



PHYSICO-CHEMICAL CHARACTERISTICS OF GLEYIC LUVISOLS AND GLEYIC LISTOSOLS PRODUCTION AREAS OF GARDEN PRODUCE IN NIEKI VALLEY, SOUTH-EAST OF CÔTE D'IVOIRE

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Abstract

A study of the physico chemical properties of gleyic Luvisols and gleyic Histosols was carried on in Nieké Valley, a vegetable crops production area in South-East of Côte d'Ivoire. Soil samples were collected at different depths (0-15 cm and 15-40 cm) on each of the sites studied for laboratory analysis. The results obtained of physical analysis show that the texture of soil is generally less thin and essentially provided in heavy clays. The observed average values of the index of crusting and the ability to cracking show that soils are not crusting and have an excellent ability to cracking. The results of physical analysis also show that the soils have an index of structural stability that change from very stable to stable and a very high risk of asphyxiation. Results of chemical analysis reveal that the pH values increased with soil depth and are higher in field soils than in control soils. Moreover, organic matter in soils studied is more abundant in surface horizons and decreases with depth. However, the contents of calcium, magnesium and potassium are lower in the surface horizons and increase with depth.

Keywords: Gleyic fluvisols, gleyic histosols, vegetable crops, Nieké valley, Côte d'Ivoire

1. INTRODUCTION

In the world, agriculture has become, one of the activities necessary to ensure the food security of people and procure at some of them, financial resources. In the current context of global agriculture, the quality of food products is becoming increasingly important, particularly with regard to vegetable production (Baize, 2000). In Africa, in large cities and surrounding areas, market gardening is seen as a solution to the vegetable supply problems. However, it remains subject to numerous constraints, of which the most important is constituted by the insect attack and pathologies, urging gardeners to use chemical pesticides anarchic and abusive manner. These

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practices are dangerous, because the workers, who handle these delicate products, are not qualified (Madjouma *et al.*, 2009). It is an often informal activity, generating income and employment, practiced by poor of the urban and peri-urban areas (Assogba-Komlan *et al.*, 2007).

In Côte d'Ivoire, particularly in Abidjan (economic capital) and its peripheral areas, we are witnessing in recent years, a development of urban agriculture, as a result of high population growth, leading to an increase food needs, after the socio-political crisis since 2002. The development of vegetable crops faces significant constraints, including land pressure, resulting over-cultivation, pest attacks, causing huge production losses and sometimes the abusive use of inputs. However, the presence of trace elements in chemical (Traore *et al.*, 2006) and biological (Doelsch *et al.*, 2006) inputs used in urban and peri urban agriculture, is a major constraint, as these can be supplied in labile forms and are potentially bioavailable. Agrochemicals used in farms are implicated in the degradation of the quality of soil and water, both surface and ground, particularly in soil where vegetable crops are produced as well as banana production (Traoré *et al.*, 2003). Then, to improve yields, farmers who produce these crops in Niekivalley use mineral and organic fertilizers and chemical pesticides on vegetable crops (spinach, okra, eggplant and Jew's mallow). In the absence of adequate monitoring mechanism, the use of pesticides is rarely in compliance with health and environmental standards (Traore *et al.*, 2006). The consequences on the environment in general and on the quality of soil in particular, are significant because these agricultural practices are likely to cause an accumulation of trace metals in the surface horizons, rich in organic matter (Vogel *et al.*, 2008), where concentrations well above of the pedo-geochemical bottom and standards (Burnol *et al.*, 2006).

Fertility management techniques practiced by Ivorianfarmers, lead to a rapid depletion of soils (Yemefack *et al.*, 2004; Koné, 2009; Koulibaly *et al.*, 2009). In many cases, the failure to take into account the physical, chemical and microbiological soil constraints remains detrimental to their operation. Yet it has long been known that some soil parameters play a key role in the management of plant nutrition and an adequate supply of nutrients depends on their optimization (Troeh and Thompson, 2005).

This study aims to assess the physico-chemical characteristics of gleyic Fluvisols andgleyic Histosols and production areas of the vegetable crops in Nieki valley in South-East of Côte d'Ivoire.

2. DESCRIPTION

2.1. Study area

Located in South-East region of Côte d'Ivoire, the study area (Nieki valley) is part of a sub-watershed with a surface of approximately 2.5 km², bounded by the coordinates N 5°25'48 and N 5°18'36 ; W 4°17'24 and W 4°13'48 (Figure 1). The different study sites are located in a climate of humid tropical type, characterized by the existence of two (02) rainy seasons and two dry seasons, as follows:

- A long dry season, from December to March;
- A long rainy season from April to mid-July;
- A short dry season from mid-July to mid-September;
- A short rainy season from mid-September to November.

The rainfall for the first quarter of 2010 varied from 0.5 to 1.2 mm of rain, with a temperature average of 28.3 °C.

Soil samples analyzed come from control plots (in natural vegetation) and cultivated plots, in different soil horizons, on the three study sites that are Azaguié, Attinguié and Dabou.

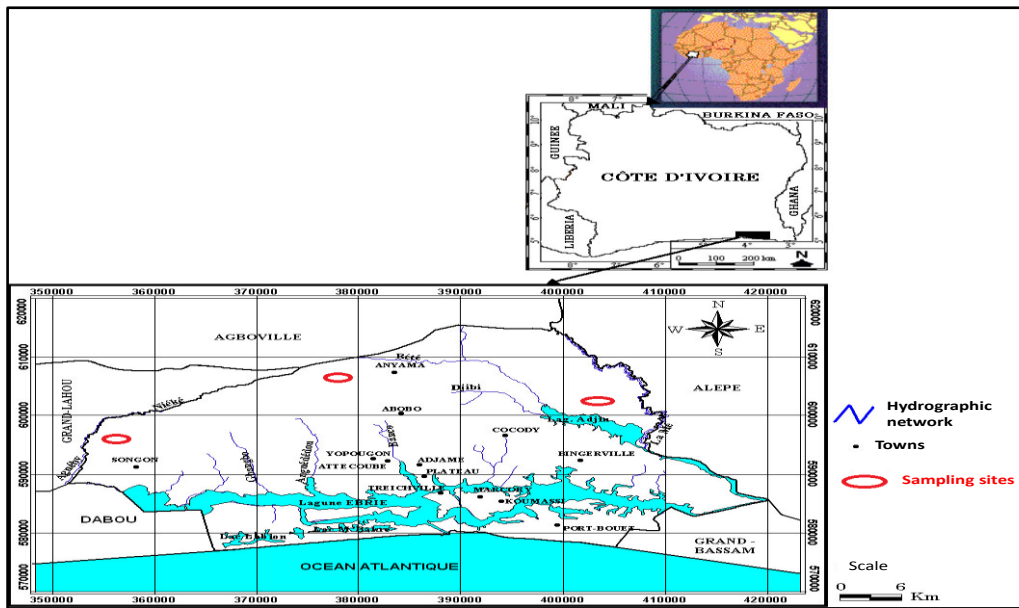


Figure 1: Location of the different study sites

3. MATERIAL AND METHODS

3.1. Physical characteristics of soils

3.1.1. Granulometry

Granulometric analysis of sediment is to determine the proportion of the various classes of particle size (sand, silt, clay, etc.). This study enables to determine the specific surface (m^2 / g) of the sediment, which allows estimating the ability of adsorption of metals and organic substances (CEAEQ, 2003). According to the pipette method of Robinson-Köln, 20 g of fine soil is suspended in water, after heat destruction of organic matter by hydrogen peroxide. This operation is followed by the dispersion of the particles with a sodium pyrophosphate solution (50 g / l).

The principle of the method consists in determining, after removal of carbonates and organic substances, of any iron oxides and the fine fraction below 38 microns. The method is based on the difference in sedimentation velocity between the fine particles and the heavier particles. Particle sedimentation is due to two opposing forces, gravity and friction, resulting in a movement in a fluid medium. In this method, a sample is pipetted at different times and at different depths of the suspension of the sample in a graduated cylinder. The duration and depth are determined from the Stokes law. The pipetted suspension is condensed and dried and weighing determines the mass ratio of the pipetted fraction. The removal of clay and fine silt fractions is done by pipetting. The coarse silt, fine sand and coarse sand are obtained by dry sieving, after complete siphoning all (clay + silt).

3.1.2. Index of soil crusting

The formula used to calculate the index of crusting (IC) is given by the work of Baize (1988). For soils with a basic tendency of $pH > 7$, the formula of index of crusting (IC) is:

$$IC = \frac{1.5 Fs + 0.75 Cs}{C + 10 OM} \dots\dots\dots (1)$$

With Fs: fine silt; Cs: coarse silt; C: Clay; OM: organic matter.

In acid soils trend, with a pH <7, the index formula of crusting (IC) is:

$$IC = \frac{1.5 Lf + 0.75 Lg}{A + 10 OM} \cdot 0.2(pH-7) \dots\dots\dots (2)$$

With, Lf = Stringers purposes, Lg = coarse silts, A: clays and OM: Organic matter.

3.1.3. Ability to cracking, risk of asphyxia and structural stability

The ability to crack, the risk of asphyxiation and the structural stability are appreciated from the charts in the works of Goulard *et al.* (1987).

3.1.4. Dry bulk density and total porosity of soil

The bulk density was determined using the method with sand described by Yoro (1992). In this method, beach sand used to determine the volume of soil sample comprises grain diameter between 1 and 2 mm. Then, the volume density of sea sand has been determined. In that purpose, 2 kg sand samples were weighed and placed in plastic bags. At the plot in field, soil sample is taken from the circular opening (similar to the orifice [152 mm]) of the circular densitometer membrane base; the aluminum plate is secured on the floor. The mass of the soil sample was determined after drying at 105 °C. The thus formed cavity was filled to the top of the aluminum plate, with each sand sample of 2 kg, poured into the cavity close to the ground, and the excess, recovered and then weighed. The sand mass poured into the cavity was calculated as the difference between the initial mass of the sample of sand and the excess recovered. The volume of the cavity is that of sand; it is the ratio of its mass to its density. Determining the bulk density of a soil is to determine the dry mass (P') and the volume (V) of a soil sample, and to establish the relationship:

$$P' = \frac{(D-D')}{D} \times 100 \dots\dots\dots (3)$$

Where P' is the total porosity; D is the actual density of the soil constituents and; D' is the dry soil bulk density, such as:

$$D' = \frac{P'}{V} \dots\dots\dots (4)$$

Where V is the total volume of voids as a percentage of total ground; the value of D' in g.cm⁻³

3.2. Chemical characteristics of the soil

3.2.1. pH

Soil pH was determined using a pH meter type ORION 4-Star, equipped with a glass electrode and a reference electrode; the two electrodes are combined in a single electrode, the pH-H₂O or current acidity is determined in a soil-water suspension according to the weight ratio land/solution equal to 1/2.5. The procedure for the determination of pH-H₂O is to introduce 20 g of fine soil in a 100 ml beaker, add 50 ml of distilled water and allow 30 minutes stirring regularly at first, with a glass stirrer. Determining the pH of a soil is used to define the state of acidity or alkalinity (or acid-base status). Agricultural soils have a pH of between 4 and 9.

3.2.2. Total Carbon

According to the method of Walkley and Black (1934), the organic matter is oxidized with cold potassium dichromate (1N) in the presence of sulfuric acid. The excess dichromate is determined by return with the Mohr salt (1 M). Organic carbon is obtained by considering, in the operating conditions, that 1 ml dichromate oxidizes 0.39 mg carbon monoxide. Organic matter is calculated by multiplying the total carbon content by 1.724. The organic matter was obtained by the formula: OM = C_{Organique} x 1.724

3.2.3. Organic total nitrogen

According to the Kjeldahl method, the organic matter is mineralized to hot (300 °C) with sulfuric acid in the presence of a catalyst ($K_2SO_4 + CuSO_4 + Se$) for 3 hours. The mineral deposit is filtered; an aliquot is distilled. Ammonia moved by 10N sodium hydroxide is recovered in a sulfuric acid solution (0.01 N) mixed with a color indicator (methyl red + bromocresol green, dissolved in ethanol). The nitrogen content is obtained after back titration of the excess sulfuric acid with sodium hydroxide.

3.2.4. Adsorbent complex (CEC)

The determination of the parameters of the adsorbent complex is made in two steps:

- Percolation cations retained on the adsorbent complex with the ammonium acetate buffered to pH 7. Cations Ca^{2+} , K^+ and Mg^{2+} were determined by atomic absorption spectrophotometry;
- Washing the excess of ammonium acetate in alcohol and saturation of the complex with Na^+ ions provided by a 10% solution of NaCl. All cations adsorbed on the CEC exchange sites are displaced, and then the sites are saturated by a single cation which is ammonium (NH_4^+). Ammonium is removed and assayed by Kjeldahl method. The number of exchange site of the CEC is exactly proportioned to the number of ammonium ions.

The result is expressed as the number of loads for soil 100g (100g for milli equivalents (meq/100g) or centimoles / kg soil). The values of exchangeable cations, expressed conventionally in g / kg or ‰ may also be expressed as meq/100g, which allows calculating CEC saturation level for each of these elements.

3.2.5. Total phosphorus

The determination of total phosphorus is made by acid digestion (nitric and per chloric acid) 0.5 g of fine soil reground until the complete discolouration. The extract is assayed by spectrophotometry phosphorus, using molybdenum blue through an UV-visible spectrometer of Shimadzu mark.

3.2.6. Determination of metals

The various desired metals in the soil samples are: Fe, Al, Zn, Pb, Cu and Cd. ICP-AES method was used for the determination of these metals (Jeannot *et al.*, 2001).

Solubilization of elements from a soil may be performed in two different ways: either by soil preparation and treatment with regiawater or leaching followed by treatment with nitric acid. Soil preparation based on drying, grinding and sieving of the soil, while leaching comprises contacting the solid sample with an aqueous solution to determine the portion of the available elements run off of rainwater. The acid used for the digestion of the solids resulting from the preparation of the soil is a solution of regiawater. The latter consists of three parts hydrochloric acid (37% hydrochloric acid solution) and a volume of nitric acid (nitric acid solution at 65%). Regiawater, also called royal water, can dissolve all metals. The standard application of the mineralization of the solids is NF EN ISO 15587-1 "digestion for the determination of certain elements in water and the regiawater digestion." As part of our work to the operating protocol followed is soil preparation and regiawater treatment. It first involves weighing 0.5 g of dry soil sample and place it in a digestion tube "DigiTube". Then, 6 ml of a hydrochloric acid solution and 2 ml of nitric acid are added to the tube. Then, the sample is heated at 95 ° C for 75 minutes on a heated block mineralizer. The mineral deposit obtained is cooled to room temperature and the volumetric following 50 ml with deionized water and centrifuged at 2,000 revolutions / minute for three minutes. The samples from the leaching are meanwhile, acidified with a nitric acid solution.

3.2.7. Iso volumique masse assessments

The isvolumetric method was chosen to calculate the stocks of chemical elements different soil horizons. The interest of the isvolumetric method is to determine the gain or loss elements between

rock and soil (sum of the different soil horizons) (Soubrand-Colin, 2004). In this study, due to lack of source rock for the two soils studied, we have chosen the same horizon for each soil type that was considered as a reference horizon. For fluvisol and / or gleysol, choosing the deepest horizon profiles is justified by the fact that this is a soil derived from successive sedimentation. Thus, to calculate the isovolumique stocks, it was speculated that the alteration of our reference horizon is at the origin of the formation of the soil that is above. Stocks are calculated by multiplying the chemical content of the element considered by the apparent density and the thickness of the horizon:

$$\text{Stocks} = [x]. D. l. \dots\dots\dots (5)$$

With:[x] = content of the element x ; D = bulk density ; l = thickness
 Stocks are estimated in kg.m⁻³ and g.m⁻³, respectively, for major elements and trace elements. While the contents are expressed in g.kg⁻¹ for major elements and mg.g⁻¹ for trace elements.

3.2.8. Enrichment factor (EF)

The method of enrichment factor (EF) was used, on the one hand, consider the distribution of chemical elements within a weathering profile and, on the other hand, compare the behavior of chemical elements to each other on all pedons. This method makes it possible to see the changes of a chemical element as a function of the depth, in relation to a reference element for which the variation would be zero and the value of EF remain equal to one (1). Thus, for a given element X, the corresponding enrichment factor is determined as follows:

$$EF(X) = \frac{X_i}{X_{oio}} \dots\dots\dots (6)$$

x and x_o are the contents of the element x, respectively, in a given soil horizon and the reference horizon, while i and i_o are the contents of the invariant element, respectively, in a given soil horizon and in the reference horizon.

3.2.9. Statistical analysis

A statistical study was performed to compare the knowledge and practices accumulated during data processing. With ANOVA (Analysis of Variance), Fischer, based on the null hypothesis for levels of significance α = 0.05 and 0.01, we checked any changes on each site, the effect of different fertilizers on the floor, the physical properties, the content of different chemical elements and agronomic parameters studied.

Whenever the computed probability is significant, the Tukey HSD test for significance level α = 0.05 and 0.01, is performed to compare the mean and appreciate various significant differences among them. Principal Components Analyses (PCA) (Wolff, 2003; Wolff and Visser, 2005) were performed to look for correlations between the different elements. Data processing was done with the STATISTICA 7.1 for Windows. The variance analyzes were done with the GLM procedure (General Linear Model: analysis of variance with Tukey mean test at 5 pc threshold).

4. RESULTS

4.1. Physical studied

4.1.1. Granulometry

Considering the transect East-West, Azaguié-Attinguié-Dabou, we note generally that the texture is less fine and essentially endowed with heavy clay. The clay proportions are changing in a decreasing manner. It is observed that the clay content is considerably higher in soils of Azaguie that in those Attinguié and Dabou (Clay: 70% in Azaguié; 56% in Attinguié and 48% in Dabou). Regarding sand and silt observed, values change increasingly using the same transects. Dabou soil

is filled by sand than other sites (Sand: 19% in Azaguié; 28% in Attinguié and 31% in Dabou). Silt rate is also changing in the same direction (Silt: 11% in Azaguié; 16% in Attinguié and 21% in Dabou). Taking into account the vertical dynamics, the examination of the variation of clay content in the horizons shows that clay proportions increase with depth. That is true for the soils at the sites of Azaguié and Attinguié. In contrary, clay proportions decrease with depth in the soils at Dabou (Table 1).

Table 1: Assessment of soil particle size in the study sites

Location	Sites	horizons (cm)	Granulometry (g.kg ⁻¹)				
			A	Limons		Sand	
			Lf	Lg	Sf	Sg	
Azaguié	Field	0-15	69.55	8.26±0.0058	3.08±0.0088	10.23±0.0088	8.85±0.0133
		15-40	70.05	8.43±0.0058	3.20±0.0577	9.20±0.0577	8.87±0.0115
	Control	0-15	70.22	8.27±0.0088	4.12±0.0088	8.18±0.0058	9.16±0.0088
		15-40	72.22	8.76±0.0058	3.52±0.0058	8.05±0.0088	7.37±0.0088
Attinguié	Field	0-15	53.5	10.74±0.0088	5.42±0.0088	12.20±0.0577	17.86±0.0088
		15-40	55.38	10.85±0.0058	5.26±0.0088	13.33±0.0088	15.14±0.0318
	Control	0-15	57.57	10.27±0.0058	5.85±0.0058	12.86±0.0058	13.44±0.0145
		15-40	58.43	10.75±0.0058	5.73±0.0088	13.26±0.0088	11.81±0.0088
Dabou	Field	0-15	48.77	14.27±0.0088	6.23±0.0120	12.45±0.0233	18.17±0.0666
		15-40	47.7	13.98±0.0058	5.98±0.0088	13.30±0.0577	19.13±0.0088
	Control	0-15	48.77	14.42±0.0058	6.40±0.0577	12.58±0.0033	17.74±0.0058
		15-40	47.8	14.22±0.0058	6.20±0.0577	13.20±0.0577	18.41±0.1419
F _{cal}			610.67**	140.62**	175.7**	357.7**	897.3**
P _{cal}			0	0	0	0	0
P _{theor}			0.01	0.01	0.01	0.01	0.01

Means followed by the same letter in the same column are not statistically different at P < 0.01 by Tukey test. Cal = calculated theoretical = theor. * = Significant; ** = highly significant; *** = Very highly significant

4.1.2. Index of soil crusting

The index of crusting, calculated from the results of the particle size and chemical properties, is reported in Table 2. The average values of the observed crusting index are below 1.4. Soils of the different study sites are not crusting.

Table 2: Mean values of the index of soil crusting following depths on different sites

Location	Sites	Horizons (cm)	Crusting index (IC)
Azaguié	Field	0-15	0.17
		15-40	0.18
	Control	0-15	0.18
		15-40	0.18
Attinguié	Field	0-15	0.22
		15-40	0.22
	Control	0-15	0.22
		15-40	0.23
Dabou	Field	0-15	0.29
		15-40	0.29
	Control	0-15	0.33
		15-40	0.33

ICappreciation (Callot *et al.*, 1982): <1.4: not crusting; 1.4 to 1.6: few crusting; 1.6 to 1.8: enough crusting; 1.8 to 2: crusting; > 2: very crusting

4.1.3. Ability to cracking of the soil

The values obtained on different sites show that the study sites soils have excellent ability to cracking (Table 3).

Table 3: Soil cracking index following the depths on different sites

Location	Sites	Horizons (cm)	Ability to cracking
Azaguié	Field	0-15	1
		15-40	1
	Control	0-15	1
		15-40	1
Attinguié	Field	0-15	1
		15-40	1
	Control	0-15	1
		15-40	1
Dabou	Field	0-15	1
		15-40	1
	Control	0-15	1
		15-40	1

Assessment of fitness to cracking (Keita, 2000): 1: Excellent ability; 2: Ability average with good and without MO MO; 3: Ability with low and medium without MO MO; 4: No same ability without MO; 5: Crumbling; MO = Organic Matter

4.1.4. Structural stability

Table 4 show that the East-West transect soils, Azaguié-Attinguié-Dabou, have a structural stability index that changes from very stable to stable.

Table 4: Level of soil structural stability following the depths on different sites

Sites	Location	horizons (cm)	Structural Stability
Azaguié	Field	0-15	1
		15-40	1
	Control	0-15	1
		15-40	1
Attinguié	Field	0-15	1
		15-40	1
	Control	0-15	1
		15-40	1
Dabou	Field	0-15	1
		15-40	2
	Control	0-15	2
		15-40	2

Assessment of structural stability (Keita, 2000): 1: very stable; 2: Stable; • 3: average; 4: unstable; 5: very unstable

4.1.5. Risk of asphyxiation

The values reported in Table 5, indicate that soils of the sites have a very high risk of asphyxiation.

Table 5: Level of soil asphyxiation risk following the depths on different sites

Sites	Location	horizons (cm)	Risk of asphyxiation
Azaguié	Field	0-15	1
		15-40	1
	Control	0-15	1
		15-40	1
Attinguié	Field	0-15	1

		15-40	1
	Control	0-15	1
		15-40	1
	Field	0-15	1
Dabou		15-40	1
	Control	0-15	1
		15-40	1

Assessment of risk of asphyxiation (Keita, 2000): 1: very high risk; 2: medium to high risk; 3: low to medium risk; 4: no risk

4.1.6. Density and porosity

Examination of the porosity values show that, for both profiles of the plots cultivated on different sites, tillage resulted in compaction of surface horizons. Indeed, the porosity of the surface horizon different soil profiles irrigated by well water is lower than that of the control soil. Dabou the control soils have a higher bulk density than other materials, with low porosity values (Table 6).

Table 6: Bulk density, real density and porosity of different horizons of soil profiles made on the different study sites

Sites	Location	Horizon (cm)	real Density (g.cm ³)	apparent Density (g.cm ³)	Porosity (%)
Azaguié	Field	0-15	2.61	1.45	44
	Field	15-40	2.35	1.43	39
	Control	0-15	2.57	1.44	41
	Control	15-40	2.78	1.66	40
Attinguié	Field	0-15	2.73	1.6	46
	Field	15-40	2.54	1.37	41
	Control	0-15	2.69	1.67	37
	Control	15-40	2.67	1.68	37
Dabou	Field	0-15	2.75	1.45	47
	Field	15-40	2.83	1.59	43
	Control	0-15	2.83	1.58	35
	Control	15-40	2.63	1.58	34

4.2. Chemical features studied

4.2.1. Acidity and organic matter

4.2.1.1. Acidity

Analyzed soils are acidic to weakly acidic. The pH values increase with depth of the soil and are higher in soils of fields than in the control soil (bare soil). Weakly acidic soils are observed in the fields of Azaguié (5.1 and 6.1) and Attinguié (6.2 and 6.7) and the control plots of Dabou (6.2 and 6.5).

Attinguié and Dabou soils are relatively more acidic, with pH values up to 4.2 in Dabou observed (Table 7).

4.2.1.2. Carbon

In general, the surface horizons are richer in carbon than the depth of horizons on all the sites studied. The observed values show that the Azaguié soils are poor in carbon, with levels below 1 pc The richest soil carbon are observed in Dabou with an average of 1.77 to 2.3 g.kg⁻¹, and Attinguié, with an average of 1.97 to 1.63 g.kg⁻¹ (Table 7).

4.2.1.3. Nitrogen

The average contents of nitrogen in soils remain very low, with maximum of 0.1 mg.kg⁻¹ determined in Dabou soil. The vertical distribution of nitrogen in the soil of the different sites shows a relative constancy in different backgrounds (Table 7).

4.2.1.4. Organic matter

The levels of organic matter in soils of the sites operate in the same direction as carbon. Indeed, we note that the organic matter is more abundant in surface horizons and decreases with depth on all study sites. On all sites, the organic content is less than 5 g.kg⁻¹. However, it is noted that Azaguié soils are less filled with organic matter, with levels ranging between 1.23 and 1.48 g.kg⁻¹, than the Dabou soils, with contents ranging between 3.03 and 4, 05 g.kg⁻¹ (Table 7).

4.2.1.5. C/N ratio

In this study, the most high C/N ratio are recorded on control soils (bare soils). It is also noted that this ratio decreases with depth, and for all the soils studied.

In general, the values of C/N observed are very high, between 8 and 10. The observed mean values are 14.15 in Azaguié; 29.7 in Attinguié and 23.8 in Dabou (Table 7).

Table 7: Assessment of the acidity and the organic matter in the different soils studied

Sites	Location	horizons (cm)	acidity and organic matter (mg.kg ⁻¹)					
			pH _{water}	pHKCl	C	Nitrogen and organicmatter N	MO	C/N
Azaguié	Field	0-15	5.9 ± 0.1 b	4.7 ± 0.1 b	0.86 ± 0.0002 c	0.07 ± 0.000019 b	1.48 ± 0.00011 c	11.95 ± 2.09 c
		15-40	6.1 ± 0.11 a	5.8 ± 0.1 a	0.78 ± 0.00018 c	0.07 ± 0.000019 b	1.34 ± 0.0001 c	10.43 ± 1.88 c
	Control	0-15	5.2 ± 0.08 b	4.6 ± 0.003 b	0.80 ± 0.0002 c	0.04 ± 0.00001 c	1.38 ± 0.00009 c	18.68 ± 3.11 b
		15-40	5.6 ± 0.09 b	4.7 ± 0.003 b	0.71 ± 0.00016 c	0.04 ± 0.00001 c	1.23 ± 0.00007 c	15.53 ± 2.34 b
Attinguié	Field	0-15	6.2 ± 0.12 a	5.4 ± 0.09 a	2.01 ± 0.0023 a	0.08 ± 0.00002 b	3.47 ± 0.00087 a	24.22 ± 5.16 b
		15-40	6.7 ± 0.20 a	5.8 ± 0.1 a	1.93 ± 0.0021 b	0.08 ± 0.00002 b	3.32 ± 0.0078 b	22.46 ± 5.21 b
	Control	0-15	4.8 ± 0.009 c	4.3 ± 0.003 b	1.65 ± 0.00019 b	0.04 ± 0.000001 c	2.85 ± 0.0065 b	38.62 ± 9.13 a
		15-40	4.9 ± 0.009 c	3.4 ± 0.005 c	1.61 ± 0.00017 b	0.04 ± 0.000001 c	2.77 ± 0.0045 b	33.56 ± 8.67 a
Dabou	Field	0-15	4.2 ± 0.007 c	3.3 ± 0.004 c	1.76 ± 0.0002 b	0.05 ± 0.000001 c	3.03 ± 0.0034 b	32.83 ± 8.59 a
		15-40	4.6 ± 0.007 c	3.5 ± 0.005 c	1.78 ± 0.0003 b	0.13 ± 0.00012 a	3.07 ± 0.0031 b	13.53 ± 2.12 c
	Control	0-15	6.2 ± 0.12 a	5.4 ± 0.1 a	2.35 ± 0.0024 a	0.09 ± 0.00002 b	4.05 ± 0.0098 a	24.83 ± 5.02 b
		15-40	6.5 ± 0.21 a	5.7 ± 0.2 a	2.24 ± 0.0017 a	0.09 ± 0.00002 b	3.86 ± 0.0095 a	24.07 ± 4.85 b
F _{cal}			341.63**	367.78**	154.18**	51.48**	155.75**	27.23**
P _{cal}			0	0	0	0	0	0
P _{theor}			≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01

Means followed by the same letter in the same column are not statistically different at P < 0.01 by Tukey test. Cal = calculated theoretical = theor. Ns = not significant; * = Significant, ** = highly significant

4.2.2. Exchange complex and cation exchange capacity

The clay humus complex (CHC), also called "adsorbent complex," is all the forces that hold the exchangeable cations (Ca²⁺, Mg²⁺, K⁺, Na⁺) on the surface of mineral and organic components of soils.

4.2.2.1. Calcium (Ca²⁺)

Ca²⁺ values reported in Table VIII show two types of soil:

- soils with very low to low level in Ca²⁺, obtained infields of Azaguié, Attinguié and Dabou, with contents ranging between 0.24 and 2.75 cmol.kg⁻¹;
- soils with normal concentration in Ca²⁺, in control plots at Dabou, with 3.88 and 3.57 cmol.kg⁻¹ in the horizon of 15-40 cm in fields at Attinguié.

Calcium content is lower in surface horizons and increases with depth at Azaguié, while at Attinguié and Dabou, it tends to decrease from the surface to the deeper horizons. Mean levels of

calcium vary from very low to low, in all studied horizons, with values between 0 and 1 cmol.kg⁻¹. High levels are however observed at Attinguié (3.82 cmol.kg⁻¹) and Dabou (3.88 and 3.57 cmol.kg⁻¹).

4.2.2.2. Magnesium (Mg²⁺)

Magnesium is in small quantities in the surface horizons and increases in the deeper ones at Azaguie and Dabou. In contrary, magnesium is higher at the surface and decreases in deeper horizons in Attinguié soils. The observed mean levels (Table 8), are in general relatively weak; however with a peak is noted at Dabou (1.1 cmol.kg⁻¹).

4.2.2.3. Potassium (K⁺)

Potassium values obtained show relatively low levels compared to the scale of appreciation of the richness of soluble potassium in soils. However, the upper horizons are richer in potassium than deeper ones. Of all the studied sites, Dabou soils present the highest values of K⁺ (Table 8).

4.2.2.4. Sodium (Na⁺)

Sodium is present in the soil in the form of sodium ions (Na⁺). It has a destructive effect on the soil structure, when it exceeds 5% of the CEC. It is a secondary nutrient compared to nitrogen, potassium and phosphorus. It should therefore be reduced to a minimum.

According to the results obtained (Table 8), there is not considerable variation in sodium content from one site to another, or from one horizon to another, with oscillating levels around 1 cmol.kg⁻¹. However, the highest levels are at Dabou (1.4 to 1.9 cmol.kg⁻¹).

Table 8: Characterization of the absorbent complex and the cation exchange capacity in the different soils studied

Sites	Location	horizons (cm)	absorbent complex and cation exchange capacity(cmol.kg ⁻¹)				
			K ⁺	Ca ²⁺	Mg ²⁺	Na ⁺	CEC
Azaguie	Field	0-15	1.87 ± 0.0002 c	1.06 ± 0.0001 b	0.27 ± 0.00021 c	1.06 ± 0.00014 b	5.94 ± 0.1 c
		15-40	1.64 ± 0.00017 c	1.23 ± 0.0001 b	0.46 ± 0.00043 b	1.26 ± 0.00022 a	10.23 ± 2.02 b
	Control	0-15	1.36 ± 0.00011 c	0.45 ± 0.00009 c	0.34 ± 0.00033 c	1.06 ± 0.00015 b	12.46 ± 2.17 b
		15-40	1.23 ± 0.00009 c	1.75 ± 0.0002 b	0.54 ± 0.00042 b	1.05 ± 0.00015 b	10.08 ± 2.01 b
Attinguié	Field	0-15	2.84 ± 0.00021 b	2.75 ± 0.021 b	0.42 ± 0.00043 b	1.08 ± 0.00016 b	4.6 ± 0.09 c
		15-40	2.17 ± 0.0002 c	3.82 ± 0.032 a	0.37 ± 0.00032 c	1.15 ± 0.00019 b	8.8 ± 1.25 c
	Control	0-15	3.54 ± 0.00034 b	0.65 ± 0.000091c	0.92 ± 0.0011 a	1.08 ± 0.00016 b	6.24 ± 1.12 c
		15-40	1.37 ± 0.000011 c	0.24 ± 0.00009 c	0.12 ± 0.00007 c	1.08 ± 0.00016 b	6.82 ± 1.14
Dabou	Field	0-15	3.69 ± 0.032 b	0.65 ± 0.00021c	0.96 ± 0.0010 a	1.4 ± 0.00027 a	24.29 ± 5.21 a
		15-40	5.03 ± 0.1 a	0.36 ± 0.000091c	1.01 ± 0.0011 a	1.95 ± 0.00034 a	15.89 ± 2.78 b
	Control	0-15	3.44 ± 0.023 b	3.88 ± 0.032 a	0.25 ± 0.00019 c	1.94 ± 0.00031 a	20.24 ± 5.19 a
		15-40	3.43 ± 0.025 b	3.57 ± 0.023 a	0.65 ± 0.00037 c	1.06 ± 0.00014 b	22.15 ± 5.03 a
Fcal			969.85**	199.07**	34.72**	155.75**	10.59**
Pcal			0	0	0	0	0
Ptheor			≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01

Means followed by the same letter in the same column are not statistically different at P < 0.01 by Tukey test. Cal = calculated theoretical = theor. Ns = not significant; * = Significant, ** = highly significant

4.2.3. Levels of trace metals

4.2.3.1. Manganese (Mn²⁺)

The results show a strong accumulation of Mn²⁺ in the upper horizons; these manganese concentrations decrease with depth. The highest concentrations of Mn²⁺ were observed in the soils at Azaguie with values between 15 and 25 mg.kg⁻¹ compared to control soils at Dabou (17.26 and 13.3 mg.kg⁻¹).

The values obtained for the soils at Attinguïé and Dabou are relatively low (less than 8 mg.kg⁻¹). These are poor soils in Mn²⁺ (Table 9).

4.2.3.2. Aluminum (Al³⁺)

Aluminum content decreases from the upper horizons to deeper ones, except of soils in Dabou fields. Soils of Azaguié and Attinguïé are richer in aluminum. The lowest values were observed in Dabou (Table 9).

4.2.3.3. Iron (Fe³⁺)

Iron in soils tends to decrease with depth in Azaguié. But the evolution of iron concentration is not significant. In contrast, iron accumulates in the lower levels of the soils in Dabou and Attinguïé. Azaguié soils are richer in iron, with an average of 18.43 mg.kg⁻¹. Similar values were also obtained in the control soils at Dabou. However, very poor values have been recorded in the fields of Dabou (4.76 and 4.85 mg.kg⁻¹) (Table 9).

4.2.3.4. Zinc (Zn²⁺)

The distribution of zinc in the various soil horizons shows a decrease in the concentration of Zn²⁺ with depth. The reverse phenomenon is observed in the control of soils at Attinguïé and Dabou. The contents of Zn²⁺ are generally low on different sites (less than 5 mg.kg⁻¹). Some peaks are observed at Azaguié: 10.63 mg.kg⁻¹ (fields) and 7.34 mg.kg⁻¹ (control) at 0-15 cm, and also 9.94 and 10.83 mg.kg⁻¹ in Dabou about control soils (Table 9).

4.2.3.5. Lead (Pb²⁺)

The distribution of Pb²⁺ in different soil horizons shows, overall, a decreasing concentration with depth. The reverse phenomenon is observed in the fields at Azaguié and Dabou. The contents of lead, however, remain low in all sites, with a peak of 2.34 mg.kg⁻¹ in dry matter observed in 0-15 cm horizon at Attinguïé. Soils at Azaguié and Attinguïé are poorer in lead than those of Dabou (Table 9).

4.2.3.6. Copper (Cu²⁺)

Copper tends to accumulate in the upper soil horizons of the sites, except in Azaguié control soils, where concentrations are higher in depth. Very low contents of Cu²⁺ are observed in Attinguïé and Dabou. Some peaks are however observed: 3.34 mg.kg⁻¹ in soils of fields at Azaguié, 3.16 mg.kg⁻¹ in field at Attinguïé, and 3.89 mg.kg⁻¹ in control soils at Dabou (Table 9).

Table 9: Major elements and trace metals in different soils studied

Location	Sites	horizons (cm)	Major elements(g.kg ⁻¹) et trace metals (mg.kg ⁻¹)					
			Mn ²⁺	Al ²⁺	Fe ²⁺	Zn ²⁺	Pb ²⁺	Cu ²⁺
Azaguié	Field	0-15	25.78 ± 5.21 a	97.32 ± 14.12 a	18.25 ± 4.23 a	10.63 ± 2.11 a	1.56 ± 0.0012 b	3.34 ± 0.0033 a
		15-40	14.95 ± 2.21 ab	83.28 ± 13.31 a	18.23 ± 4.22 a	4.85 ± 0.0078 b	0.83 ± 0.0008 c	2.03 ± 0.0021 a
	Témoins	0-15	17.53 ± 3.23 ab	99.67 ± 14.45 a	18.65 ± 4.32 a	7.34 ± 1.21 ab	0.92 ± 0.0009 c	2.17 ± 0.0027 a
		15-40	23.8 ± 5.01 a	98.77 ± 14.15 a	18.62 ± 4.31 a	3.27 ± 0.0056 b	0.83 ± 0.0008 c	2.63 ± 0.0029 a
Attinguïé	Field	0-15	7.95 ± 1.01 bc	91.45 ± 14.01 a	12.46 ± 2.03 b	4.84 ± 0.0076 b	0.65 ± 0.0007 c	3.16 ± 0.0031 a
		15-40	6.8 ± 0.12 bc	90.73 ± 13.31 a	18.64 ± 4.32 a	3.24 ± 0.0054 b	0.75 ± 0.00071 c	0.93 ± 0.000012 c
	Control	0-15	9.5 ± 1.78 b	89.75 ± 13.78 a	12.36 ± 2.01 b	2.75 ± 0.0023 bc	2.34 ± 0.0021 a	0.95 ± 0.000015 c
		15-40	3.7 ± 0.00007 c	73.74 ± 10.24 b	11.76 ± 1.91 b	2.97 ± 0.0033 bc	1.14 ± 0.00081 b	0.44 ± 0.00012 c
Dabou	Field	0-15	3.04 ± 0.004 c	56.91 ± 8.56 b	4.76 ± 0.0067 c	1.35 ± 0.0012 c	1.33 ± 0.00071 b	1.66 ± 0.00071 b
		15-40	3.15 ± 0.002 c	72.67 ± 10.11 b	4.85 ± 0.0078 c	1.24 ± 0.0009 c	1.34 ± 0.00071 b	0.49 ± 0.00015 c
	Control	0-15	17.26 ± 3.17 ab	92.17 ± 14.02 a	18.03 ± 4.02 a	9.94 ± 2.03 a	1.35 ± 0.00072 b	3.89 ± 0.0067 a
		15-40	13.3 ± 2.17 ab	35.64 ± 6.34 c	18.33 ± 4.21 a	10.83 ± 2.21 a	1.25 ± 0.00056 b	0.53 ± 0.00021 c
F _{cal}		146.61**	427.23**	965.87**	624.69**	142.37**	13.64**	
P _{cal}		0	0	0	0	0	0	
P _{theor}		≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01	≤ 0.01	

Means followed by the same letter in the same column are not statistically different at $P < 0.01$ by Tukey test. Cal = calculated theoretical = theor. Ns = not significant; * = Significant, ** = highly significant

4.2.4. Relative enhancements for major and metal elements

Examining the enhancements for the different profiles of the agricultural plots and control soils, major elements and trace metals show enrichment factors in most of the surface horizons, with a value up to 2. Mnat Attinguié gives enrichment factors much higher than 2 (9 to 13). About Cu, it induces the values obtained in the surface layers that are of the order of 2 to 7 in the site at Attinguié. For the Pb, the highest enrichment factor is in upper horizons of the control soils in Attinguié site (Table 10).

The data in Table 10 indicate enrichment of Mn in Attinguié soils, and Cu in Attinguié and Dabou soils.

Table 10: Change in enrichment factors (EF) of the metal elements according to soil horizons

Location	Sites	Horizon (cm)	Enrichment factor (EF)					
			Mn	Al	Fe	Zn	Pb	Cu
Azaguié	Field	0-15 cm	1.083	0.985	0.980	3.251	1.880	1.270
	Field	15-40 cm	0.628	0.843	0.979	0.606	1.000	0.772
	Control	0-15 cm	0.737	1.009	1.002	2.245	1.108	0.825
	Control	15-40 cm	1	1	1	1	1	1
Attinguié	Field	0-15 cm	11.357	1.240	1.060	1.630	0.570	7.182
	Field	15-40 cm	9.714	1.230	1.585	1.091	0.658	2.114
	Control	0-15 cm	13.571	1.217	1.051	0.926	2.053	2.159
	Control	15-40 cm	1	1	1	1	1	1
Dabou	Field	0-15 cm	0.229	1.597	0.260	0.125	1.064	3.132
	Field	15-40 cm	0.237	2.039	0.265	0.114	1.072	0.925
	Control	0-15 cm	1.298	2.586	0.984	0.918	1.080	7.340
	Control	15-40 cm	1	1	1	1	1	1

4.2.5. Total isovolume major stocks and metallic elements in different soil horizons

Table 11 summarizes the assessments of stocks isovolumiques determined for all profiles.

The results show that isovolumique stocks, in the surface horizons of agricultural plots at Azaguié and those of the control plots at Dabou exceed 2.

Table 11: Summary inventory isovolumiques major and metal elements in soils of different sites

Sites	Location	Horizon (cm)	Iso volume stocks of the major (kg m ⁻³) and metal (gm ⁻³) elements					
			Mn	Al	Fe	Zn	Pb	Cu
Azaguié	Field	0-15	0.005	0.021	0.004	2.312	0.339	0.726
	Field	15-40	0.005	0.029	0.006	1.733	0.296	0.725
	Control	0-15	0.003	0.021	0.004	1.585	0.198	0.468
	Control	15-40	0.009	0.041	0.007	1.357	0.344	1.091
Attinguié	Field	0-15	0.002	0.022	0.003	1.161	0.156	0.758
	Field	15-40	0.002	0.031	0.006	1.109	0.256	0.318
	Control	0-15	0.002	0.022	0.003	0.688	0.586	0.237
	Control	15-40	0.001	0.031	0.005	1.247	0.478	0.184
Dabou	Field	0-15	0.001	0.012	0.001	0.293	0.289	0.361
	Field	15-40	0.001	0.029	0.002	0.492	0.532	0.194
	Control	0-15	0.004	0.021	0.004	2.355	0.319	0.921
	Control	15-40	0.005	0.014	0.007	4.277	0.493	0.209

5. DISCUSSION

Lamouroux (1972), referring to the action of the rock material, said alteration of primary minerals is causing multiple pedogenic transformations, and it largely determines soil differentiations. Thus, differentiation and evolution of soils appear strongly conditioned by the middle of soil formation that can be defined as the physicochemical environment responsible for the evolution of soil and soil differentiations.

Rich horizons of coarse elements, like furniture horizons covering the stone-lines (Lanfranchi and Schwartz, 1991), seem to have been formed under the combined action of biological alterations, driving by gravity and lateral transport material and colluvial erosion in the catchment during the rewetting phases.

Thickness, depth, density and nature of the coarse elements are linked on the one hand, to the nature of the rock and on the other hand, to the topographic position (Kouadio, 2012).

The strong presence of coarse elements mid-slope and down slope could be explained by the fact that transport by water runoff through graded bedding. Indeed, the further away from the summit, the coarse elements are relatively small, making them easily transportable then by water and wind, resulting in their accumulation on the more or less flat surfaces (Kouadio, 2012).

Soil samples collected and analyzed at the different sites are generally acidic to moderately acidic, with pH values of around 5.1 (control soil) and 6.5 (cultivated land). Such acidity is often characteristic of soils rich in organic matter. When the ground is grown continuously, this quickly leads to acidification due to the decomposition of organic matter as a result of microbial activity and root respiration. When soil acidity increases, following cultivation in successive years, the soil pH decreases (Elberling *et al.*, 2004). Indeed, the pH is one of the most important factors that explain the mobility of trace metals in the soil. In general, lowering the pH (acidic pH or slightly acid) promotes metal mobilization by proton exchange, dissolving the insoluble salts or destruction of the retention phase. There is a provision in the middle of the proton of which the binding is highly competitive on the exchange sites and those sorption (Baize, 1997). Dissolution of metal salts or the destruction of the retention phase may also take place under acidic conditions (Wu *et al.*, 2002).

In our study, the presence of metals is certainly due to soil acidity. Also, the change in pH appears to be the parameter which easily modifies the behavior of metals (Martinelli, 1999). The surface horizons of the studied vegetable crops production soils are relatively rich in organic matter, especially those in Dabou soil, with contents of between 3.03 and 4.05 g.kg⁻¹. It is noted that the organic matter is more abundant in surface horizons and content decreases with depth on the three study sites. This richness could be due to the repeated intake of animal waste (manure chicken, pig excrement and others). The richness of different organic matter in soils can also be explained by the return of crop residues and by inputs of nutrients, as noted Naman *et al.* (2002) at Morocco. This enrichment in organic matter may ultimately affect the physical properties of the soil, because we know that there are strong positive correlations between organic matter content of the soil and the rate of stable aggregates (Wesemael, 2006). Also, among the most reactive components about the metal, organic matter are known for their complexing properties adsorbent or by acting as ligands. They sometimes play the role of storage of metals (Lamy, 2002).

The organic matter may fix trace metals and immobilize them in the ground within stable organo-mineral complex, or, in contrary, migrate with the soil solution and induce a transfer of trace metals associated to it, in ecosystem, to groundwater. This affinity is of great importance in the behavior of toxic metals. For example, the dissolved organic matter is capable of complexing the metal and to increase their solubility (Wu *et al.*, 2002). Due to their small size, their high surface site and their

filling properties, organic soil colloids may potentially have a greater affinity for the metal than the other soil components. Accordingly, the soluble metal types present in the soil solution may preferably be associated with mobile solid phases that are colloids (in particular organic) in the solution, rather than stationary solid phases of the components of the soil matrix, and therefore increase the mobility and transport of metals in depth. Humic substances affect the speciation of metals by their chelating power, but also by their redox properties (Asatiani *et al.*, 2004).

The organic matter in the soil is characterized, as clay, by a large specific surface and by its swell ability, allowing the penetration of water and the diffusion of small molecules, which can also bind with humic substances. However, humic substances may fix metal ions by complexing. The metal-organic matter bonds can be viewed as an ionic exchange process between H^+ and metal ions on the acid-functional groups (Xue *et al.*, 2003). This may explain the metallic trace metal levels in the studied soils, rich in organic matter. The various reversals in vegetable crops soil upper horizons may cause migration of organic matter to the underlying horizons.

Values of C/N determined on all sites are high. C/N ratio is a criterion to measure the progress of the humification in soils. When this ratio is between 8 and 10, the biological activity is normal and the soil working properly. However, when humidification conditions are bad (poor ventilation, excessive acidity, too poor soil nutrient solution), the speed of the humidification is slow and then fresh organic matter accumulates. In peat soils, like those found on the sites of Attingu   and Dabou, the humidification process is slowed down by excess water, acidity of the medium and low-nutrient (especially phosphorus). This explains the C/N ratios observed on these sites (29.7 at Dabou and 23.8 at Attingu  ).

In this type of soil, humus, relatively stable, consists of humic and fulvic acids, known for their chelating power (Calvet, 2003).

It forms a bond between organic compounds humified (FA, HA) or simple organic substances (organic acids, polyphenols) and metal cations, especially iron, aluminum and trace elements (Calvet, 2003). That is the formation of a sort of "association" organometallic more or less stable chelate type. It is about of chelating phenomenon or sequestration.

The monovalent cations (Na^+ , K^+) and divalent (Ca^{2+} , Mg^{2+}) are retained on humic compounds, basically a simple phenomenon of cation exchange. However, cations such as Cu^{2+} , Zn^{2+} and Mn^{2+} (trace elements), as well as Fe^{2+} (probably as Fe^{3+}) and Al^{3+} , are able to form with organic compounds, coordination bonds.

The cation exchange capacity in the different soil shows relatively high values in soils of Azagu   and Attingu  , with respectively 9 and 10 $cmol.kg^{-1}$, and higher in Dabou soil (20 $cmol.kg^{-1}$). CEC values recorded in studied soils are relatively high, and can be an index of immobilization of trace metals (cations) analyzed (Assa, 2005).

The cation exchange capacity of the soil depends more on organic colloids than clay. Decreasing of the cation binding capacity can be attributed to leaching of the clay, and above all to just polymerized humus, less abundant, dominated by fulvic acids, unable to form a clay-humus complex (Yeboua and Ballo, 2000). The high levels of CEC in studied soils could mean that the type of humus observed is polymerized, thus capable of binding, hence the retention of heavy metals, which increases with increasing soil CEC.

The highest Cu contents recorded in soil horizons reached respectively 3.34 $mg.kg^{-1}$ in agricultural plots at Azagu   and 3.89 $mg.kg^{-1}$ in the control soils at Dabou, especially in the surface horizons. These values are below the limit value of 35 $mg.kg^{-1}$ proposed by Baize (1997). Examination of enrichment factor observed about Cu in soils indicates that the vertical distribution of this metal is,

since the surface horizons to the depth ones; this could be explained by the use of organic fertilizers that enrich copper soils; including the use of pesticides such as Bordeaux mixture (Cu sulfate addition of lime), as a fungicide (Tonneau, 2003). About the spray water, the levels are relatively low ($<0.2 \text{ mg.l}^{-1}$), not exceeding the limit concentration in drinking water (2 mg.l^{-1}) according to the OMS(1989), but high in vegetable crops (values between 1.34 and 20.82 mg.kg^{-1}) particularly in *Corchorus tridens* on all sites. The correlations between the Cu content in the irrigation water and those plants ($r = -0.59$) could indicate that this metal, provided by the irrigation water in the ionic form (Cu^{2+}), is sensed by the leaves. Also, high levels in the plant on studied sites could demonstrate the presence Cu, mainly labile (Castaldi et al. 2003).

There is no significant correlation between soil Cu and organic matter. However, the work of Nazih et al. (2009) indicate that Cu generally reacts with organic matter in the soil to form coordination complexes stable, rather than forming compounds via hydrogen bonds or electrostatic attraction, because of its low power and low moisture load. This could allow the roots of vegetable crops to make Cu available to plants. These results are consistent with those of McLaughlin et al. (2000), who explain that the distribution of Cu in soil is often affected by various environmental factors such as soil temperature, moisture, and especially the distribution of plant roots in the ground.

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