# Major relationships between iron and soil characteristics under different vegetation cover in the south-east of Côte d'Ivoire

## ABSTRACT

To identify the main soil properties influencing the dynamics of iron in the main agricultural land use activities in the south-east of Côte d'Ivoire, soil samples were taken from fields of rubber, rice and in natural forest, in the plots of block B29. The iron concentrations in the soils were determined by atomic emission spectroscopy with inductively coupled plasma, and the physico-chemical characteristics of the soil (pH, organic carbon, total nitrogen, assimilable phosphorus, exchangeable cations, the capacity of exchange, sand, clay and silt) were analyzed according to the usual methods. The results show that free iron (Fed) is relatively more concentrated in the surface horizons, firstly under rice cultivation, then secondarily under rubber cultivation, compared to the soil under natural forest. The bioavailability of iron in the soil has highlighted a significant correlation between iron and three parameters, namely, clay and fine sand which reflect the fixing power of the soil, then the sum of exchangeable cations. By contributing to the iron storage potential in the soil, these parameters should not be underestimated, especially in cultivated soils. They should be seen as important components of ecological agriculture.

*Key words***:** *Correlation, Free iron, Land use, Soil physico-chimical characteristic, South-Est of Côte d'Ivoire.*

## 1. INTRODUCTION

Like most heavy metals (copper, zinc, manganese, etc.), iron is an essential nutrient necessary for crop growth at low levels in the soil [1]. However, it can be absorbed and accumulated in crops, and cause contamination of agricultural soils and food crops [2 ; 3]. In order to prevent such a situation, this study was carried out on the plots of Block B29, in the town of Mamlanso, department of Alépé, in the south-east of Côte d'Ivoire. The B29 perimeter is the result of the declassification of a former protected area. It is now exploited for various speculations. It is known for its management of a socio-economic system in which agriculture and livestock are complementary components [4]. Food crops (banana, taro, etc.), cereals (rice, corn, etc.) and vegetables (eggplant, okra, tomato, etc.) are regularly grown there, which could accumulate bioavailable heavy metals in the soil. This situation has raised environmental and food security concerns at B29 agropastoral farm level. The methods generally used to express the bioavailability of heavy metals in soil are based on the relationship between the amounts of heavy metals taken up by plant tissues and the concentrations of heavy metals in the soil [5]. Numerous studies have demonstrated that soil properties can influence the bioavailability of heavy metals [6]. However, little attention has been paid in the literature to the effect of iron dynamics in relation to the physico-chemical characteristics of the soil under different vegetation covers. Hence the interest of studying the dynamics of iron in the soil of farm B29, in relation to the properties of the soil. Indeed, according to [7], there would be in lowland soils, a fairly high quantity of iron ($Fe^{2+}$) mobilized and accumulated in the soil solution. Therefore, to study the bioavailability and accumulation of iron in soil under vegetation cover, this research attempted to establish models to explain how soil characteristics influence soil iron concentrations under different vegetation covers. The objective of the present study is to determine the important physico-chemical characteristics of the soil influencing the accumulation of forms of iron in the soil in the main plant covers (rubber, rice fields and natural forest) of the agricultural lands of B29.

## 2. MATERIAL AND METHODS

### 2.1 Study area location

The study area covers the dense humid forest of southeastern Côte d'Ivoire. The study was conducted in the locality of Aboisso Comoé, about 20 km northeast of the town of Mamlanso (Figure 1). The soils in this area are the result of the alteration of materials from the volcano-sedimentary complex, consisting mainly of microgabbro and amphibolo-pyroxenite. The soil has been classified in the Cambisols group [4]. Soil samples from the rhizosphere (0–20 cm depth) and deep soil (20-60 cm depth) were taken from agropastoral farm B29 (5°45' N; 3°18' W).

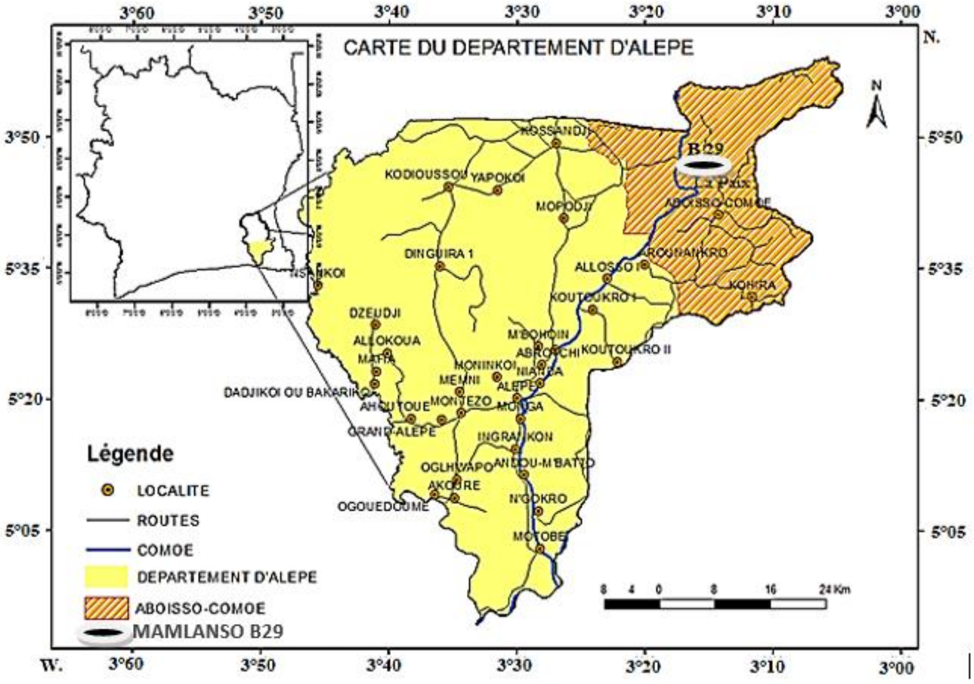
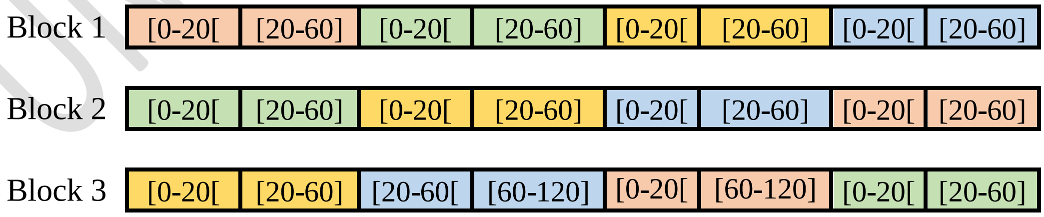


Fig. 1. Presentation of the study area in the department of Alépé

## 2.2 Methodology

### 2.2.1 Sampling plan and experimental device

The sampling concerned a site characterized by plant formations representative of agro-pastoral farm B29. Three types of plant cover, at different topographic positions, have been identified: rubber cultivation at the top of the slope, natural forest at the bottom of the slope and rice cultivation at the bottom position. Considering the slope, that could be a source of heterogeneity, four toposequences with a total length of about 2 km were selected. The observations were made in a split plot device whose main factor is the topographic position, with three levels (summit, lower slope and low land) and the secondary factor represented by the soil horizons, with two levels (0 -20 cm, 20-60 cm of depth) (Figure 2). A representative profile at different topographic positions has been described. Four composite samples per topographic segment and per horizon (4 x 3 x 2) for a total of 24 samples were collected under the identified vegetation covers. Soils are classified according to the World Reference Base for Soil Resources (WRB). GPS points facilitated the in-situ identification of sampling points and their location.



| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Block 1 | [0-20[ | [20-60] | [0-20[ | [20-60] | [0-20[ | [20-60] | [0-20[ | [20-60] |
| Block 2 | [0-20[ | [20-60] | [0-20[ | [20-60] | [0-20[ | [20-60] | [0-20[ | [20-60] |
| Block 3 | [0-20[ | [20-60] | [20-60[ | [60-120] | [0-20[ | [60-120] | [0-20[ | [20-60] |

Fig. 2. Split plot device for collecting data along a toposéquence

### 2.2.2 Physico-chemical soil analyzes

The harvested samples were air-dried in the open air for a period of one to two weeks (depending on soil texture). Once dried, theses samples are sifted through a 2 mm diameter sieve. This operation leads to the separation of the coarse elements from the fine elements. The physico-chemical analyzes were carried out on the fine fraction at Laboratories of reference, which are plant, water and soil laboratory of the Agronomic Higher School (ESA) located at National Polytechnic Institute (INPHB) of Yamoussoukro, and laboratory of the mining development company (SODEMI), in Abidjan.

Organic carbon was determined by the modified Walkley & Black method, based on the oxidation of the organic carbon by potassium dichromate (K2Cr2O7) in sulfuric acid (H2SO4) [8]. Total nitrogen was determined by the Kjeldhal method [9].

pH was measured using a standard pH meter (Hanna Instruments, The Netherlands), in a suspension of soil in water at a ratio of 1:2.5 (m/v) [10]. The texture was measured by the "Robinson" method [11], consisting in the elimination of any cement such as carbonates, oxides and other organic substances by oxidation with hydrogen peroxide; the dispersion of particles is made with sodium hexametaphosphate and the samples were pipetted at different times, different depths following different sedimentation intervals according to Stokes law. All granulometric data were expressed in percentage of fine fraction of soil (<2 mm). The Aquamerck Eisen-Test 8023 (Merck-1) method of extractable assay using a Shimadzu ® UV -1205 type spectrophotometer was used to determine the reduced iron ($Fe^{2+}$) contents [12].

### 2.2.3 Selection of important soil characteristics influencing iron dynamics

To select the important parameters associated with iron, the Boruta algorithm was applied [13]. This method makes it possible to select the relevant parameters and classify them according to their relevance. [14]. The importance of a parameter is estimated by calculating the loss of classification accuracy caused by a random permutation of parameter values, then the mean and standard deviation of the loss of classification accuracy are calculated [15]. The Boruta algorithm classifies entities into three types: "confirmed", "tentative" and "rejected". The important soil parameters confirmed by the Boruta selection method are taken as predictive variables, while the "iron" variable constitutes the response (explanatory) variable. Various type of regression models were developed between these two variable entities. Step-by-step regression analyzes were used to compare the types of equations developed.

### 2.2.4 Statistical analysis of data

A Welch test was also carried out to check if there is a difference between the SCO values of the soil under the three plant covers studied. The Games-Howell post-hoc test is used [16]. According to [17], the Games-Howell test is a robust method that compares in pairs even if there are differences in the number of samples compared, the data being heterogeneous, variable and when the data does not meet the normality assumption. The data was analyzed in the statistical environment R version 4.2.3 [18] and its working interface RStudio [19]. Each soil parameter measured for all repetitions of the soil units was averaged and reported with the standard deviation.

## 3. RESULTS

### 3.1 Soil morphology under rubber cultivation, natural forest and rice cultivation

The in-situ morphological characters of the profiles differ on a clay-loam-sandy material, the clay content varying between 35 and 40% in the first 10 centimeters at the top and bottom position of the slope. Under rice cultivation (bas-fond), the profile is differentiated on a silty-clayey-sandy material, with clay content varying between 35 and 40% in the first 20 centimeters. Under rubber cultivation (summit), internal drainage is good (drainage class <2) reaches 60 cm; which sets it apart from the control soil (natural forest), at the bottom of the slope where good drainage was about 30 cm, and was limited to the first 20 cm at the bottom. The thickness of the humus horizons, less than 10 cm, under the rubber tree field and under the control soil, reaches 20 cm in the lowlands. The three typical profiles studied are illustrated in Figures 3, 4 and 5.

### 3.2 Analytical characteristics of the soils studied

The sum of the bases, with the exception of the rice-cultivated soil which indicates an average value of 2.3 cmol.kg-1, all the others are lower than this value. The cation exchange capacity has average values between 13.85 and 23.43 cmol.kg-1. This generates a base saturation rate of around 51% for soils under natural forest (control) and under rice cultivation, while it is lower under rubber cultivation, with an average value of 13.64%. These values are observed in soils with medium levels of sand (fine and coarse) ranging from about 45% in rubber cultivation to 70% in rice cultivation. In these soils, the average soil organic carbon (SOC) content is also lower (1.260%) in rubber cultivation and higher respectively, 3.345% and 4.220% in rice cultivation and under natural forest. The C/N ratio is close to 11 under crops, while it has higher values (28) under natural forest. The average levels of assimilable phosphorus (P205) are around 0.01% (100 mg.kg-1) under rubber and natural forest, then 0.005% (50 mg.kg-1) under rice cultivation. The pH values varied between 4.2 and 7.3, with averages of 6.2 (under rubber cultivation) and 5.75 under the control and under rice cultivation.

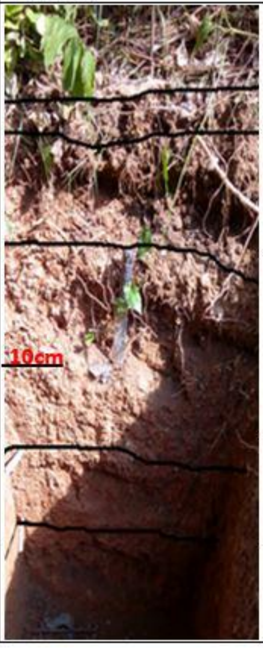
| Layer (cm) | Profiles | Features |
|---|---|---|
| AB<br>0 |  | 2.5YR3/2 (Brown), fresh, humus, clay-loam-sandy, fine sand, 35-40% clay, lumpy, 75% coarse elements (quartz < 10%, nodules > 50%, other: 30%), cohesive, porous, many millimetric roots, good drainage, clear transition. |
| 4/6<br>$B_{13}$ | | 2.5YR3/3 (Brown), fresh, humus, clayey-sandy-loamy, 55-60% clay, polyhedral to nuciform, 89% coarse elements (quartz < 5%, concretions: 95%, other: 2 %), coherent, porous, many millimetric roots, good drainage, more or less regular limit, progressive transition. |
| 17/22<br>$B_{21}$ | | 10R4/3 (Brown), cool to dry, apparently humus, clayey-sandy, fine and coarse sand, 65-70% clay, nuciform, 76% coarse elements (quartz: 10%, concretions: 80%, others: 10%), cohesive, porous, many millimetric roots; good drainage, more or less regular limit, clean transition. |
| 61/64<br>B22(g)<br>83/87 | | 10R4/6-10R5/4 (brown to brown, mottled), cool, slightly humus-rich, clay-sandy, 65-70% clay, blocky, sub-angular, 76% coarse elements (quartz: 10%, concretion: 80%, others: 1%), coherent, slightly porous, a few millimetric roots mm, medium drainage, more or less regular limit, clean transition. |
| $B_{23}$ g<br>116 | | 10R5/8, 10YR7/8 (mottled reddish brown, orange), fresh, not humus-rich, clayey-sandy, 70-75% clay, sub-angular polyhedral, 83% coarse elements (quartz < 10%, concretions: 70%, others: 20%), coherent, rare millimetric roots, poor drainage. |

**Fig. 3. Organization of a representative Plinthic Cambisol (Endostagnic) at the top of topographic position**

| Layer (cm) | Profiles | Features |
|---|---|---|
| A3<br>0 |  | 10R3/1 (Brown), fresh, humus, clay-loam-sandy, fine sand, 30-45% clay, lumpy, 53% coarse elements (quartz < 20%, nodules > 50%, other: 10 %), cohesive, porous, many millimetric roots, good drainage, clean transition. |
| 6/8<br>B211<br>21/30 | | 10YR5/4 (Brown orange), fresh, humus, sandy clay, fine sand, 60-65% clay, massive to polyhedral, 63% coarse elements (quartz < 10%, concretions: 10%, other: 80%), coherent, porous, many millimetric roots, good drainage, more or less regular limit, diffuse transition. |
| B212(g)<br>61/66 | | 10YR6/6 (Brown with orange speckles) and beige (10YR6/4), little humus, clayey-sandy, fine and medium sand, 70-75% clay, blocky to massive structure, 81.25% coarse elements (quartz: 40%, concretion: 30%, others: 30%), cohesive to massive, porous, few roots mm, good drainage, irregular limit, clean transition. |
| B22G<br>96/102 | | 7.5YR4/6, 5Y8/4 (mottled orange, yellowish brown), fresh, little humus, clayey-sandy, with fine and medium sand, 75-80% clay, blocky, 90% coarse elements (quartz <50%, concretion: 40%, other elements: 10%), sticky, not very porous, few millimetric roots, poor drainage, irregular limit, gradual transition. |
| B23 G<br>120 | | 2.5YR4/8 (variegated brown, reddish), gley1 8/10Y, humid, not humus-rich, clayey-sandy, fine and medium sand, 80-85% clay, massive, 75% coarse elements (quartz < 30%, concretion: 30%, others: 40%), coherent and not very porous, few millimetric roots, poor drainage. |

**Fig. 4. Organization of a representative Endogleyic Cambisol (Clayic) profile at the bottom topographic position**

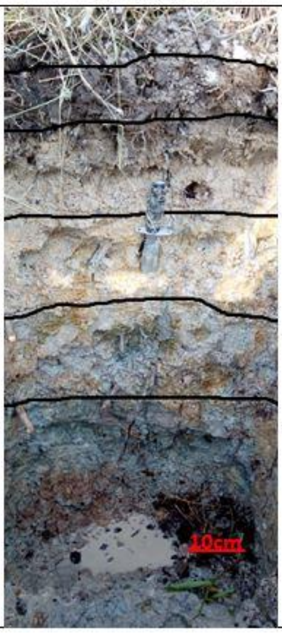
| Layer (cm) | Profiles | Features |
|---|---|---|
| A3/H<br>0 |  | 5R3/1 (Brown), fresh, humus, silty-clay-sandy, fine sand, 35-40% clay, lumpy structure, 72.22% coarse elements (quartz < 1%, nodules: 80%, other: 19%), coherent, not very porous, a lot of millimetric roots, good drainage, more or less regular limit, clean transition. |
| 9/20<br>B2G<br>5/31 | | 5YR4/6, gley1 5/N (Greyish brown, orange spot), cool to humid, low humus, clayey-sandy, fine and medium sand, 50-55% clay, continuous structure, 40% coarse elements (quartz <1%, concretion <1%, others: 98%), not very porous, a few millimetric roots, poor drainage; sharp transition. |
| Gley/<br>48/52 | | Gley1 4/5G_/1, greenish brown (10Y5/2), moist to tempered, apparently not humus-rich, sandy-clayey, medium and coarse sand, 25-30% clay, continuous structure, 62.96% coarse elements (quartz < 10%, concretions< 1%; others: 89%), not very porous, rare roots, clean transition. |
| Gley1/<br>73/80 | | Gley1 8/N, gley2 6/5BG (brown brown), non-humus-rich, clayey-sandy, medium sand, 80% clay, massive structure, 77.78% coarse elements (quartz: 70%, concretion < 10 % and %; others: 20%), sticky, rare roots, poor drainage, clean transition. |
| Gley2<br>113 | | Gley2 6/10G (bluish brown), cool, non-humus-rich, clayey-sandy texture, fine sand, 80% clay, continuous structure, 77.78% coarse elements (quartz 40%, concretion < 10% and other elements: 50%), continuous structure with a massive tendency, not porous, rare millimetric roots, with a preferential sub-horizontal orientation, very poor drainage. |

**Fig. 5. Organization of a representative Gleyic Cambisol (Vertisolic) profile at the lowland topographic position**

**Table 1. Physicochemical characteristics of the soils of the studied area**

| | Rubber cultivation | | | Natural forest | | | Rice cultivation | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Moy | Min | Max | Moy | Min | Max | Moy |
| pHH2O | 5.3 | 7.1 | 6.2 | 4.4 | 7.1 | 5.75 | 4.2 | 7.3 | 5.75 |
| COS (C) | 0.04 | 2.48 | 1.26 | 0.1 | 8.34 | 4.22 | 0.19 | 6.5 | 3.345 |
| Total nitrogen (N) | 0.01 | 0.21 | 0.11 | 0.01 | 0.51 | 0.26 | 0.01 | 0.2 | 0.105 |
| C/N | 7.14 | 16.89 | 12.015 | 0.33 | 54.75 | 27.54 | 2.9 | 23.86 | 13.38 |
| Available Phosphorus P2O5 | 0 | 0.02 | 0.01 | 0 | 0.02 | 0.01 | 0 | 0.01 | 0.005 |
| CEC (T) | 8.86 | 38 | 23.43 | 2 | 29.8 | 15.9 | 2.3 | 25.4 | 13.85 |
| Free iron (Fed) | 0.18 | 0.39 | 0.285 | 0.1 | 0.43 | 0.265 | 0.14 | 1.7 | 0.92 |
| Total iron (Fet) | 2.94 | 8.16 | 5.55 | 0.59 | 11.79 | 6.19 | 1.45 | 4.86 | 3.155 |
| Report Fed/Fet | 0.02 | 0.09 | 0.055 | 0.02 | 0.42 | 0.22 | 0.04 | 1.17 | 0.605 |
| Manganese | 0 | 0.28 | 0.14 | 0 | 0.32 | 0.16 | 0 | 0.17 | 0.085 |
| Clay | 3.02 | 39.32 | 21.17 | 0.5 | 40.11 | 20.305 | 0.37 | 28.77 | 14.57 |
| Fine silt | 12.34 | 47.83 | 30.085 | 1.11 | 55.38 | 28.245 | 6.01 | 24.25 | 15.13 |
| Coarse silt | 5.29 | 8.72 | 7.005 | 0.5 | 13.22 | 6.86 | 3.16 | 18.91 | 11.035 |
| Fine sand | 7.66 | 30.21 | 18.935 | 5.77 | 47.39 | 26.58 | 16.71 | 46.45 | 31.58 |
| Coarse sand | 13.56 | 40.10 | 26.83 | 17.81 | 41.38 | 29.595 | 2.25 | 76.98 | 39.615 |
| Ca2+ (cmol.kg-1) | 0.272 | 0.873 | 0.573 | 0.486 | 1.113 | 0.799 | 0.422 | 4.32 | 2.371 |
| Mg2+ (cmol.kg-1) | 0.131 | 0.676 | 0.404 | 0.247 | 2.054 | 1.151 | 0.231 | 1.447 | 0.839 |
| K+ (cmol.kg-1) | 0.029 | 0.120 | 0.075 | 0.064 | 0.107 | 0.086 | 0.053 | 0.120 | 0.087 |
| Na+ (cmol.kg-1) | 0.083 | 0.089 | 0.086 | 0.078 | 0.094 | 0.086 | 0.086 | 0.094 | 0.09 |
| Sum of bases (SB) | 0.53 | 6.54 | 3.535 | 0.84 | 5.44 | 3.14 | 1.45 | 2.67 | 2.06 |
| Saturation SB/T | 1.66 | 25.62 | 13.64 | 1.9 | 101.3 | 51.6 | 12.21 | 89.67 | 50.94 |
| Aluminium | 0 | 0.24 | 0.12 | 0 | 0.22 | 0.11 | 0 | 0.05 | 0.025 |
| Ca/Mg | 1.3 | 2.1 | 1.7 | 1.04 | 3.89 | 2.47 | 1.59 | 4.65 | 3.12 |
| Mg/K | 3.12 | 4.19 | 3.66 | 6.33 | 15.42 | 10.88 | 3.00 | 24.75 | 13.88 |
| Ca/K | 6.55 | 9.38 | 7.97 | 11.77 | 46.17 | 28.97 | 5.48 | 52.02 | 28.75 |

## 3.3 Evolution of free iron according to depth under different plant covers

### 3.3.1 Selection of important soil parameters influencing free iron under rice cultivation

In Tables 2 and 3, Boruta's algorithm indicated the response on the importance of soil parameters associated with free iron, at the level of the 0-20 cm and 20-60 cm depth horizons and then of the topographic positions of lowland (rice growing). Out of 14 parameters, two (02) important parameters are confirmed. These are clay (Arg) and sum of bases (SB). The other characteristics are either rejected or marked as provisional. Based on these results, it can be concluded that the important (confirmed) parameters that affect the evolution of free iron in the depths 0-20 cm and 20-60 cm in the lowland profiles are clay and sum of bases (Figure 6).

**Table 2. Selection matrix of soil parameters influencing the mobility of free iron in surface horizons (0-20 cm) under rice cultivation according to the Boruta algorithm**

| Parameters | Mean | Median | Minimum | Maximum | CV (%) | Decision |
|---|---|---|---|---|---|---|
| Clay | 5,347 | 5,250 | 4,190 | 6,142 | 1,000 | Confirmed |
| Total nitrogen (Nt) | 0,302 | 0,467 | -0,875 | 1,761 | 0,000 | Rejected |
| Report C/N | -1,252 | -1,300 | -2,939 | -0,088 | 0,000 | Rejected |
| Available Phosphorus P2O5 | -1,063 | -1,071 | -2,485 | 1,117 | 0,000 | Rejected |
| Organic carbon (COS) | 1,136 | 1,158 | -0,465 | 2,612 | 0,273 | Provisional |
| pHwater (pH) | 0,887 | 1,143 | -1,550 | 1,980 | 0,091 | Provisional |
| CEC | 3,527 | 3,674 | 2,895 | 4,242 | 0,909 | Provisional |
| Manganese (Mn) | 0,743 | 1,486 | -1,803 | 2,137 | 0,182 | Provisional |
| Fine silt | -0,503 | -1,157 | -1,816 | 1,684 | 0,091 | Provisional |
| Coarse silt (Cs) | 4,862 | 4,982 | 4,030 | 5,536 | 0,909 | Provisional |
| Fine sand (Sf) | 0,429 | 0,590 | -1,280 | 1,537 | 0,091 | Provisional |
| Sum of bases (SB) | -0,055 | -0,167 | -1,389 | 1,329 | 0,091 | Provisional |
| Saturation (SB_CEC) | 0,002 | 0,111 | -2,013 | 1,419 | 0,091 | Provisional |
| Aluminium (Al) | 1,526 | 1,628 | -0,701 | 3,437 | 0,364 | Provisional |

*CV: coefficient of variation*

**Table 3. Selection matrix of soil parameters influencing free iron mobility in mid-depth horizons (20-60 cm) under rice cultivation, according to the Boruta algorithm**

| Parameters | Mean | Median | Minimum | Maximum | CV (%) | Decision |
|---|---|---|---|---|---|---|
| Sum of bases (SB) | 6,323 | 6,267 | 5,191 | 8,140 | 1,000 | Confirmed |
| Organic carbon (COS) | 0,714 | 1,016 | -1,606 | 2,240 | 0,000 | Rejetced |
| pH-water (pH) | -2,162 | -2,073 | -3,441 | -0,653 | 0,000 | Rejetced |
| Report C/N | -0,649 | -0,475 | -2,386 | 0,983 | 0,000 | Rejetced |
| Manganese (Mn) | 0,138 | 0,286 | -1,555 | 1,666 | 0,000 | Rejetced |
| Clay | 0,257 | 0,234 | -1,038 | 2,195 | 0,000 | Rejetced |
| Aluminium (Al) | 0,219 | 0,119 | -1,281 | 1,647 | 0,000 | Rejetced |
| Fine sand (Sf) | -1,670 | -2,021 | -3,703 | 0,735 | 0,000 | Rejected |
| Saturation (SB_CEC) | 0,479 | 0,734 | -1,491 | 2,346 | 0,000 | Rejected |
| CEC | 2,017 | 2,271 | 0,549 | 3,718 | 0,182 | Provisional |
| Total nitrogen (Nt) | 0,778 | 1,113 | -1,104 | 2,316 | 0,091 | Provisional |
| Available Phosphorus P2O5 | 2,657 | 2,780 | 1,040 | 4,330 | 0,273 | Provisional |
| Fine silt | 0,113 | -0,075 | -1,707 | 2,716 | 0,091 | Provisional |
| Coarse silt (Cs) | 1,223 | 0,880 | 0,129 | 2,258 | 0,182 | Provisional |

*CV: coefficient of variation*

### 3.3.2 Regression models associated with the 0-20 cm horizon of soil under rice cultivation

Figure 7 illustrates the correlation pattern between clay and free iron (Fed) in the surface horizon (0-20 cm) of the soil. This model results in a polynomial equation of order 2 in which the variable "Clay", explains very significantly the variations in the content of free iron (Fed) in this layer of soil. The expression of this equation is:

**Fed (0-20 cm) ~ 0.0042*Clay2 - 0.1036*Clay + 0.7269.**

The distribution of the Fed content presents an inverted bell shape. It shows the predominance of the lowest Fed contents in the soil for intermediate values of clay contents. Thus, the optimum rate of clay that produces the lowest Fed content is 12.39% with a tolerance of ± 10.94 (Figure 7).

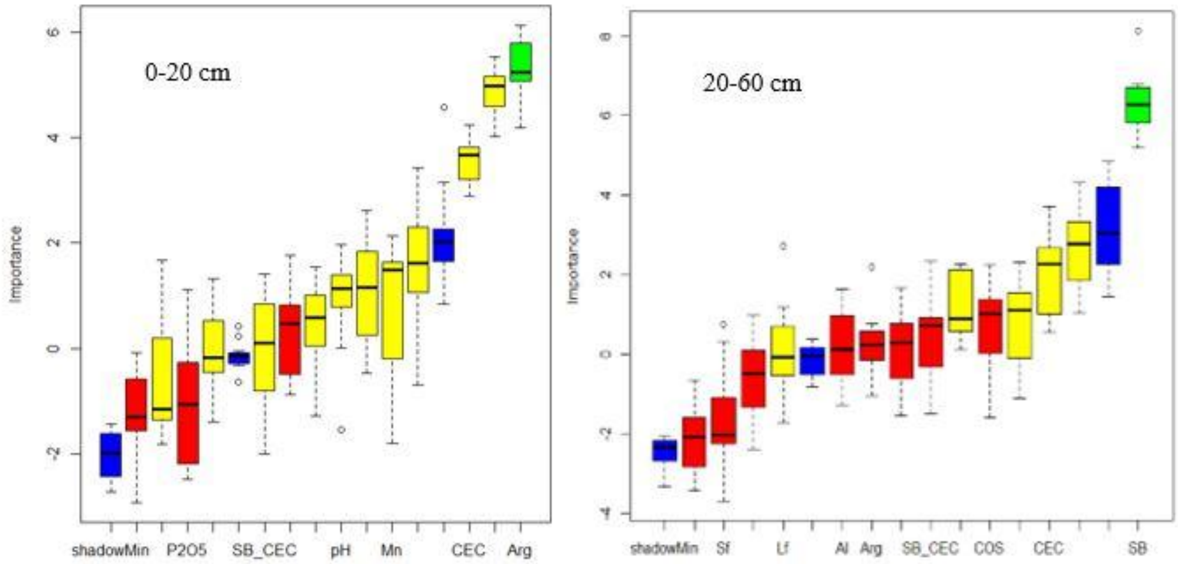
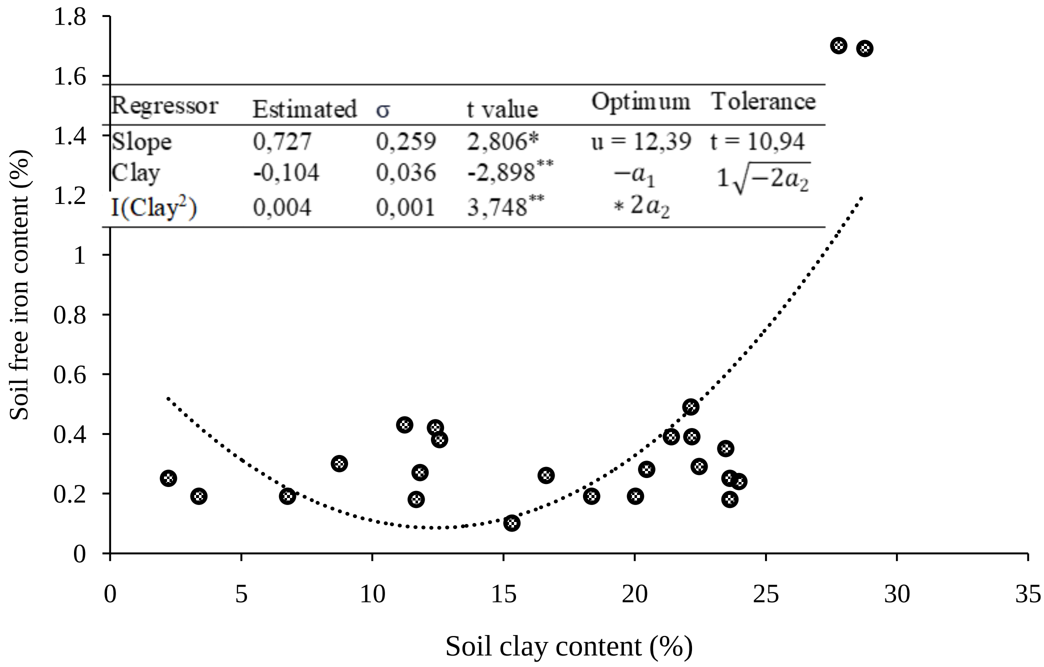


**Fig. 6. Boxplot of importance of selection of characteristics under rice cultivation at 0-20 cm and 20-60 cm, using the Boruta algorithm**

*The value of the number of variables to be taken into account for each tree node is marked by a vertical line. The color code put in place makes it possible to illustrate a certain concordance between the relative importance measured in the data sets. This observation was possible by associating a color to each variable according to its relative importance of the variables. The most important variables have a green color while the less relevant variables have a red color (score with confirmed and rejected attributes, respectively). The yellow-colored boxplot indicated the provisional attributes; the blue boxplots being associated with the minimum, average and maximum score of a shadow attribute. For acronyms, see Tables 2 and 3.*



| Regressor | Estimated | σ | t value | Optimum | Tolerance |
|---|---|---|---|---|---|
| Slope | 0,727 | 0,259 | 2,806* | u = 12,39 | t = 10,94 |
| Clay | -0,104 | 0,036 | -2,898** | $-a_1$ | $1\sqrt{-2a_2}$ |
| I(Clay$^2$) | 0,004 | 0,001 | 3,748** | $* 2a_2$ | |

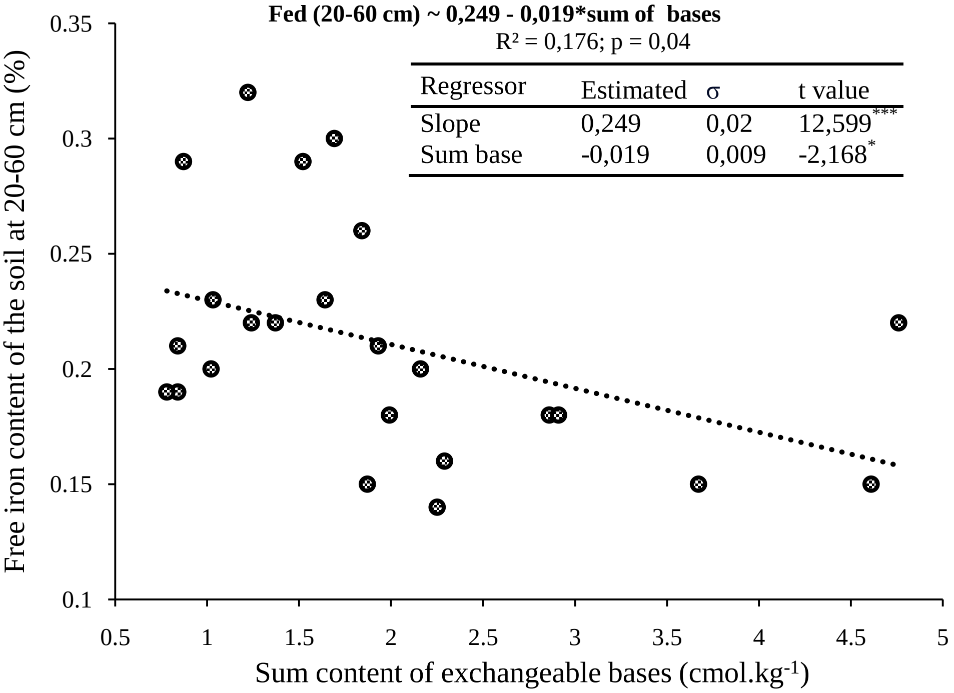
**Figure 7: Model of influence of clay on free iron at 0-20 cm under rice cultivation**

### 3.3.3 Regression models associated with the 20-60 cm horizon of soil under rice cultivation

The evolution of free iron levels associated with the "sum of bases (SB)" variable at a depth of 20-60 cm, in lowland soils, is adjusted by a simple linear regression. The "sum of the bases" variable explains very significantly the variations of free iron in this layer of soil. The equation is:

**Fed (20-60 cm) ~ 0.25 - 0.02*Sum of bases**

Figure 8 illustrates the shape of the curve of this regression between the sum of the bases and the free iron content at a depth of 20-60 cm in the soil. It is a straight line, indicating that at 20-60 cm depth in the soil, an enrichment in alkaline cations (Ca, Mg, K and Na), produces a drop in the free iron, and vice versa.



| Regressor | Estimated | σ | t value |
|---|---|---|---|
| Slope | 0,249 | 0,02 | 12,599*** |
| Sum base | -0,019 | 0,009 | -2,168* |

**Fig. 8. Influence of the sum of the bases on the free iron at 20-60 cm under rice cultivation** '***', '**', '*' significant at p<0.001, 0.01; 0.05, respectively

### 3.3.4 Selection of important soil parameters influencing free iron under rubber and natural forest

In Figure 9, Boruta's algorithm has indicated the response on the importance of soil parameters associated with free iron, in the 0-20 cm and 20-60 cm horizons of soils under rubber plantation (top of slope) and natural forest (bottom of slope). It does not reveal any parameter significantly influencing (confirmed) the free iron content of the soil. The details show that, at the bottom of the slope, out of 14 parameters, 11 are rejected and 3 are marked as provisional, while at the top of slope, 9 parameters are rejected and five (05) are marked as provisional.

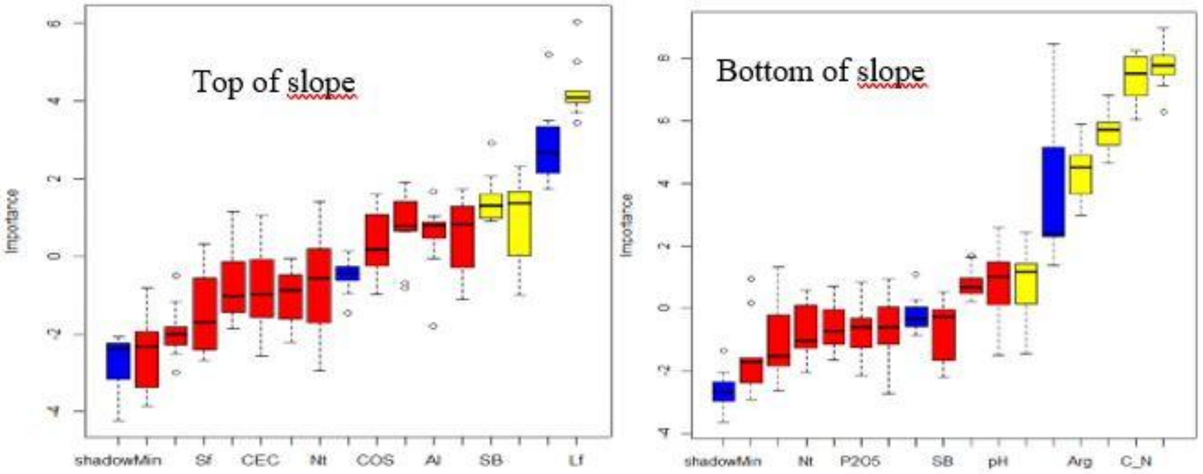


**Fig. 9. Boxplot of the importance of the selection of influential characteristics on free iron under rubber and under natural forest, using the Boruta algorithm**

## 3.4 Evolution of total iron according to the depth under the plant covers

### 3.4.1 Selection of important soil parameters influencing total iron under natural forest and rice cultivation

In Figure 10, the Boruta selection method did not identify any important soil parameters influencing total iron, under natural forest and under rice cultivation. Regression equation models were therefore not developed. Thus, out of 14 parameters, under natural forest, 10 are rejected and 4 are marked as provisional. Under rice cultivation, 8 are rejected and 6 are marked as provisional.

### 3.4.2 Selection of important soil parameters under rubber cultivation influencing total iron

In table 4, Boruta selection indicated "fine sand" as the answer on the importance of soil parameters associated with total iron, in the 0-20 cm depth horizon under rubber cultivation. Further, Boruta's method indicated that 7 parameters are rejected and 6 are marked as provisional. Based on this result, the "fine sand" variable is confirmed, and is used as an important predictive variable associated with the evolution of total iron content under rubber plantations (Figure 11)

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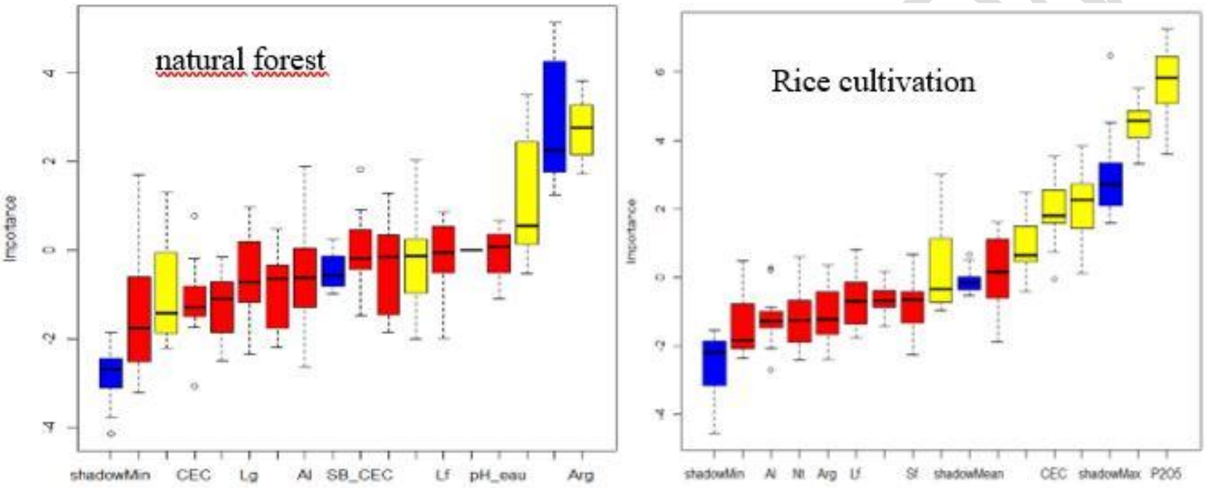

**Fig. 10. Boxplot of importance of the selection of influential characteristics on total iron under natural forest and under rice cultivation, using the Boruta algorithm**

**Table 4. Selection matrix of soil parameters influencing total iron in the 0-20 cm horizon under rubber cultivation, according to the Boruta algorithm**

| Parameters | Mean | Median | Minimum | Maximum | CV (%) | Decision |
|---|---|---|---|---|---|---|
| Fine sand (Sf) | 8,96 | 9,19 | 7,73 | 9,66 | 1,00 | Confirmed |
| Organic carbon (COS) | -1,65 | -1,51 | -3,15 | -1,04 | 0,00 | Rejetced |
| Total nitrogen (Nt) | -2,26 | -2,30 | -3,31 | -1,25 | 0,00 | Rejetced |
| CEC | -1,82 | -1,57 | -3,23 | -0,29 | 0,00 | Rejetced |
| Manganese (Mn) | -1,70 | -1,82 | -2,92 | 0,33 | 0,00 | Rejetced |
| Fine silt | -1,01 | -1,33 | -1,89 | 0,50 | 0,00 | Rejetced |
| Sum of bases (SB) | -1,57 | -1,44 | -2,73 | -0,59 | 0,00 | Rejetced |
| Aluminium (Al) | -1,78 | -2,01 | -2,30 | -0,66 | 0,00 | Rejetced |
| pH-water (pH) | -0,52 | -0,64 | -1,66 | 1,74 | 0,18 | Provisional |
| Report C/N (C_N) | 2,18 | 2,29 | 0,29 | 3,25 | 0,64 | Provisional |
| Available Phosphorus P2O5 | -0,59 | -0,44 | -2,42 | 0,92 | 0,09 | Provisional |
| Clay | 2,84 | 2,89 | 0,61 | 4,76 | 0,64 | Provisional |
| Coarse silt (Cs) | 1,43 | 1,08 | 0,16 | 3,23 | 0,36 | Provisional |
| Saturation (SB_CEC) | -0,07 | 0,02 | -1,51 | 1,50 | 0,09 | Provisional |

*CV: coefficient of variation*

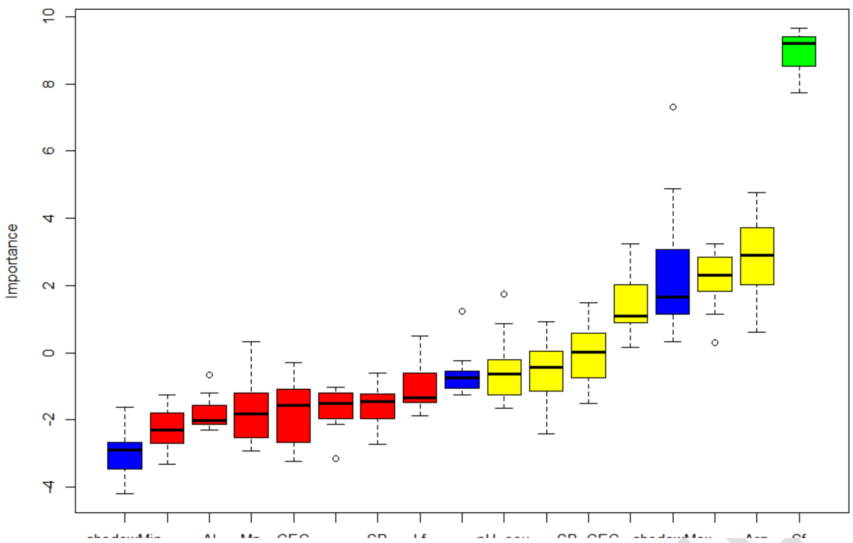

**Fig. 11. Boxplot of importance of feature selection influencing total iron at the summit topographic position, using the Boruta algorithm**

### 3.4.3 Regression models between total iron and fine sand under rubber cultivation

In soil surface horizon (0-20 cm), the evolution of the total iron (Fet) content is fitted by a simple linear regression, with a highly significant regression coefficient (R2 = 0.456; p = 0.0003).
The equation is:

**Fet (Top of slope) ~ 8.948 - 0.181*fine sand.**

These results indicated a negative linear relationship (Figure 12) between the predictor variable fine sand and the explanatory variable total iron (Fet). In other words, under rubber plantation, soil with a sandy texture induces a low total iron content.

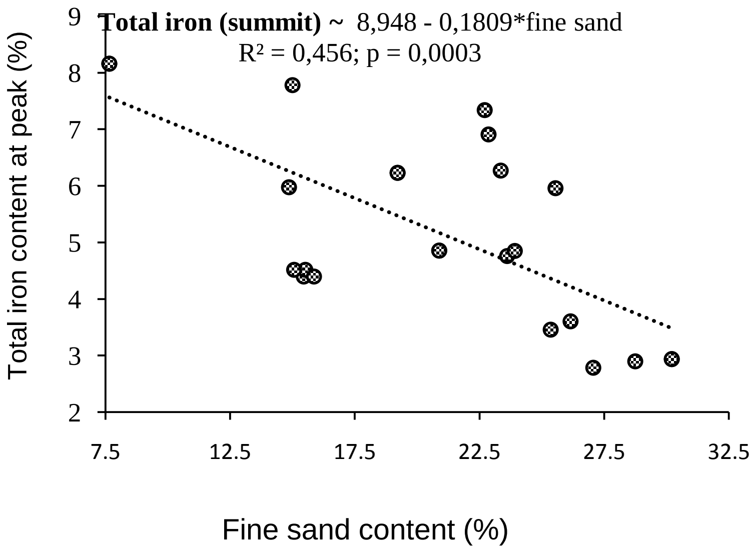

**Fig. 12: Linear relationship between total iron and fine sand at 0-20 cm under rubber cultivation**

## 4. DISCUSSION

### 4.1 Physico-chemical characteristics of the soil and different sources of iron in the study area.

The results of the present study indicated that the three land uses did not accumulate iron in the same way. The average concentrations of free iron (Fed) in the soils studied were significantly higher under rice cultivation (lowlands) than those observed in the soils located under rubber cultivation (top of slope). These last values were also relatively higher than the levels observed under natural forest (control). This observation highlights two major phenomena. First, the unequal spatial distribution of Fed between cropland and control shows the influence of anthropogenic factors [20], in particular the impact of the type of soil vegetation cover on the level of accumulation of fed. The vegetation would lead to a greater concentration of Fed in relation to a decreasing gradient of the density of this vegetation. Second, the unequal distribution of iron, in relation to the topographic segments, indicates that the areas of depression such as the lowlands would accumulate more Fed compared to the areas of the high slope. [7] thus noted the accumulation of iron around rice fields (generally cultivated in lowlands). [21] even noted the accumulation of cadmium, an MTE similar to Iron, in the different parts of the rice. This imposes a chemical analysis of the consumable parts of the cultures for food safety. This accumulation could be explained by the transport of particles through water erosion. These particles could also come from artisanal mining activities, observed in the study area, then transported by wind to the surrounding areas. This last source was also mentioned by [22]. The accumulation of the Fed would therefore, have largely an anthropogenic origin, as also shown by [23]. However, the high concentration of total iron (Fet) in the depth horizons would largely indicate a geochemical origin of iron.

## 4.2 Relationship between soil properties and iron accumulation in soils.

The results showed the relationship between the type of land use and the free iron in the soil. Thus, the comparison of the pH of the soil under the different cultures (rice cultivation and rubber cultivation), revealed an increase in the relative content of free iron, in relation to an increasing acidification of the soil. This would confirm the assertion of [24], according to which iron mobility can also be facilitated by relative variations in the pH of cultivated soils. Also, [25], point out that acidification is one of the three mechanisms contributing to the increase in the dissolution and solubility of iron oxides; [26], also, specify that the effectiveness of these mechanisms decreases when the soil pH increases.

Furthermore, the correlations observed between the free iron content and those of the clay, as well as the sum of the exchangeable cations, would be the reflection of the iron adsorption capacity on the surface of the clays, which also develop certain bonds with some exchangeable cations such as calcium [27]. Indeed, in-situ observations of soils, in the south of Côte d'Ivoire, under a similar climate, had enabled [28] to note the presence of iron in clay. However, this correlation would require special attention, as it could be the cause of the occurrence of induration in soils. The high loads of coarse elements (concretions and nodules) of a ferrous and/or ferromagnanic nature observed in the soil profiles of the area of this study would be one of the precursor signs [28].

Conversely, the only ecosystem, where no important soil parameters could explain the accumulation of iron in the soil, had been the natural forest. This also resulted in the absence of significant correlations between iron and other soil parameters in this environment. However, the other ecosystems (rice and rubber), where this significant correlation had been observed, it had been attributed mainly to activities of anthropogenic origin. This reinforces the thesis of the impact of anthropogenic activities on the accumulation of iron, already mentioned. Human intervention in the environment should therefore be well thought out for sustainable development [29]. This requires mapping of areas of potential contamination [30]

## 5. CONCLUSION

At the end of this study, carried out in plot B29, in Mamlansso, in the south-east of Côte d'Ivoire, it appears that the iron would be of geochemical origin. However, the cultivation of these soils could lead to contamination of the surface horizons. This contamination is accentuated in proportion to the reduction in the density of the plant cover and the topographic positions of the top towards that of the bottom. Thus, under rubber cultivation, contamination was lower, lower under natural forest and higher under rice cultivation, also lower at the top of the slope and higher at the bottom. This last iron dynamics highlighted the important role of water erosion in the transport of iron-bearing particles. These particles would partly come from dust suspensions related to gold panning activities in the said area. Clay and exchangeable cations, on the one hand, then fine sand, on the other hand, were the main factors that could predict the concentrations of free iron and total iron respectively. The possible consequences are the risk of induration of soils with a high clay content. The sustainable management of these soils would therefore require special provisions. Also, for good food security, it would also be important to carry out chemical analyzes of the consumable organs of crops grown in alluvial plains (lowlands).

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