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Chemical variability of climate sequence of manganesiferous soil derived from volcano-sedimentary materials in Côte d'Ivoire

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Abstract

Knowledge of limiting factors is an important prerequisite for ensuring efficient agricultural production, agronomically, economically and environmentally. The objective of this study is to determine the basic physicochemical properties of manganiferous soils derived from volcano-sedimentary material under different climatic facets. Three sites on different climatic facets were prospected. An analysis of soil samples was carried out in order to determine the physicochemical parameters (water pH, exchangeable bases, CEC, organic matter, phosphorus). The results show that soils are acidic with pH <5.5. The available phosphorus is better supplied with contents greater than 20mg.kg^{-1}, while the complex is strongly desaturated. This study has highlighted the existence of a marked climatic gradient for organic matter and CEC. These elements follow a decreasing trend, from the North (Savannah zone and Sudanese climate) to the South (forest zone and Attiean climate). The forest area (Guitry) in Attiean Climate remains better enriched in bases compared to the other zones studied. The influence of microclimatic conditions on pedogenesis is important in the individualization of Cambisols.

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Introduction

The soil is the physical and nutritive support of living beings on the surface of the continents, and, as a result, the life support of man. Although the man is in permanent contact with the ground, it is still, in many ways, a black box whose operation is still only partially known. The floors are constantly changing under the combined action of the flow of materials and energy, which, when applied to a parent material, gradually transforming the primary minerals into secondary components (Chadwick and Chorover 2001; Cornu, 2005). These permanent interactions give the soil a large spatial and temporal variability, which is difficult to grasp. This complexity characterizes natural environments and makes their study delicate.

Manganese soils in Côte d'Ivoire are mainly formed on volcano-sedimentary complexes. These volcano-sedimentary complexes give rise to browned soils (Cambisols) (Perraud, 1971), and are under different climatic facets. The study of these soils has been limited to morphological characterization and the study of metallic trace elements (Nangah *et al.*, 2019). This does not allow to apprehend the physicochemical environment that reigns in these soils. In addition, they also do not guide decision-making on the prevention of potential risks and the adoption of adequate cropping systems by the majority of the population, which is rural. However, failure to take into account the physico-chemical constraints of soils is detrimental to the exploitation of these, because, certain soil parameters play a preponderant role in the management of plant nutrition, and an adequate supply of nutrients. nutrients depend on their optimization (Troeh and Thompson, 2005). Knowledge of limiting factors is therefore an important prerequisite for ensuring efficient agronomic, economic and environmental agricultural production from reliable diagnoses (Dahnke and Olson 1990, Parent and Dafir 1992).

The objective of this study is to determine the basic physicochemical properties of manganese soils derived from volcano-sedimentary material under different climatic facets.

Material and methods

The choice of the different study areas was mainly based on the lithological and climatic criteria. Indeed, from the geological map of Côte d'Ivoire, we proceeded to the inventory of areas with manganese occurrences, then, depending on the different climatic facets, three (3) zones were selected: Korhogo in Sudanese climate, Attiégouakro in Baoulean climate and Guitry in Attiean climate. on each site, three pits were opened and then samples were taken from each horizon. Sites characteristics are shown in Table 1.

Table 1. Characteristics of study sites.

Characteristics	Guitry	Attiegouakro	Korhogo
Geographic coordinates	5°20'5" N 5°23' W	6°48' N 4°58' W	9°23'27"N 5°48'49"W
Precipitation (mm/year)	1400 à 2500	850 à 1700	1000 à 1200
Monthly average temperatures (°C)	25 à 33	16 à 34	12 à 39
Climate	Attiean	Baoulean	Sudanean
Average relative humidity (%)	80 à 90	60 à 70	65
Natural vegetation	Evergreen forest	Clear forest/savannah	Savannah shrub
Parenting material	Volcano-sedimentary	Volcano-sedimentary	Volcano-sedimentary
Soil type	Cambisols	Cambisols	Cambisols

The horizons, of different thicknesses, identified in the soil profiles, have been codified by creating depth classes according to the root profile of the crops. The need for codification was all the more necessary as the profiles had varying thicknesses. The codifications, carried out in accordance with the work of Koné (2007), made it possible to distinguish the following classes:

- H1 (0-20), bringing together all horizons between 0 and 20cm deep, rich in organic matter, crossed by many roots;
- H2 (20-60), grouping all horizons between 20 and 60cm deep, with progressive depletion in organic matter, there are many small roots; it is the depth of exploitation of the root system of many food crops;
- H3 (60-80), corresponding to horizons between 60 and 80cm deep, this is the minimum depth recommended for agricultural mechanization;

- H4 (80-120), gathering all horizons between 80 and 120cm, this class characterizes the deep soils.

Soil samples were analyzed at the Soil and Plant Laboratory of Agronomy School (ESA) at INP-HB. The pH was measured in a sol: solution ratio of 1: 2.5, using a glass electrode (Thomas, 1996). Carbon was determined by the method of Walkley and Black (1934). Nitrogen was determined by the Kjeldhal method (Bremner, 1996). Total phosphorus was assayed by colorimetry and available phosphorus was determined by the Olsen method modified by Dabin (Olsen and Sommers, 1982). At pH 7, cation exchange capacity (CEC) and exchangeable bases were determined by ammonium acetate extraction (NH4Ac, pH 7) (Van Reeuwijk, 2002).

Analysis of the variance (ANOVA), using the Newman-Keuls test, was adopted for structuring the different averages obtained between the horizons of the different study areas (climatic facets).

Results and discussion

Soil pH according to the study site

The average pH values are shown in Table 2. The pH values are acidic and less than 5.5 regardless of the study site and soil depth. A significant difference at the 5% threshold is observed between Korhogo (Sudanese climate) and the other sites (Attiegouakro and Guitry).

Table 2. Soil Acidity by Site and Depth.

Horizon	Korhogo (soudanean climate)	Attiégouakro (baoulean climate)	Guitry (attiean climate)	Pr > F
H_1	4,6±0,07^a	5,21±0,70^b	5,23±0,2^b	0,006
H_2	4,275±0,5^a	5,26±0,5^a	4,85±0,6^a	0,170
H_3	4,5±0,6^a	4,9±0,4^a	4,76±0,5^a	0,588
H_4	5,1±0,6^a	4,96±0,36^a	4,8±0,8^a	0,578

Mineralization of organic matter according to the study sites

Table 3 shows the mean values of C and N for the study sites. We didn't observe any significant difference between the carbon, nitrogen and the ratio of carbon to nitrogen values. On the other hand, at the level of the horizon H1, we noticed that the values of C are decreasing, of Korhogo (North) to Guitry (South). The highest levels of C, N and C/N are observed in Korhogo in Soudanean climate.

Table 3. Average soil organic carbon, total nitrogen and C/N ratios by site and depth.

		Korhogo (soudanean climate)	Attiégouakro (baoulean climate)	Guitry (attiean climate)	Pr > F
C (%)	H_1	2,96^a ±0,63	1,933^a ± 0,52	1,633^a ±0,73	0,35
	H_2	2,89^a± 0,78	0,75^a± 0,64	1,03^a± 0,91	0,14
	H_3	1,48^a± 0,55	0,467^a± 0,45	1,267^a± 0,45	0,36
	H_4	1,17^a± 0,78	1,340^a± 0,64	1,167^a± 0,64	0,97
N (%)	H_1	0,24^a± 0,05	0,148^a± 0,04	0,193^a± 0,06	0,45
	H_2	0,22^a± 0,05	0,063^a± 0,04	0,083^a± 0,06	0,12
	H_3	0,11^a± 0,05	0,040^a±0,04	0,157^a±0,04	0,27
	H_4	0,09^a± 0,07	0,100^a± 0,06	0,133^a± 0,06	0,88
C/N	H_1	12,12^a ± 1,19	12,73^a± 0,97	10,28^a ± 1,38	0,38
	H_2	12,76^a± 1,45	11,81^a± 1,18	10,38^a ± 1,67	0,57
	H_3	12,48^a± 1,36	11,44^a± 1,11	7,50^a ± 1,11	0,06
	H_4	12,67^a± 4,22	12,2^a± 3,44	10,65^a ± 3,44	0,92

The mean followed by the same letter on the same line do not differ in the Newman-Keuls test at $\alpha = 0.05$.

Total phosphorus and available phosphorus contents

Table 4 shows the respective values of total phosphorus and available phosphorus of the different sites studied, for horizons H1, H2, H3 and H4. No significant difference was observed for total phosphorus. This shows that the total phosphorus contents of these soils do not differ according to the studied site, whatever the depth. On the other hand, at the level of available phosphorus, significant differences were observed in the first two horizons, at the threshold $\alpha = 0.05$. The available phosphorus values of the horizons were all decreasing, from Korhogo in Sudanean climate to Guitry in the Attiean climate. The lowest levels of available P were observed at Guitry. Manganiferous soils have levels of available phosphorus that exceed 20mg.kg-1 in general.

Distribution of exchangeable base contents on the studied sites

Table 5 presents the values of the exchangeable base contents (Ca^{2+},mg^{2+} and K^+) of the soils of the different sites in the horizons H1, H2, H3 and H4. Soil contents in Ca^{2+} showed a significant difference between them, at the threshold $\alpha = 0.05$ in the H2 horizon. The values are all less than 5.5cmol.kg^{-1}. Soil levels inmg^{2+} all showed a significant difference in the first two horizons. mg^{2+} values are mostly greater than 0.5cmol.kg^{-1}. The average values of K^+ were substantially the same in the surface horizon at all sites. Significant differences were observed in H2 and H3 horizons.

The site of Guitry (Attiean climate) is better equipped with exchangeable bases compared to other sites located in Baoulean and Sudanean climate.

Table 4. Variation of the average soil contents in P total and Pass according to the sites. and the depth.

		Korhogo (soudanean climate)	Attiégouakro (baoulean climate)	Guitry (attiean climate)	Pr > F
P. total	H_1	457,50^{a}± 133,18	630,33^{a}± 108,74	574,33^{a}± 153,78	0,61
	H_2	520,25^{a}± 105,09	400,16^{a}± 85,81	367,66^{a}± 121,36	0,58
	H_3	364,00^{a}± 138,37	242,00^{a}± 112,97	526,33^{a}± 112,97	0,29
	H_4	340,50^{a}± 143,16	366,66^{a}± 116,89	414,00^{a}± 116,89	0,91
P.assi	H_1	80,75^{a}± 16,1	80,50^{a}± 13,14	28,66^{b} ± 18,59	0,01
	H_2	62,25^{a} ± 8,74	46,16^{a}± 7,24	16,66^{b}± 10,25	0,02
	H_3	68,00^{a}± 41,53	20,33^{a}± 33,91	20,67^{a}± 33,91	0,52
	H_4	71,00^{a}± 16,92	51,00^{a}± 13,82	23,33^{a}± 13,82	0,17

Table 5. Means of Ca^{2+} andmg^{2+} soil levels by site and depth.

		Korhogo (soudanean climate)	Attiégouakro (baoulean climate)	Guitry (attiean climate)	Pr>F
Ca^{2+} (cmol.kg^{-1})	H_1	1,17 ^{a}± 0,75	1,81 ^{a}± 0,61	2,697 ^{a}± 0,87	0,44
	H_2	0,41 ^{b}± 0,23	0,25 ^{b}± 0,19	1,58 ^{a}± 0,27	0,007
	H_3	0,51 ^{a} ± 0,50	0,06 ^{a}± 0,41	1,87 ^{a}± 0,41	0,06
	H_4	0,805 ^{a}± 0,66	0,204 ^{a}± 0,54	2,007 ^{a}± 0,54	0,15
Mg^{2+} (cmol.kg^{-1})	H_1	0,660 ^{b}± 0,51	1,614 ^{ab}± 0,42	2,947 ^{a}± 0,59	0,04
	H_2	0,60 ^{b}± 0,42	0,22 ^{b}± 0,34	2,33 ^{a}± 0,49	0,01
	H_3	0,73 ^{a}± 0,69	0,077 ^{a}± 0,57	2,250 ^{a}± 0,57	0,10
	H_4	0,602 ^{a}± 0,55	0,770 ^{a}± 0,45	1,160 ^{a}± 0,45	0,72
K^{+} (cmol.kg^{-1})	H_1	0,14 ^{a}± 0,08	0,18 ^{a}± 0,06	0,15 ^{a}± 0,09	0,90
	H_2	0,03 ^{b}± 0,01	0,03 ^{b}± 0,01	0,097 ^{a}± 0,01	0,006
	H_3	0,033 ^{b}± 0,01	0,014 ^{b}± 0,007	0,063 ^{a}± 0,007	0,01
	H_4	0,026 ^{a}± 0,11	0,050 ^{a}± 0,09	0,260 ^{a}± 0,09	0,25

Cation exchange capacity, saturation rate in bases and sum of bases

Average values of the sum of the exchangeable bases (S), base saturation rate (V) and cation exchange capacity (CEC) are presented in Table 6. Values of the sum of the bases are higher on Guitry, compared to other sites. The values expressed a significant difference for the H2 and H3 horizons. However, a growth in values has been observed from Korhogo to Guitry for the H1 horizon. This growth was also observed for the values of the saturation rate in bases for H1. Values of the saturation rate in bases all showed a significant difference at the threshold α = 0.05. At the level of the H2 and H3 horizons, the Guitry samples showed a significant difference compared to the samples from the other sites (Attiégouakro and Korhogo), constituting a statistical group. Base saturation rates ranged from 76.15 % to 34.05% at Guitry, in Attiean climate; from 9.87% to 5.09% in Korhogo, in Sudanean climate. Values of cation exchange capacity have an inverse behavior of the values of the sum of the bases and those of the saturation rate in bases, in the horizon H1 (values of V decreasing). The values are higher in the North (Korhogo) (value between 22.35 and 17.8cmol.kg^{-1}) compared to the South (Guitry) (value between 16 and 7.33cmol.kg^{-1}).

Table 6.

		Korhogo (soudanean climate)	Attiégouakro (baoulean climate)	Guitry (attiean climate)	Pr>F
CEC (cmol.kg^{-1})	H_1	22,35^{a}±2,82	18,33^{a}± 2,31	16^{a}± 3,26	0,350
	H_2	20,4^{a}± 2,46	15,08^{ab}± 2,01	7,33^{b}± 2,84	0,01
	H_3	23,50^{a} ± 3,45	9,29^{b}± 2,82	11,8^{b}± 2,82	0,05
	H_4	17,80^{a}± 4,13	9,94^{a}± 3,37	10,88^{a}± 2,2	0,37
S (cmol.kg^{-1})	H_1	2,01^{a}± 1,19	3,61^{a}± 0,97	5,79^{a}± 1,38	0,16
	H_2	1,11^{b}± 0,61	0,5^{b}± 0,49	4,01^{a}± 0,71	0,007
	H_3	1,33^{a}± 1,03	0,157^{a}± 0,84	4,187^{b} ± 0,84	0,04
	H_4	1,48^{a} ± 1,02	1,02^{a} ± 0,83	3,42^{a} ± 0,83	0,19
V (%)	H_1	9,869^{a}± 8,14	19,169^{a}± 6,65	40,213^{a}± 9,4	0,09
	H_2	5,18^{b}± 13,59	3,260^{b}± 11,09	76,156^{a}± 15,69	0,008
	H_3	5,093^{b}± 6,01	1,402^{b}± 1,4	34,059^{a}± 4,91	0,01
	H_4	8,320^{a}± 26,74	6,949^{a}± 21,89	52,560^{a}± 21,84	0,34

Relationship between the physico-chemical parameters of soils

The relationships between soils physico-chemical elements in Korhogo are given in Table 7. The soil pH is significantly and negatively related to organic matter and total nitrogen (respectively -0.62 and 0.52). The evolution of pH is therefore inversely proportional to that of organic matter and total nitrogen. Total phosphorus has been significantly related to CEC (0.62), which means that these two components evolve in the same way. Ca^{2+} had positive, highly significant correlations with K^+ (0.71). The correlations observed between clay and Ca^{2+}, clay andmg^{2+}, were significant, but negative (respectively -0.52 and -0.60). The destruction of clay allows a significant release of K^+ andmg^{2+}.

Correlations between physico-chemical elements in Attiégouakro soils are presented in Table 8. This table shows that the organic matter has been correlated, in a highly significant and positive way, with the elements of the adsorbent complex ((Ca^{2+} (0.58mg^{2+} (0.66), Ca^{2+}+mg^{2+} (0.66), K^+ (0.51), S (0.69) and V (0.73).

Table 7. Correlation between physico-chemical attributes of soils on Korhogo.

Couple de variables	Correlation de Pearson
MO-pH$_{eau}$	-0,62*
N-pH$_{eau}$	-0,60*
CEC-P$_{total}$	0,62*
N-P$_{ass}$	0,69*
P$_{ass}$-MO	0,68*
K^+-Ca^{2+}	0,71**
Clay-Mg^{2+}	-0,52*
Clay-K^+	-0,60*

Organic matter was also correlated with phosphorus assimilable (0.64), but no linear correlation was observed with total phosphorus. Linear bonds between the clay and the constituents of the adsorbent complex ((Ca^{2+} (-0.53),mg^{2+} (-0.53), Ca^{2+}+mg^{2+} (-0.57), S (-0.58) and V (-0.54)). Positive and very highly significant correlations were observed between the assimilable phosphorus and the constituents of the adsorbent complex ((Ca^{2+} (0.85),mg^{2+} (0.77), Ca^{2+}+mg^{2+} (0.87) , K^+ (0.72), S (0.85) and V (0.89). Relations express the predominant role of the adsorbent complex in soil genesis.

At the Guitry level, in the Attiean climate, soil pH had a significant positive relationship with organic matter and nitrogen. Table 9 shows a positive, very highly significant correlation between organic matter and exchangeable cations (Ca^{2+} (0.72), mg^{2+} (0.66), Ca^{2+}+mg^{2+} (0.76)), exception of K^+, with which there was no significant correlation.

Table 8. Correlation between soils physico-chemical attributes on Attiegouakro.

Couple de variable	Coefficient de corrélation de Pearson
P$_{ass}$-MO	0,64**
Ca^{2+}-MO	0,58**
Mg^{2+}-MO	0,66**
K^+-MO	0,69**
S-MO	0,69**
V-MO	0,73***
Sand-P$_{ass}$	0,50*
Clay-P$_{ass}$	-0,61**
Clay-Ca^{2+}	-0,53*
Clay-Mg^{2+}	-0,53*
Ca^{2+}-P$_{ass}$	0,85***
Mg^{2+}-P$_{ass}$	0,77***
K^+-P$_{ass}$	0,72***
S-P$_{ass}$	0,85***
V-P$_{ass}$	0,89***
Mg^{2+}-CEC	0,62**
K^+-CEC	0,51*
S-CEC	0,56*
Clay-Ca^{2+}+Mg^{2+}	-0,57*
Clay-S	-0,58**

Table 9. Correlation between soils physico-chemical attributes on Guitry.

Couple de variables	Coefficient de corrélation de Pearson
MO-pH$_{eau}$	0,61***
MO-N	0,73***
N-pH$_{eau}$	0,51**
Ca^{2+}-MO	0,72***
Mg^{2+}-MO	0,66***
Ca^{2+}-N	0,84***
Mg^{2+}-N	0,68***
S-MO	0,74***
V-MO	0,55***
S-N	0,83***
V-N	0,50**
K^+-CEC	0,57***
S-CEC	0,53**
V-CEC	-0,35*
Clay+Limon-Ca^{2+}	-0,53**
Clay+Limon-V	-0,73***

Positive relationships are also observed with saturation rate in bases (0.55) and the sum of exchangeable bases (0.74). The sum of silt and clay had a negative, significant relationship with organic matter. There is no significant linear correlation between cation exchange capacity and organic matter. Table 9 shows no correlation between assimilable phosphorus and organic matter, because of low values of correlation coefficient.

In general, the exchangeable bases were correlated, positively with each other, but also, with the sum of the exchangeable bases and the CEC, in the soils, whatever the zone studied.

Discussion

The manganese soils observed in this study are Cambisols developing on volcano-sedimentary material as observed by Yao-Kouamé (2008a).

pH value is generally less than 5.5. According to Brady and Weil (2002), there are very few chemical and microbiological reactions that are not sensitive to pH. At low pH values, there are many phenomena that are harmful to plant growth, such as the reduction of nitrification, P deficiency, aluminum and manganic toxicities, the low mobility of organic pollutants and the high availability of certain elements metallic traces (Landon, 1991). pH's close to 5 indicate the pH range where kaolinites are negatively charged, while oxides and organic materials are positively charged. Indeed, under conditions of average acidity, the net charge of the 1: 1 (kaolinite) type mineral colloids, even if low, is still negative (Menzies, 2003). However, soils derived from volcano-sedimentary materials in Côte d'Ivoire are characterized by an abundance of kaolinite (Yoboue *et al.*, 2010, 2018). According to Duchaufour (1977), this fact reveals the absence of clay minerals with high permanent loads, of the vermiculite, smectite or halloysite type. This result is contrary to that of Quantin *et al.* (2007), obtained on Cambisols derived from volcanic materials.

Manganese Cambisols appear relatively deficient in organic matter. In fact, the organic carbon contents of the soils studied were relatively low compared to the standards established by Landon (1991). Organic matter, because of its low content in the soils studied, is not involved in cation exchange processes that depend on the mineral fraction (Ben Hassine *et al.*, 2008). According to Agusto *et al.* (2006), any intervention tending to influence the organic carbon stock, would lead to changes in the physicochemical properties. Total nitrogen is more or less well represented in the soils studied.

Landon (1991) considers grades greater than or equal to 1.3mg.kg-1 to be satisfactory in tropical soils. In the case of our work, the levels are all higher than this value in the surface horizons, whatever the study site. Since total nitrogen is closely linked to organic carbon (Dorel *et al.*, 2005), its evolution or behavior is similar to that in the soils studied.

The ratio between these two C/N elements is an indicator of the quality of organic matter. An average C/N ratio indicates good decomposition of organic matter with several consequences, such as improved availability of nitrogen for plants, and greater soil microbial activity (Genot *et al.*, 2009, Jandl *et al.*, 2012). The C/N ratio in the soils studied is average (10 <C/N <14) in humus horizons and/or humus penetration. These values of the C/N ratio reflect a more or less normal mineralization, involving a good decomposition of the organic matter and nitrogen availability (Mallouhi, 1997). The pH would therefore be responsible for this mineralization because, according to Elbering *et al.* (2003), soil acidification, as found in this study, would promote rapid mineralization of organic matter through stimulation of biological activity. The C/N ratio is lower in the horizons at Guitry compared to the other sites (Korhogo and Attiégouakro), implying a strong mineralization from N to Guitry. Maithani *et al.* (1998), working on subtropical soils of India, have demonstrated the influence of zonal climate on the degree of mineralization of nitrogen. According to these authors, the high rainfall, associated with the dense vegetation, would be essential for a microbial environment favoring rapid decomposition of organic matter.

Although there are no significant differences observed statistically, organic carbon levels in the surface horizon have followed a decreasing trend, from Korhogo (savanna site) to Guitry (forest site), in passing through Attiégouakro. In other words, organic matter levels have varied according to climate. Several authors have already observed that the stock of soil organic matter is influenced by various soil-forming factors, such as climate (Ganuza and Almendros 2003, Dai and Huang 2006), topography (Burke 1999), parental material (Aranda *et al*., 2011) and land use (Sollins *et al*., 1996). It is generally recognized that among these factors, climate, including temperature and rainfall, is the most important factor in regulating levels of organic matter (Callesen *et al*., 2003; Dai and Huang, 2006; Ponge, 2011), because it determines the type of vegetation cover, the quantity and quality of organic residues entering the soil, as well as the degree of mineralization or decomposition of the litter (Quideau *et al*., 2001, Heviaa *et al*., 2003).

In this study, organic matter levels did not follow a climate-related evolution, as described by Ganuza and Almendros (2003), Lemenih and Itanna (2004) and Liu *et al*. (2011). According to these authors, the rate of organic matter increases with precipitation, and decreases with temperature. The organic matter levels in manganiferous soils are therefore linked to the cropping systems, since the high levels are observed in areas of low rainfall and high temperature (Korhogo), and the low levels are observed in areas with high rainfall. (Guitry). Ganuza and Almendros, (2003) report that cation exchange capacity (CEC) controls the organic carbon content, increasing with it. This is consistent with our work, and would explain the gradient in organic carbon, since the CEC values are strong in Korhogo, and low in Guitry. The relationships between cation exchange capacity and organic matter have also been observed by Bigorre *et al*. (2000).

Total phosphorus is abundant in the surface horizons. According to Mbonigaba *et al*. (2009), available phosphorus levels below 20mg.kg^{-1} P_2O_5 were considered too low to provide phosphate nutrition for most plants. Values considered to be low in the studied soils were observed in the soil depth layers. At the level of the study sites, the contents of P ass at Guitry were lower compared to other sites, despite high values of total P. At low pH, Fe and Al oxides and their hydroxides react with available phosphorus and form insoluble complexes such as variscite and strengite (Moyin-Jesu, 2008). The formation of these complexes will reduce the amount of P ass in soils. This process could be responsible for low P ass levels to Guitry. Turner and Haygarth (2001) have observed that soil drying and wetting cycles can lead to release of P in solution following the destruction of microbial cells. This would explain the strong values of P ass. Observed in Korhogo and Attiégouakro.

The Mean Ca^{2+} values in these soils, ranging from 0.48 to 2.33cmol.kg^{-1}, are considered low by Landon (1991). According to this author, exchangeable calcium deficiencies in soils normally occur at low CECs, at pH ≤ 5; which corresponds to our results, since the pH are, in most cases, less than 5.5. Themg^{2+} values are well above 0.5cmol.kg-1 in surface horizons, magnesium deficiency threshold for tropical soils (Mbonigaba, 2009). The contents of K^+ are, for their part, acceptable in the surface horizon; which is favorable for agriculture, because, according to Römheld and Kirkby (2010), potassium available for plants is generally located in the humus layer and at humus penetration of the soil. These higher or lower levels ofmg^{2+} and K^+ may result from the presence of reasonable amounts ofmg^{2+} and K^+, from the alteration of primary minerals carryingmg and K such as biotite (K (Mg, Fe) 3 (AlSiO10) (OH) 2) and muscovite (KAl2 (AlSi3O10) (OH) 2), orthoclase and microcline (KAlSi3O8) (Mustapha, 2007); chlorite ((FeMgAl) 6 (SiAl) 4O10 (OH) 8) and feldspar (Marques *et al*., 2002). These results are similar to those of Nangah *et al*. (2012).

A vertical and oblique transfer of the exchangeable bases is translated by the accumulation of these in the horizons of depth. According to Yeboua and Ballo (2000), the leaching of the bases would be related to rainfall, permeability, the sharp decline in adsorbent capacity and the density of the root system.

The cation exchange capacity (CEC) of these soils is considered low according to Martin and Nollin (1991), and shows no significant difference between sites. The CEC actually reflects the size of the soil reservoir in positively charged nutrients, which depends primarily on the soil texture, and more specifically, its clay content, as well as the nature of the OM (Masmoudi *et al*, 2011). Low CEC values may result in low amounts of organic matter and the presence of clay such as kaolinite and illite. Indeed, these two types of clay appear to be the most numerous in Côte d'Ivoire soils from volcano-sedimentary materials (Yoboue *et al*., 2010).

Base saturation rates of between 8 and 43% would rank these soils in the class of oligosaturated to desaturated or dystric soils (WRB, 2006).

The influence of climate in the study area shows a significant difference in most soil horizons for exchangeable bases. The highest values are observed at Guitry, in the Attiean climate. The significant difference can probably be attributed to the same processes as those described by Chauvel *et al*. (1986), Lucas *et al*. (1993). According to the work of these authors, the relatively high levels of basic cations are due to the fallout of leaves in the forest, which would help to recycle cations and silica in the upper soil.

The parallel evolution of the cation exchange capacity and the organic matter according to the study area, suggests a strong contribution of the organic matter to the CEC, as observed by Ben Hassine *et al*. (2008).

The correlation studies carried out allow us to mention the great complexity of chemical phenomena in manganese soils. Indeed, some correlations characterize all the sites and others individualize them. The correlations between different exchangeable bases, those with their sum and CEC, are due to the fact that under local conditions, where most of the adsorbent complex comes from organic matter, the soils rich in a given base, are also in other. Certain relationships between the physico-chemical properties established in each study area accentuate the zonal disparities between the different sites studied, although the soils and source rocks are identical.

Conclusion

This study has highlighted the existence of a marked climatic gradient for organic matter and CEC. These elements follow a decreasing trend, from the North (Savannah zone and Sudanese climate) to the South (forest zone and Attiean climate). The forest zone (Guitry) remains better enriched in bases compared to the other zones studied. The influence of microclimatic conditions on pedogenesis is important in the individualization of Cambisols considered desaturated, due to the low rate of desaturation in bases.

It appears that relatively low stocks of organic carbon and poor organic matter, low pH levels and cationic imbalance could pose serious constraints to agricultural production if appropriate technical pathways are not adopted, such as raising the pH, which would create better conditions for the release of the other chemical elements. The raising of the pH of these soils should be considered with a view to a good release of the chemical elements and an increase in yields. However, regional and climatic disparities will have to be taken into account when using appropriate techniques.

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