone (Niamey) in the Niger River Valley. Int. J. Biol. Chem. Sci. 2022;16(2):842-854.
50. Tedontsah VPL, Mbog MB, Ngon Ngon GF, Edzoa RG, Tassonwa B, Bitom D, Etame J, Physicochemical properties and fertility assessment of soils in Foumban (West Cameroon). Applied and Environmental Soil Science. 2022;22:1-14.
    Available:https://doi.org/10.1155/2022/7889430
51. Yancouba S, Aidara CALF, Alioune B, Dieye BAS, Bouba DB, Physicochemical characteristics of the soils of the rice-growing valleys of the Diouloulou watershed, lower Casamance, Senegal. American Journal of Innovative Research and Applied Sciences. 2021;13(4):478-487.



*Peer-review history:*
*The peer review history for this paper can be accessed here:*
*https://www.sdiarticle5.com/review-history/103475*