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*Full Length Research Paper*

# Statistical approach to the analysis of the variability and fertility of vegetable soils of Daloa (Côte d'Ivoire)

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**This study was conducted to determine the morphological and physicochemical properties of vegetable soils of Daloa (Center West region of Côte d'Ivoire). Thus, we could know the reasons for the variability in crop yields experienced by operators of these soils. The study consisted firstly to localize the principal sites of vegetable soils. During this investigation phase, five gardening sites were identified. Soils of these sites have been described and samples were taken for laboratory analyzes. Finally, statistical analyzes were performed on soil properties determined. The results showed that the soils of these different sites correspond to three subsets of soils fertility which differed essentially by their textures and cationic exchange capacity, their rate of organic matter, iron and zinc, their humidity and acidity. Soils of Labia site characterized by a balanced texture, slightly acidic pH, high cationic exchange capacity and high level of organic matter are most fertile. The organic matter in these soils are derived in general from the decomposition of household waste which had been dumped there. However, these soils have presented real risks of iron toxicity because of their high iron content. Also, their high content of zinc that comes from household waste suggests that they could be well supplied with other heavy metals contained in household waste too.**

**Keywords:** Statistical approach, vegetable soils, variability, fertility, Daloa, Côte d'Ivoire.

## INTRODUCTION

The urban food supply and access to local fresh produce is one of the advantages of urban agriculture to which urban vegetables systems contribute highly (Bricas and Seck, 2004). Unfortunately, the soils of these agricultural systems are characterized by lower yields while the food needs of people living in cities are constantly growing strongly (POPIN, 2010). So there is a food challenge for urban agriculture in Africa both in terms of quantity and quality (Mougeot and Moustier, 2004). This requires the development of new agricultural practices. But first, knowledge of agricultural soils functioning is required (Gabrielle and al, 2002a, 2002b; Ranger and al, 2002). To achieve this goal, agronomists and soil scientists generally establish references of soil at different levels of investigation. These references are built using mathematical models calculating the degree of similarity between soil profiles on the one hand and soil layers on the other hand (Arrouays, 1987; King, 1987). The comparison of the references obtained between each of these levels allows a spatial expression of soil behaviors. The approach applied in this study to vegetable soils of Daloa (center west of Côte d'Ivoire) with a view to determine the main pedogenic phenomena that govern

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the functioning of these soils is not very different from what is done in general. In fact, it came to locate the principal sites of gardening in the town of Daloa and to determine the morphologic characteristics of these soils; then different physico-chemical analyses were carried out on samples of these soils. The properties of soils determined were analyzed using multivariate statistical methods. This allowed to bring out the particularities of the studied soils and the variables of soils that significantly affected their fertility.

## MATERIAL AND METHODS

### Site description

This study was conducted in the city of Daloa, localized in the Centre-West Region of Côte d'Ivoire (6°45'36"N and 6°21'35"W) (Figure 1).

The climate of the region is characterized by an equatorial and subequatorial mode in which two maximum pluviometric exist. June represents the peak of the great rainy season while September represents the peak of the small rainy season. These peaks are separated by two months more or less rainy (Brou, 2005). The soils in the department of Daloa are developed on granitic substratum dating from the Precambrian means (Dabin and al, 1960); these soils are in general ferralitic fairly washed. The relief of the zone is little contrasted and little varied; it is dominated by uplands where elevations vary from 200 to 400 meters (Avenard, 1971). Landscape of the zone is made up of wet dense and cleared forests.

### Acquisition of data

The data acquisition process started with the phase of investigation to identify the main urban gardening sites of Daloa and to describe the morphology of the soils of these sites. Thus, five sites which are Tazibouo, Lobia, Corridor Issia, Labia and Commerce (Figure 1) were selected. On each site, the structure of the soils was determined. The texture, the color and the quality of the natural drainage of soils horizons were also described. At the same time, a sampling of soil was carried out for the analyses of laboratory; it was a mixture of two taking away to various depths (0-20 cm and 20-40 cm) of the same profile of soil. Thus, two composite samples per site were formed. The area of taking away of samples were characterized by the same culture in the same vegetative state, the same precedent farming, a homogeneous relief and homogeneous ground color and humidity (Schvartz and al., 2005). The phase of analyses of soil samples was carried out at the Analysis Laboratory of Soils and Plants of the National Polytechnic Institute "Félix Houphouët-Boigny". At the end of this step, the whole quantitative data measured on soils was divided into two essential groups: indicating and explanatory parameters of soils chemical fertility (Genot and al, 2012). This division was adopted in prevision of the statistical processing to come.

The principal indicators of soils chemical fertility relate to their acid-basic status (pH), organic status (nitrogen and carbon) and their nutritive elements status (calcium, magnesium, potassium, sodium, phosphorus and some trace elements: zinc and iron in this study). In addition to the pure quantitative aspects, carbon and nitrogen intervene in the qualitative state of the organic matter through C/N report. This report which is an indicator of the conditions of mineralization of the organic matter in soils was calculated. The explanatory parameters of soils fertility are generally composed by the texture and the cationic exchange capacity (CEC).

### Statistical data processing

Statistical treatments performed using STATISTICA 7.1 software were a matter of Analysis of Variance or ANOVA, correlation matrices and Principal Component Analysis or PCA. ANOVA was carried out to see whether the factors of variability of soils (physicochemical properties of soils) previously determined are significantly different from one ground to another. The general form of this analysis is based on the test of Fischer and thus on the normality of the distributions and the independence of samples; then, we supposed, as alternative hypothesis, that samples taken on each site are independent of the samples of the other sites. As this alternative has been checked, we carried out Fischer LSD test to identify the variables which are effectively different from one site to another. The next step consisted to calculate correlation matrices to research correlations between the indicating variables of soils chemical fertility and the explanatory variables of soils fertility. These correlations permitted to understand the functioning of the studied soils and to consider the regrouping of these grounds in more or less different subsets, each subset being characterized by soils of equal fertility. This regrouping was carried out by PCA.

## RESULTS

### Physical and chemical properties of soils

The properties of soils determined are summarized in Tables 1 and 2. We remark concerning soil textures (Table 1) that rates of sands (52.78 to 87.23%), silts (6.83 to 32.21%) and clays (2.05 to 15%) are, in this order, the highest. Thus, it turned out that soils of

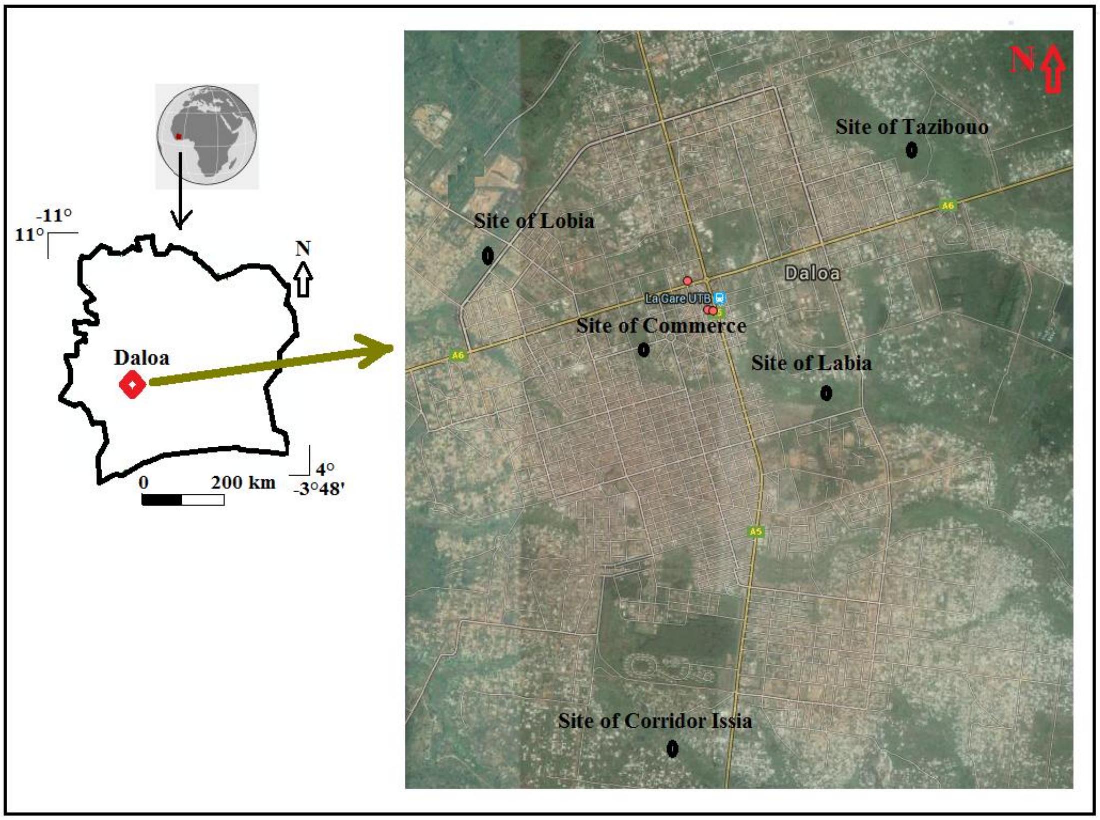



**Figure 1.** Map of localization of the study zone showing the sites of soils prospected.

**Table 1.** Particle size of the studied soils.

| Samples | Clays (%) | Silts (%) | | Sands (%) | | Textures |
|---|---|---|---|---|---|---|
| | | Fine silt | Coarse silt | Fine sand | Coarse sand | |
| Com 1 | 4.94 | 14.13 | 4.75 | 21.02 | 55.15 | Sandy soil |
| Com 2 | 2.05 | 15.87 | 5.73 | 54.27 | 22.07 | |
| Lab 1 | 12.9 | 19.98 | 10.95 | 33 | 23.17 | Silty clay sand |
| Lab 2 | 15 | 20.94 | 11.27 | 32.62 | 20.16 | |
| Taz 1 | 5.53 | 4.52 | 2.71 | 74.71 | 12.52 | Sandy soil |
| Taz 2 | 8.33 | 3.45 | 3.38 | 69.15 | 15.68 | |
| Cor 1 | 8.13 | 5.60 | 4.27 | 65.41 | 16.58 | Sandy soil |
| Cor 2 | 9.14 | 4.70 | 3.65 | 66.5 | 16 | |
| Lo 1 | 5.07 | 8.42 | 3.29 | 61 | 22.21 | Sandy soil |
| Lo 2 | 5.69 | 7.27 | 4.74 | 62.4 | 19.89 | |

**Com:** Commerce; **Lab:** Labia; **Lo:** Lobia; **Cor:** Corridor Issia; **Taz:** Tazibouo

Commerce, Tazibouo, Lobia and Corridor Issia sites are sandy when those of Labia site are silty clay sands. However, the dominant portions of sands and silts throughout all these soils are fine. Concerning chemical properties of soils (Table 2), it appeared that the studied soils are very acidic (pH ≤ 5.5), acidic (5.5 < pH ≤ 6) and neutral (6.5 < pH ≤ 7). Other chemical properties which are related to organic matter, available phosphorus, adsorbent complex, iron and zinc are also proven to be more or less varied from one site to another. The following results show the properties of soils that are statistically different.

## Analysis of variance

The results of ANOVA are summarized in Table 3. It appears through the significant p-values (in bold in the table) that the probability to commit an error stating that

**Table 2.** Chemical properties of the studied soils.

| Samples | pH | Organic matter | | | P ($g.kg^{-1}$) | Adsorbent complex ($cmol.kg^{-1}$) | | | | | Trace elements ($g.kg^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C (%) | N (%) | C/N | | CEC | $Ca^{2+}$ | $Mg^{2+}$ | $K^{+}$ | $Na^{+}$ | $Fe^{2+}$ | $Zn^{2+}$ |
| Com 1 | 6.6 | 0.9 | 0.1 | 9 | 0.041 | 1.2 | 2.85 | 0.32 | 0.03 | 0.11 | 0.275 | 0.120 |
| Com 2 | 7 | 1.66 | 0.15 | 11.06 | 0.081 | 8.24 | 3.56 | 0.56 | 0.06 | 0.18 | 0.282 | 0.126 |
| Lab 1 | 6.1 | 3.01 | 0.3 | 10.03 | 0.035 | 16.63 | 0.40 | 0.40 | 0.07 | 0.19 | 1.389 | 0.265 |
| Lab 2 | 6.3 | 2.87 | 0.3 | 9.56 | 0.031 | 16.64 | 4.43 | 0.36 | 0.09 | 0.19 | 1.488 | 0.272 |
| Taz 1 | 5.1 | 0.75 | 0.05 | 15 | 0.019 | 4.88 | 0.21 | 0.15 | 0.04 | 0.09 | 0.103 | 0.008 |
| Taz 2 | 5.1 | 0.67 | 0.04 | 16.75 | 0.020 | 4.95 | 0.22 | 0.17 | 0.04 | 0.10 | 0.110 | 0.007 |
| Cor 1 | 6.7 | 1.7 | 0.16 | 10.62 | 0.037 | 1.2 | 2.41 | 0.44 | 0.11 | 0.25 | 0.394 | 0.022 |
| Cor 2 | 6.6 | 1.4 | 0.15 | 9.33 | 0.035 | 1.09 | 2.40 | 0.42 | 0.10 | 0.23 | 0.396 | 0.024 |
| Lo 1 | 6.4 | 1.41 | 0.13 | 10.84 | 0.044 | 3.28 | 0.66 | 0.44 | 0.17 | 0.14 | 0.205 | 0.016 |
| Lo 2 | 6.5 | 1.38 | 0.12 | 11.5 | 0.042 | 3.19 | 0.64 | 0.44 | 0.15 | 0.13 | 0.208 | 0.016 |

Com: Commerce; Lab: Labia; Lo: Lobia; Cor: Corridor Issia; Taz: Tazibouo; P: Available phosphorus.

**Table 3.** ANOVA: Univariate results for each dependent variable.

| Variables | df | F-values | P-values |
|---|---|---|---|
| Clay | 4 | 14.448 | **0.005** |
| Silt | 4 | 174.813 | **0.000** |
| Sand | 4 | 175.77 | **0.000** |
| pH | 4 | 41.52 | **0.000** |
| C | 4 | 20.7295 | **0.002** |
| N | 4 | 62.1429 | **0.000** |
| C/N | 4 | 1.4805 | 0.334 |
| P | 4 | 2.843 | 0.141 |
| CEC | 4 | 14.8276 | **0.005** |
| Ca | 4 | 1.9559 | 0.239 |
| Mg | 4 | 4.8 | 0.057 |
| K | 4 | 26.8611 | **0.001** |
| Na | 4 | 11.2455 | **0.010** |
| Fe | 4 | 595.606 | **0.000** |
| Zn | 4 | 2760.761 | **0.000** |

**df:** degree of freedom.

the studied soils variability factors are different is very less than the materiality threshold which is 0.05. This result concerns 11 cases out of 15 possible which corresponds to 73.33% of the cases. Otherwise, the Fischer LSD test performed shows that clay, silt, sand, pH, organic carbon, organic nitrogen, CEC, magnesium, potassium, iron and zinc distinguish well the soils of the different sites.

## Correlation matrices

Correlations between soil chemical fertility indicator variables and soil fertility explanatory variables marked in bold in Table 4 are significant ($p < 0.05$). These are, firstly, correlations between organic matter (C & N) and texture (clays, silts and sands) and CEC also. On the other hand, these are correlations between trace metals ($Fe^{2+}$ and $Zn^{2+}$) and texture, and then CEC.

**Principal components**

The first four principal components express 92.7743% of the total inertia (Table 5). The first two components that determine the first plane express 76.5390% of the total variability of the cloud of individuals. This percentage being very significant shows that the first plan may well represent the variability contained in the entire set of data used for the study. The cloud of variables represented by the correlation circle related to axes 1 and 2 (Figure 2) is derived from the projection of soil variables on the selected plane (plane formed by the first two factors: axis 1 and 2). Except C/N, Ca, Na, P and especially K, all the other variables are well represented on this plane: indeed, it is noted at these other variables, the proximity between the end of arrows and the circle of radius 1 (Figure 2). Thus, the sand (S), magnesium (Mg), pH, nitrogen (N), carbon (C), zinc (Zn) and iron (Fe), which are closest to the circle of correlations are better represented on the graph. Moreover, the almost closed angle (from the origin) that form certain points (Mg and pH, Ca and Na, N and C, and Fe and Zn) is evidence of the existence of a good correlation among these variables. Table 4 shows the linear correlations between variables and the two factors. These correlations also express the factorial coordinates of the variables used to achieve the graph of Figure 3. There are also shown in Table 4, the values of "$\cos^2$" that express varying quality of the representation on the factorial axes. In the same table, are also present contributions of each variable to the construction of the two selected factors (axis 1 and axis 2).

The analysis of this table (Table 4) reveals that only sand and C/N ratio are positively correlated with the first factor (axis 1) whereas at the second factor (axis 2), the positive correlation provides a larger number of variables which are: clay, silt, organic carbon, nitrogen, C/N, CEC, iron and zinc. However, the axis 1 is best correlated with the general variables. This is illustrated by the examples of sand, silt, organic carbon, nitrogen, iron and zinc where correlation coefficients tend to 1 or -1.

**Soil assemblies**

Table 7 summarizes the important results of PCA on individuals. The first two columns of the table provide individuals coordinates on axes 1 and 2 that have permitted to realize the graph of individuals (Figure 3). Axis 1 of this graph groups soils of Tazibouo and Labia sites on one side and, on the other hand, soils of Commerce, Corridor Issia and Lobia sites. The first group of soils quoted, unlike the second group, is well represented on axis 1 (Table 7). Axis 2 combines the one hand, the two samples of Labia site and the first sample of Commerce site and on the other hand, all soil samples of Tazibouo, Lobia and Corridor Issia sites and the second sample of Commerce site; this latter group of soils has an overall representation on axis 2 (average of $\cos^2 = 0.2720$) better than the first group (average of $\cos^2 = 0.2453$).

The second sample of Commerce site that present the lowest coordinate on axis 2 is thus less provided in clay (2.05%) because this variable of soil appeared the most positively correlated with axis 2. Similarly, the second sample of Labia site that has the lowest coordinate one axis 1 is the least provided in sands (52.78%), variable proved to be the better correlated positively to this axis. Ultimately, ACP conducted grouped, according to their fertility, the ten soil samples studied in three different subsets (Figure 3).

**Soil Assemblies characteristics**

Soils of assembly 1 are represented by samples taken on Labia site. These soils are characterized by a sandy-silty clay texture (balanced texture) and a high correlation with axis 1. The high correlation of this axis with nitrogen and organic carbon (Figure 3) shows that these soils are very well supplied with organic matter. This is expressed by the average rates of organic carbon (2.94%) and organic nitrogen (0.3%) stored in these soils, which are the most important rates in all the studied soils. The upper horizon of these soils has a dark brown color (7.5YR 4/3) with colored spots (dark blue and rust colors in particular) (Figure 4A). The average rates of iron and zinc measured in these soils (respectively 1.4385 $g.kg^{-1}$ and 0.2685 $g.kg^{-1}$) are also the highest.

Soils of assembly 2 have the highest coordinates on both axis 1 and axis 2. However, the coordinates on axis 1 (3.2575 and 3.4529 respectively for samples 1 and 2) which are higher than those on axis 2 (2.1528 and 2.8118 in the same order) show a more significant positive correlation of these soils with axis 1. As this axis is also positively correlated with sand and C/N ratio, sands rates (average = 86.02%) and C/N report (average = 15.83) that characterize these soils are rightly higher. However, pH (average value = 5.1), available phosphorus (average value = 0.0195 $g.kg^{-1}$), exchangeable potassium (average value = 0.04 $cmol.kg^{-1}$), magnesium (average value = 0.16 cmol.kg-1), iron (average value = 0.1065 $g.kg^{-1}$) and zinc (average value = 0.0075 $g.kg^{-1}$), which are negatively

**Table 4.** Correlations between dummy variables of chemical soil fertility and soil fertility explanatory variables.

| Dummies of soil fertility | Correlation coefficients with variables of soil fertility | | | |
|---|---|---|---|---|
| | Texture | | | CEC |
| | Clay | Silt | Sand | |
| pH | -0.18 | 0.31 | -0.19 | -0.10 |
| C | **0.70** | **0.85** | **-0.90** | **0.81** |
| N | **0.73** | **0.86** | **-0.92** | **0.79** |
| P | -0.52 | 0.28 | -0.05 | 0.01 |
| Ca | 0.15 | 0.48 | -0.43 | 0.19 |
| Mg | -0.16 | 0.33 | -0.21 | 0.05 |
| K | -0.00 | -0.13 | 0.10 | -0.16 |
| Na | 0.39 | 0.25 | -0.33 | 0.14 |
| Fe | **0.86** | **0.87** | **-0.97** | **0.88** |
| Zn | 0.62 | **0.98** | **-0.98** | **0.88** |

**Table 5.** Percentages of inertia explained by the first four lines of the PCA.

| | Own values | Percentage of variances | Accumulated values | Cumulative percentage of variances |
|---|---|---|---|---|
| Component 1 | 7.8528 | 52.3525 | 7.8528 | 52.3525 |
| Component 2 | 3.6279 | 24.1865 | 11.4808 | 76.5390 |
| Component 3 | 1.5732 | 9.8213 | 12.9540 | 86.3604 |
| Component 4 | 0.9620 | 6.4139 | 13.9161 | 92.7743 |

correlated with axis 1, have for this reason, the minimum values. On the ground, soils of assembly 2 appear constantly waterlogged and covered by badly decomposed plant debris (Figure 4B).

Soils of assembly 3 (Figure 4C) are the only individuals negatively correlated with axis 2, hence their relative richness in phosphorus (average = 0.047 $g.kg^{-1}$) and magnesium (average = 0.43 cmol. $kg^{-1}$) and their relative high pH (average = 6.63).

All these variables are, in fact, proved to be negatively correlated with axis 2. As soils of assembly 2, these soils are positively correlated with axis 1, except the second sample of Commerce site. It follows that they are among the best provided in sands with rates varying from 76.305% (Commerce soils) to 82.75% (Lobia soils). The Figure 4C illustrates the morphological properties of soils of this assembly. Sometimes, we observed in the profiles of these soils a sharp boundary between the upper organic mineral horizon and mineral horizon underlying. The soils located in the downstream part of Commerce site are morphologically similar with Labia soils. Indeed, these soils are impregnated with various organic materials completely or partially decomposed that presence is very marked in upper horizons.

## DISCUSSIONS

### Origin of the variability of vegetable soils of Daloa

The PCA conducted allowed to distribute soils of the five studied sites in three different assemblies of soils.

Soils of assembly 1 are formed by the two soil samples of Labia site. These are silty clay acidic sands. These soils have also, according to the CEC interpretation standards (LANO, 2008), a high mineral reserve which would come from the mineralization of large quantities of organic matter contained in them. Indeed, these soils and their surroundings have been for a long time the sites of various kinds of household waste deposits; this garbage that is generally made of organic materials has been incorporated in soils. This has given to these soils a dark brown color (7.5YR 4/3) and a spotted character of the most superficial horizon. The spots colored in rust reflect the actual presence of metallic elements (including iron) in household waste that have integrated the soils. Significant quantities of zinc revealed in these soils could also be related to household waste; this suggests the presence in these soils, beyond the recommended limits, other trace metals such as cadmium, lead, copper and nickel, as was the case of some vegetable soils of Abidjan (Côte d'Ivoire) (Kouakou et al., 2012). Other dark blue coloration of

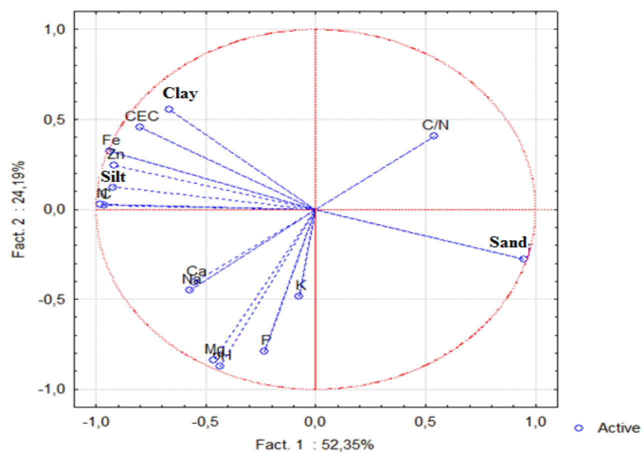
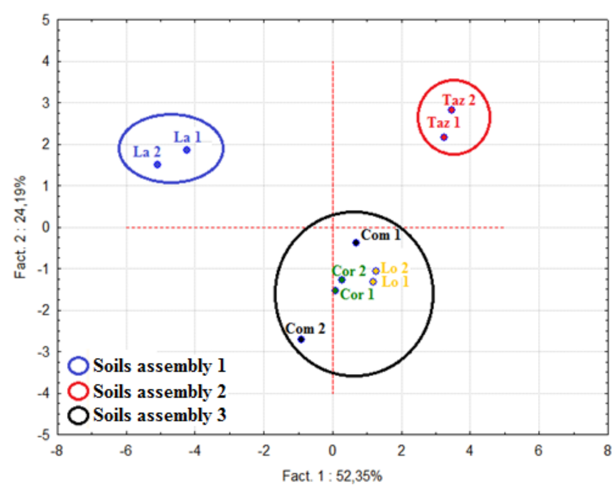



**Figure 2.** Projected variables on the factorial plan (1x2).




**Com:** Commerce; **Co:** Corridor Issia; **La:** Labia; **Lo:** Lobia; **Taz:** Tazibouo.

**Figure 3.** Projection of individuals on the factorial plan (1x2) and soil assemblies.

spots observed relate to non-metallic solid waste in decomposition. However, pseudogleys rusts spots and redox gray spots, as well as black concretions of iron and manganese, which generally reflect bad drainage of water in soils, are rare in all soil profiles studied.

Assembly 2 of soils is consisted of sandy soils of Tazibouo site. These floors are covered by badly decomposed plant debris generated by their permanent waterlogging; this led to confer them peat properties: high acidity and low mineral reserves when referring to standards of interpretation of soils variables (LANO 2008). Also, these soils appeared the least provided out of iron ($Fe^{2+}$ average = 13th of the average registered on the level of the grounds of assembly 1) and zinc ($Zn^{2+}$ average = 36th of the average registered on the level of the grounds of subset 1); this is the proof that these grounds are not contaminated yet by waste of domestic origin, as it is the case with soils of assembly 1.

Assembly 3 includes soils characterized by a relative abundance of magnesium, an alkaline earth ion. This explains their neutrality opposed to the respective soils of assemblies 1 and 2 which have acidic and very acidic pH. As soils of assembly 2, these soils are very well supplied with sands and poor in clays, factors that can explain the weakness of their mineral reserves. Indeed, there is in these soils very little clay to retain nutrients on the surface of the adsorbent complex when the sands, that are abundant, favor through leaching phenomena.

**Table 6.** Synthesis of some important results of PCA on variables.

| | Variable-factor correlations | | Square cosines ($cos^2$) | | Contributions | |
|---|---|---|---|---|---|---|
| Variables | Axis 1 | Axis 2 | Axis 1 | Axis 2 | Axis 1 | Axis 2 |
| Clay | -0.6682 | 0.5530 | 0.4465 | 0.7524 | 0.0568 | 0.0843 |
| Silt | -0.9233 | 0.1237 | 0.8525 | 0.8678 | 0.1085 | 0.0042 |
| Sand | 0.9474 | -0.2790 | 0.8976 | 0.9755 | 0.1143 | 0.0214 |
| pH | -0.4373 | -0.8744 | 0.1912 | 0.9559 | 0.0243 | 0.2107 |
| C | -0.9641 | 0.0239 | 0.9295 | 0.9301 | 0.1183 | 0.0001 |
| N | -0.9813 | 0.0266 | 0.9630 | 0.9637 | 0.1226 | 0.0001 |
| C/N | 0.5387 | 0.4055 | 0.2901 | 0.4547 | 0.0369 | 0.0453 |
| P | -0.2330 | -0.7875 | 0.0542 | 0.6744 | 0.0069 | 0.1709 |
| CEC | -0.8013 | 0.4546 | 0.6421 | 0.8488 | 0.0817 | 0.0569 |
| Ca | -0.5519 | -0.4043 | 0.3046 | 0.4681 | 0.0387 | 0.0450 |
| Mg | -0.4669 | -0.8406 | 0.2180 | 0.9246 | 0.0277 | 0.1947 |
| K | -0.0748 | -0.4843 | 0.0055 | 0.2401 | 0.0007 | 0.0646 |
| Na | -0.5737 | -0.4480 | 0.3292 | 0.5299 | 0.0419 | 0.0553 |
| Fe | -0.9390 | 0.3245 | 0.8818 | 0.9871 | 0.1122 | 0.0290 |
| Zn | -0.9198 | 0.2465 | 0.8461 | 0.9069 | 0.1077 | 0.0167 |

**Table 7.** Synthesis of some important results of PCA on individuals

| | Coordinates | | Square cosines ($cos^2$) | | Contributions | |
|---|---|---|---|---|---|---|
| Individuals | Axis 1 | Axis 2 | Axis 1 | Axis 2 | Axis 1 | Axis 2 |
| Com 1 | 0.6801 | -0.3892 | 0.0712 | 0.0233 | 0.6546 | 0.4640 |
| Com 2 | -0.8957 | -2.7127 | 0.0560 | 0.5137 | 1.1352 | 22.5383 |
| Lab 1 | -4.2410 | 1.8602 | 0.7629 | 0.1467 | 25.4487 | 10.5982 |
| Lab 2 | -5.0799 | 1.4921 | 0.8754 | 0.0755 | 36.5133 | 6.8186 |
| Taz 1 | 3.2575 | 2.1528 | 0.6285 | 0.2745 | 15.0141 | 14.1946 |
| Taz 2 | 3.4529 | 2.8118 | 0.5383 | 0.3569 | 16.8701 | 24.2145 |
| Cor 1 | 0.0927 | -1.5433 | 0.0015 | 0.4215 | 0.0121 | 7.2952 |
| Cor 2 | 0.2879 | -1.2890 | 0.0163 | 0.3284 | 0.1172 | 5.0893 |
| Lo 1 | 1.1854 | -1.3154 | 0.2225 | 0.2740 | 1.9881 | 5.2993 |
| Lo 2 | 1.2599 | -1.0671 | 0.3128 | 0.2244 | 2.2461 | 3.4877 |

**Functioning of vegetable soils of Daloa**

The calculated correlation matrices revealed significant correlations labeled at $p < 0.05$ between soil nutrients and soils fertility explanatory variables (CEC and soil texture). These correlations are: organic matter-texture, organic matter-CEC, metallic elements-texture and metallic elements-CEC.

Significant correlations with soil texture are generally positive with clay and silt and negative with sand. This reflects, firstly, the pedogenetic relationship between organic matter and soil mineral particles (clays, silts and sands) through the clay-humic complex; it is, on the other hand, the expression of the contribution of sand to the loss of nutrients through leaching phenomenon of the more superficial layers of the soil. However, the predominance of fine particles of sand and silt at the level of all of these soils is the sign that they are less filter relative to lands where sand and silt are predominantly coarse.

Positive significant correlations of organic matter and trace metals with CEC reflect the adsorption on the surface of the clay-humus complex major cations of soils ($Ca^{2+}$, $Mg^{2+}$, $K^{+}$, $Na^{+}$), but also iron ($Fe^{2+}$) and zinc ($Zn^{2+}$) which would play in studied soils a major role. It could therefore be expected in some of the studied soils iron toxicity and especially pollution induced by zinc as the rates of this metal trace element measured in soils of Labia site (0.265 to 0.272 $g.kg^{-1}$) tend ineluctably to 0.3 $g.kg^{-1}$, which is the maximum natural level of zinc in soils in general (Adriano, 2001). However, taking into account the researches of Fageria and al. (2002) where zinc critical concentrations in soils are between 0.1 and 0.25 $g.kg^{-1}$, soils of Labia site are already contaminated with zinc.

One and the other variables of soils consisting of organic matters and metallic trace elements being positively and significantly correlated with CEC are also correlated significantly and positively each other. This correlation evidenced by PCA indicates that much of

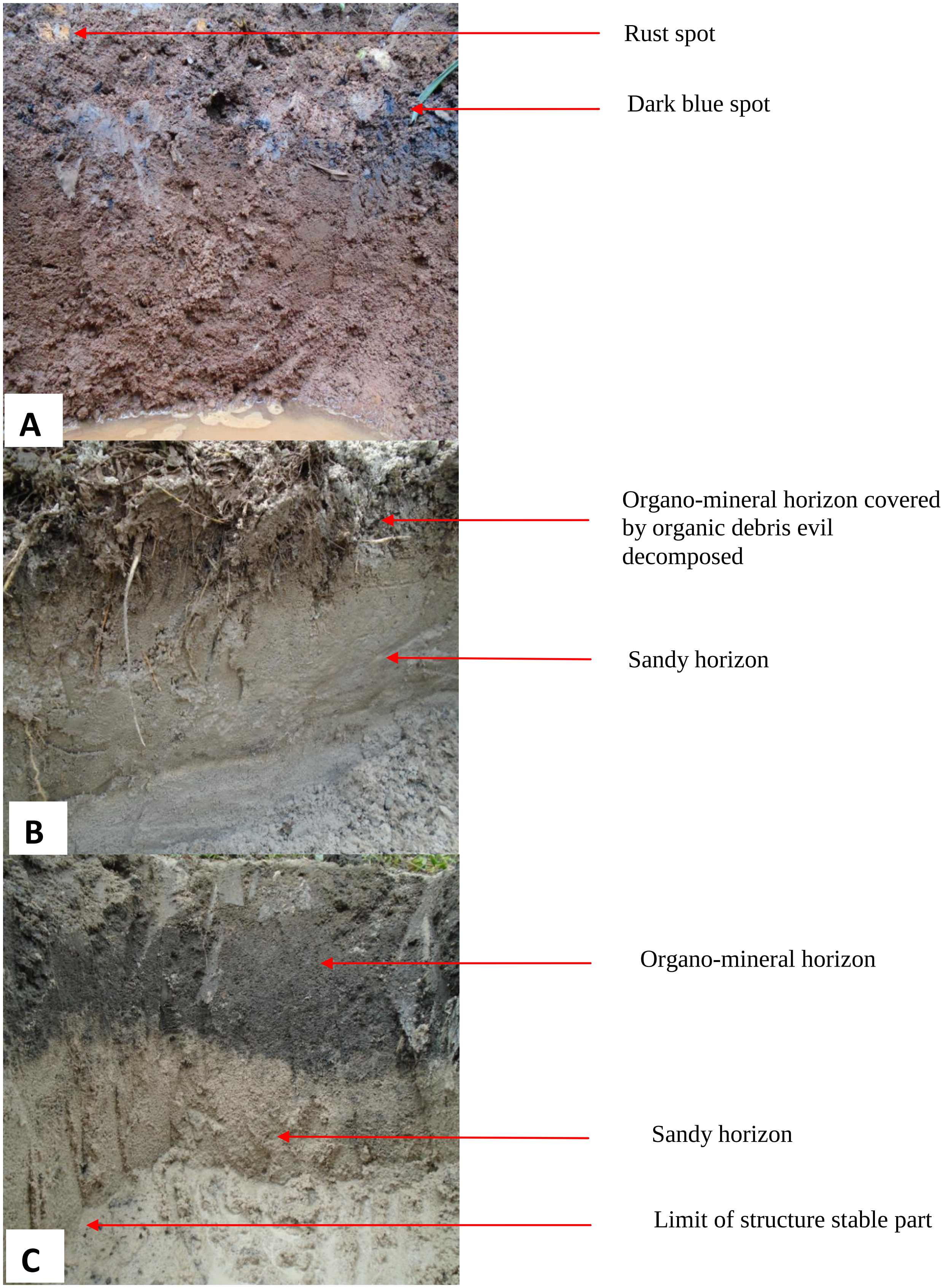



Figure 4. Soil profiles (A, B, C represent respectively soil of assemblies 1, 2 and 3).

the trace metal elements (iron and zinc) come from organic matter of soils and therefore from the domestic waste. Ondo (2011) had led in a study conducted on vegetable soils in Gabon (Libreville area) a similar comment that zinc and lead were linked to the organic fraction of soils. Indeed, these trace metals were characterized, as here, by a high correlation with organic matter. For iron, it is usually driven into lowlands by vertical transfers or by streaming and erosion (Diatta and al., 1998). It is naturally related to the mineral fraction of soils where it takes part in the constitution of secondary minerals like hematite, goethite, gibbsite and clay, particle with which it appeared here correlated positively.

PCA realized showed other positive correlations: correlations $Mg^{2+}$-pH and $Ca^{2+}$-$Na^{+}$. These correlations confirm, respectively, the role of neutralization of the acidity of grounds by $Mg^{2+}$ (alkaline-earth ion) announced to the level of grounds of assembly 3 and the adsorption of $Ca^{2+}$ and $Na^{+}$ on the surface of the argilo-humic complex.

## CONCLUSION

At the end of this study, it appears that the studied soils correspond to three subsets of soils fertility. These soils are sandy and sandy clay loam. Their sand and silt fractions which are generally fine make them less filtering; these soils therefore have a predisposition to retain soil nutrients. However, the conditions of extreme acidity in some of these soils could make their minerals unavailable to crops. When these soils are not very poor or poor in organic matter, they are impregnated with organic material of domestic origin. These garbage contain often metal elements, iron and zinc in particular, found therefore in soils where they play a key role on the clay-humic complex. This last point of the diagnosis of the functioning of studied soils is particularly disturbing in so far as trace metals of soils induce toxicity in soils to similar thresholds to what was observed at the levels of iron and zinc measured in Labia soils. These soils characterized by a balanced texture, a pH not very acid and higher rates of organic matters and higher CEC are most fertile.

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