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Differenciation Of Soil Fertility Status By Factorial Discriminant Analysis

Application On The Ferralsol Of The Malagasy Central Highlands

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***Abstract*—Forty-five soil profiles distributed on 16 observation sites and on four reference areas within the Malagasy central highlands, were identified to differentiate the fertility status of the soils cultivated on the tanety (or hill slopes). The used methodological approach was based on multidimensional statistical methods including the factorial discriminant analysis (FDA), coupled with the comparative analysis of the profiles across the site. Despite the similar characteristics of the physical and chemical properties of the studied soils, the factorial discriminant analysis allows the identification of three decisive parameters to differentiate the fertility status: exchangeable K, pH_{KCl}, Base saturation rate. The results of the comparative analysis of the profiles across the site can confirm the negative effects of the traditional fallow system on the soil fertility status. It was thus highlighted that rainfed culture laid fallow show the most deteriorated fertility status. Thus, contrary to what farmers expected, fallow plots of rainfed do not contribute to the restoration of the chemical soil fertility, it accentuates its deterioration. In the traditional cropping system, it is thus preferable to let the rainfed plots crop than leave them fallow. The fertility status of the plots under crops is better than that of those fallows. It was confirmed that the regular intake of organic and mineral fertilizers has significantly positive impacts on the maintenance and upkeep of the tanety soil fertility**

Keywords— ferralsols, tanety, traditional fallow, physico-chemical characteristics,statistical analysis, comparative analysis

I. INTRODUCTION

The central highlands are the most populated areas of Madagascar. Indeed, approximately 25% of the Malagasy population are settled in this area, which represents only 10% of the total area of the country. This demographic pressure results in heavy exploitation of the farmland. Following the example of the Antananarivo region (Analamanga and Itasy), just over a third (38%) of the cultivable area is exploited in 2001 [1]. The most fertile soils of the alluvial plains and those of the narrow bottom lands are overexploited and are no longer enough to meet the growing demand for food. People are thus forced to develop the hillsides or « tanety ».

The soil cover of the tanety is dominated by ferralsols with low content of exchangeable elements and total mineral reserves [2]. The results of experiments carried out by the Institute of Agricultural Research of Madagascar or IRAM showed that for intensive exploitation, it was necessary first of all to apply a recovery or background fertilizer on all these soils [3]. Yet, in the traditional system of cultivation, the plots of rainfed tanety are not a priority and fertilization are neglected. Only fallow is so far the most practiced ways by farmers to try to raise the fertility level of cultivated soils. The traditional fallow system is to let the plots lie during an unspecified period without making any input or performing specific maintenance.

The objective of our survey is to differentiate the status of the soil fertility according to use type in evaluating the efficiency of the traditional fallow system in restoring the tanety soil. The approach chosen was that of a soil inventory through the comparative study of soil profiles in reference areas. Some statistical methods were favored in the data analysis in order not only to determine the essential physical and chemical properties of the surveyed soils,but to assess the intensity of the relations between the different chemical or physical soil parameters , as explanatory variables, and their types of uses as qualitative variables. The goal of the statistical analysis is thus to identify the most discriminant pedophysical and pedochemical explanatory variables in relation to the determined classes of soil use.

Figure 1 below shows the spatial distribution of ferralitic soils in Madagascar as well as the location of four prospected reference sites

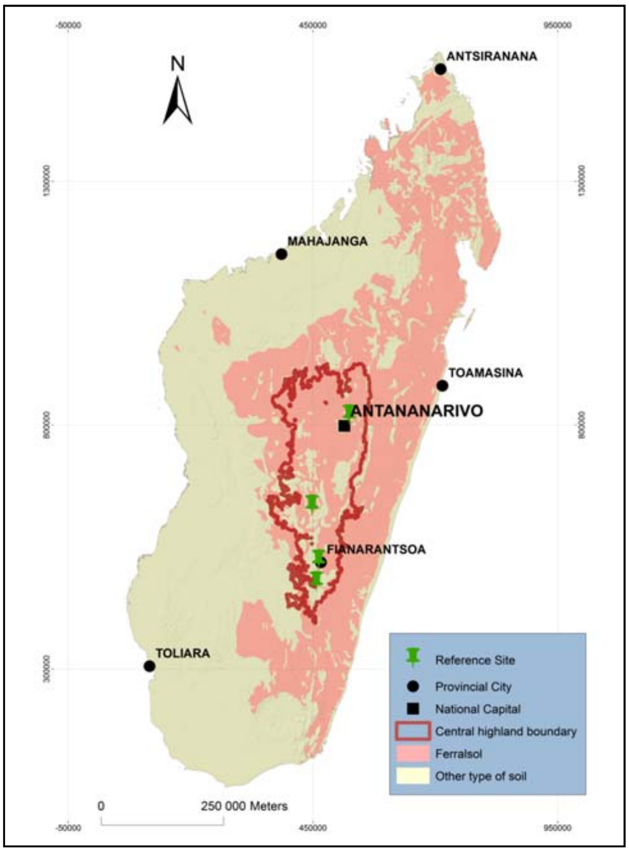

Fig. 1. Distribution of ferralsols in Madagascar

II. METHODOLOGY

2.1 Observation sites

The choice of the study area included areas with potential to nearest climatic, geomorphological and geological origin of a representative and homogeneous soil cover. The observation sites are well spread over four reference areas that are located between the cities of Ambalavao (South) and Antananarivo (North). Of tropical altitude type the regional climate is characterized by the existence of two very contrasting seasons: a season of hot shower from 6 to 7 months and a cooler dry season of 5 to 6 months. The average annual rainfall ranges from 1200 and 1500mm [4]. The geomorphological context of Malagasy highlands consists of a mountainous central plateau, from 800m to over 2700m above sea level. This region is characterized by the extending of hill reliefs derived from ancient cycles of erosion. Cristalline rocks of Precambrian age, among which the strongly 'lateritized 'gneiss is present in the low-lying areas, whereas the granites and composite gneisses constitute the elevated hills. All observation sites are located on gentle slopes (less than 10 %), wide or narrow convex hills, and belonging to the rejuvenation forms derived from the flattening of the Tertiary period.

Depending on the degree of development of the soil, an observation site includes 2 to 4 soil profiles. To minimize the differentiating factors and consider only the anthropogenic factors as source of transformation of the upper part of the soil, the homogeneity of the soil cover at each observation site was verified by comparing the appearance depth of F horizon, its thickness, color, texture. A total of 45 profiles spread over 16 observation sites were selected and studied:

- 17 profiles under natural grassland formed with grassy savanna;
- 06 profiles under rainfed cultures;
- 12 profiles of fallow rainfed culture plots;
- 05 profiles under eucalyptus plantations;
- 05 profiles under viticulture.

2.2 Physico-chemical analysis of soils

The 174 samples from 45 soil profiles mentioned above were analyzed at the Central Laboratory of FOFIFA (National Research Center for Rural Development). The methods recommended for the analysis of chemical and physical characteristics are briefly described below:

- The grain-size distribution in three fractions (Clay, Silt, Sand) was determined using the Robinson pipette method based on Stokes law;
- The measurement of pH was carried out at the laboratory using an electronic pH-meter, using distilled water for pH_{water} and normal solution of potassium chloride for the pH_{KCl}. The soil suspension: solution is 1/2.5;
- Total carbon was determined by the Walkey-Black method. The oxidation was carried out by a wet method using a mixture of potassium dichromate and sulfuric acid. The 1.72 multiplier was adopted to estimate the total organic matter from the total carbon content;
- The total nitrogen content was determined according to the Kjeldahl method, of which sulfuric acid is the main normal solution used during mineralization;
- The extractable phosphorus was assayed according to the Bray II method. The extraction reagent used is a mixture of 0,03N ammonium fluoride and 0,1N hydrochloric acid;
- The exchange acidity (Al^{+++} and H^{+}) was assayed according to the method proposed by Espiau and Peyronel [5] which recommends the normal solution of potassium chloride. The acidity of exchange $Al + H = \frac{(\mathrm{Al+H})}{\mathrm{CEC\ effective}} \mathrm{x}100$ corresponds to the rate of desaturation, while the Aluminium Saturation Rate or (Al $(\%) = \frac{\mathrm{Al}}{\mathrm{CEC\ effective}} \mathrm{x}100$;
- The Cation Exchange Capacity (CEC) was determined as per the Metson method whose exchange solution is the normal ammonium acetate;
- The exchangeable cations (Ca^{++}, Mg^{++}, K^{+} and Na^{+}) were assayed in the resulting solution to determine the CEC;
- The Effective Cation Exchange Capacity (ECEC) is the sum of the values of the sums of exchangeable cations and exchangeable acidity.

2.3 Data Analysis

2.3.1 Factorial Discriminant Analysis

The Factorial Discriminant Analysis or FDA is a multidimensional descriptive statistical method. It takes place in two steps: first, discrimination is the creation of factors or discriminant functions, linear combinations of the explanatory variables that separate maximum classes of typology to explain; then classification is to recognize the class of each individual from its position in the space of above functions [6] [7]. FDA reduces to a principal component analysis or PCA, performed on all of the centers of gravity of the individuals of the same class, each class corresponds to one of the k modalities of the original qualitative variable

[8]. Implemented using the XLSTAT software, FDA provides the ability to visualize the observations in a space of two or three dimensions so as to graphically distinguish homogeneous groups of observations. The graphical representation is considered optimal, particularly if reliable percentages of variability associated with the axes of the representation space, is sufficiently high, more than 80%. Using XLSTAT thus allows the performing of the Wilks Lambda test automatically. This is to verify if the vectors of the averages for the different « soil uses » modalities are equal or not. Then, the implementation of the FDA using the XLSTAT enables to establish the confusion matrix presenting the overall percentage of well classified or «correct %» observations. In other words, it provides the opportunity to assess the risk of confusion between the different modalities of an estimation sample when classifying a priori and a posteriori.

2.3.2 Comparative Method of profiles across the site

The purpose of this method is to specify the importance and perceived differences existing between the levels of fertility of the soils studied. To do this, the profile under grassy savanna is considered as « control sample » for the set of 2 to 4 soil profiles that constitute an observation site. For each pedochemical indicator, the difference expressed in percentage relative to the control value determines the importance of the negative (regressive) or positive (progressive) evolution of the chemical changes related to land use. For an overview by type of land use, the mean values of the negative or positive evolution of the pedochemical indicators were computed.

III. RESULTS

3.1 Morphology of profiles

The first factor taken into account is color; it helps to distinguish the red horizon profiles from the profiles formed by yellow horizons. If dry, red soils are characterized by shades ranging from 2,5YR to 10R. The shades range from 7,5YR to 10YR for dry yellow soils. The lightness values are between 3 and 6 for the three horizons A, F and C. Compared to those of the underlying mineral horizons, the values of the purity of the topsoil are lower, between 3 and 4 against 6 to 8 for the lower horizons.

- The second factor taken into account refers to the differentiation of the horizons of the soil profile. On the depth of 100 to 150cm, the profile consists of a succession of horizons A, F and C:
- The A topsoil, is characterized by fine to medium lumpy structures, which may be related to biological activity (roots and invertebrate fauna). The aggregates are more or less fragile and inconsistent. The development of these structures and rooting gives a good porosity to this horizon. For non-crop profiles, the transition with the F horizon is distinct;
- The F horizon is very compact, the structure is continuous, very coherent and very little fragile. This horizon is a real barrier to good root development. Hence the weakness of the rooting density. Compared to the Ah horizon, it contains more clay and is stickier. The biological activity is much reduced during observations. Macroporosity is essentially biological (tubules). Some shrinkage cracks are sometimes observed. The transition to the underlying horizon is done in a progressive manner.
  The alteration horizon has no clear structure. It is not compact, and even loose and fragile. The horizon is siltier and slightly sticky. The biological activity is almost absent. Living roots are rare, only a few roots of medium to large size are present.
- The third factor taken into account is the depth of occurrence of the lower limit of the horizons: for humus surface horizons (Ah), almost all the recorded values are significantly below the bar of 20cm.
- For the control profiles, under grassy savanna, the average depth of occurrence of the lower limit of the Ah horizon is 11.4cm against 13.4cm for that of Ap horizon of the cultivated soils. The depths of greater than 20cm lower limit are only observed on the profiles of vineyard soils, surely due to the deep plowing of these plots. For all the soils studied, the average occurrence depth of the F horizon lower limit is 114. 2cm.

3.2 Physical and chemical characterization of the horizons studied

3.2.1 Grain size distribution

The medium texture of the studied soils is characteristic of typical profiles of ferralsols located on gentle slopes of broad or narrow hills derived from ancient erosion cycles of the central highlands. Indeed, with an average clay content of 310g.kg-1, associated with 490g.kg-1 sand and 200g.kg-1 silt, the texture of soils studied is roughly sandy clay.

The topsoil surface contains more sand than the two underlying horizons. The texture is sandy loam to sandy clay. As for F horizon, it is in the class of sandy clay to clay texture. The C horizon samples are more or less dispersed within the textural diagram; but if we look only at the average contents of the three grain size fractions, C horizon belongs to the group of silty clay texture.

3.2.2 Soil acidity

pH_{water} values vary between 4,2 and 5,9 with a mean of 5,0. As for pH_{KC1}, the measured values are between 4,1 and 6,5 with a mean of 4,9. Referring to the classification proposed in the soil frame of reference of 1995, the soils studied belong to the «acid to low-acid » soil group. The average values of the two types of pH measurement slightly increase with depth. In pH_{water}, the averages are respectively about 4,9 for Ah, 5,0 for F and 5,2 for C.

The differences between the pH_{water} and the pH_{KC1} vary between -1,3 and +1,0. Some samples display a negative delta pH, characteristic of soils particularly rich in iron oxide such as ferritic ferralitic of New Caledonia [9]or Brazilian ferralsols [10].

The Al toxicity threshold is reached when Al (%) ≥ 30% [11]. The average values of Al saturation or Al% recorded are well below the toxicity threshold for the three types of horizons studied. The average value of Al% is 25,23% for Ah horizons, 21,78% for F horizons and 13,30% for C horizons.

3.2.3 Total organic matter and Total nitrogen

As expected, the organic matter and the nitrogen concentrate in the humic horizon. The average content of total organic matter is 28,68 $g.kg^{-1}$ in the topsoil, 13,16 $g.kg^{-1}$ in F horizon, and 3,83 $g.kg^{-1}$ in C horizon. This average content of organic matter in the topsoil is considered within the range observed for the Oxisols and Ultisols of « Soil taxonomy of USDA » values (on average 20.,7 $g.kg^{-1}$) [12]

For total nitrogen, humic surface horizons record an average value of 1,25 $g.kg^{-1}$ against 0,66 g. kg-1 for F-1 and 0,31 g.kg for C. Thus, the humic horizons of the soils studied generally have low levels of total nitrogen compared to ferralsol values of Africa or Brazil [13]

3.2.4 Bray extractable Phosphorus (P)

With few exceptions, the measured concentrations are well below 10 mg.kg-1. Out of all the samples analyzed, the average value is 3,40 $mg.kg^{-1}$. Thus, the values recorded are considered low to medium [13]. The average value is 5.24 $mg.kg^{-1}$ in Ah or Ap horizon, 2,40 $mg.kg^{-1}$ in F horizon and 2,33 mg. kg^{-1} in C horizon.

3.2.5 Exchange complex and minerals

The average values of the cation exchange capacity are well below the bar of 5 $cmol.kg^{-1}$: 4,6$cmol.kg^{-1}$ in the Ah horizons; 2,9 $cmol.kg^{-1}$ in F horizons and 3,2 $cmol.kg^{-1}$ in C horizons.

The analytical results achieved also confirm the low concentrations in exchangeable cations of the ferralsols studied: the average values of the total of exchangeable, TEB, are below 3 $cmol.kg^{-1}$, the average value is 1,97$cmol.kg^{-1}$ for Ah horizons, 0,02 $cmol.kg^{-1}$ for F and C horizons. The averages of base saturation rates do not exceed 50% for the three horizon types.

Compared to the humus surface horizon, the F horizon is significantly depleted of exchangeable bases. Indeed, the average value of the Ah TEB is twice higher than that of F. In contrast, we detected a slight increase of the average content of the TEB at the C horizon level. The slight enrichment in exchangeable bases in the C horizon is due to the presence of some alterable minerals. These alterable minerals are the main source of exchangeable cations of these soils. But given the high degree of alteration of the original material, concentrations of exchangeable bases of mineral origin are very low.

Calcium widely dominates the absorbant complex cation pad of the three horizon types analyzed. It makes about 34 to 48% of the effective cation exchange capacity of the absorbent complex. Furthermore, we find that the share of exchangeable magnesium is significant since it takes up on average 19 to 23% of the cationic pad. While the proportions of potassium and sodium are low, even negligible. On average, the exchangeable potassium would represent but between 4 and 8% and the exchangeable sodium between 10 and 11% of the effective cation exchange capacity.

The average values of the chemical and physical variables of the analyzed horizons are recorded in Table 1 below.

TABLE 1. Mean values of chemical and physical variables of the 03 analyzed horizons

	A (N = 60)	F (N = 86)	C (N=28)
pH_{eau}	4,9 ± 0,3	5,0 ± 0,4	5,2± 0,4
pH_{KCl}	4,7 ± 0,4	5.0 ± 0,5	5,5 ± 0,6
C (g.kg^{-1})	16,56 ± 5,99	7,60± 4,88	2,21 ± 1,56
MO (g.kg^{-1})	28,68 ± 10,38	13,16± 8,44	3,83 ± 2,71
N (g.kg^{-1})	1,25 ± 0,44	0,66 ± 0,34	0,31± 0,11
P (mg.kg^{-1})	5,24 ± 5,60	2,40 ± 2,62	2,33 ± 2,86
Al^{3+} (cmol.kg^{-1})	0,48 ± 0,37	0,00 ± 0,00	0,00 ± 0,00
H^{+} (cmol.kg^{-1})	0,31 ± 0,49	0,00 ± 0,00	0,00 ± 0,00
Ca^{++} (cmol.kg^{-1})	0,99 ± 1,18	0,01 ± 0,00	0,01 ± 0,01
Mg^{++} (cmol.kg^{-1})	0,63 ± 0,37	0,00 ± 0,00	0,00 ± 0,00
K^{+} (cmol.kg^{-1})	0,22 ± 0,21	0,00 ± 0,00	0,00 ± 0,00
Na^{+} (cmol.kg^{-1})	0,08 ± 0,06	0,00 ± 0,00	0,00 ± 0,00
TEB (cmol.kg^{-1})	1,97 ± 1,58	0,02± 0,01	0,02 ± 0,01
ECEC (cmol.kg^{-1})	2,59 ± 1,42	0,02 ± 0,01	0,02 ± 0,01
CEC (cmol.kg^{-1})	4,61 ± 1,51	2,90 ± 1,31	3,23 ± 1,90
Al % (%)	25,23 ± 23,98	21,78 ± 22,08	13,30 ± 17,70
Al+H(%)	31,70 ± 24,59	32,40 ± 25,78	19,05 ± 20,88
V (%)	41,57 ± 24,08	39,48 ± 23,65	48,04 ± 22,19
Silt (g.kg^{-1})	187 ± 67	186 ± 82	234 ± 79
Clay (g.kg^{-1})	262 ± 80	358 ± 93	266 ± 108
Sand (g.kg^{-1})	543 ± 87	455 ± 76	499 ± 113

3.3 Differentiation of types of soil uses by FDA based on the physical and chemical properties of the humus surface horizon

This is an analysis of the correlation between the discrimination factors and the initial pedochemical variables. The purpose of the analysis is to test if the 20 pedophysical and pedochemical variables used allow to differentiate the 45 individuals of humus horizons by type of soil use. First of all, the eigenvalues associated with different factors, as well as the percentages and the cumulative discrimination corresponding percentages are shown in Table 2.

TABLE 2. Eigenvalues associated to the factors and corresponding percentage of Discrimination

	F1	**F2**	**F3**	**F4**
Eigenvalue	2,245	0,957	0,771	0,428
Discrimination (%)	51,005	21,740	17,522	9,732
Cumulative %	51,005	72,745	90,268	100,000

With a discrimination rate of 51%, the first factor here seems the most decisive in the differentiation of soil individuals. Furthermore, the sum of the discrimination percentages of F1 and F2 gives the highest and the closest value (72,7%) to that considered as optimal threshold (80%) in the interpretation of the graphical representation results. So F1 and F2 are the most appropriate factors to differentiate graphically the different forms of soil use. However, this slight decrease in cumulative percentages of discrimination of F1 and F2 has a negative impact on the readability of the graph in the differentiation of soil individuals. It should be noted that 17,5% of the variability are associated to F3 factor and 9,7% related to F4 factor.

Table 3 shows the calculation results of the correlations between the coordinates of observations in the initial variable space and in the discriminant factor space.

TABLE 3. Correlations Variables/Factors

	F1	F2	F3	F4
pH(eau)	0.244	0.012	0.490	-0.109
pH(KCl)	**0.550**	0.107	**0.514**	-0.136
C	-0.399	-0.268	0.106	**-0.652**
N	-0.189	-0.214	0.044	-0.383
P	0.454	0.097	-0.046	0.037
Al	-0.328	-0.294	-0.160	0.424
H	0.157	0.027	-0.044	0.246
Ca	0.238	-0.264	0.432	-0.220
Mg	0.250	-0.169	0.493	-0.184
K	**0.639**	0.129	0.490	-0.189
Na	-0.149	0.083	0.156	-0.297
Silt	0.328	-0.282	0.021	-0.245
Clay	0.068	0.007	0.143	0.355
Sand	-0.293	0.198	-0.135	-0.121
CEC	-0.114	-0.220	0.362	-0.222
TEB	0.315	-0.215	**0.508**	-0.243
V	**0.516**	0.011	0.411	-0.193
ECEC	0.267	-0.370	0.448	-0.158
Al%	-0.326	-0.177	-0.152	0.444
Al+H	-0.295	-0.272	-0.363	0.314

Analysis of the correlation values reported in Table 3 distinguishes the following five variables to differentiate the soils studied by type of use: K exchangeable, pHKCl, Base Saturation rate or V,

Bray extractable P, and Total Carbon. They are characerized by significantly higher levels of correlation in absolute value, with the main components F1 and F2. This first group of variables is thus more sensitive to changes in the type of soil use and can therefore be a relevant indicator for assessing soil fertility status. These five explanatory variables positioning closer to the correlation circle radius and forming smaller angles with the F1 et F2 axes. But given the importance of the discrimination rate of F1 factor (explaining 51% of the variability), exchangeable K, pH_{KCl}, base saturation rates or V are considered in this case as the most discriminant. On the other hand, the following variables are located in the immediate vicinity of the circle centre: pHwater, N, exchangeable (Na, H), clay. Their correlation rates with the two factors F1 and F2 are thus lower. This second group of variables does not significantly evaluate differences between the types of uses; their mean values are more or less homogeneous whatever the type of soil use.

Finally; the exchangeable (Ca, Mg, Al), the TEB, Al%, Al+H, the CEC, as well as the variables Silt and Sand are an intermediate group between the first two.

Figure 2 shows the graphical result of the correlations between variables and the first two factors F1 and F2. On Figure 3 graph, the individuals are shown according to the factorial axes F1 and F2. Indeed, all the confidence ellipses overlap in the central area of the diagram.

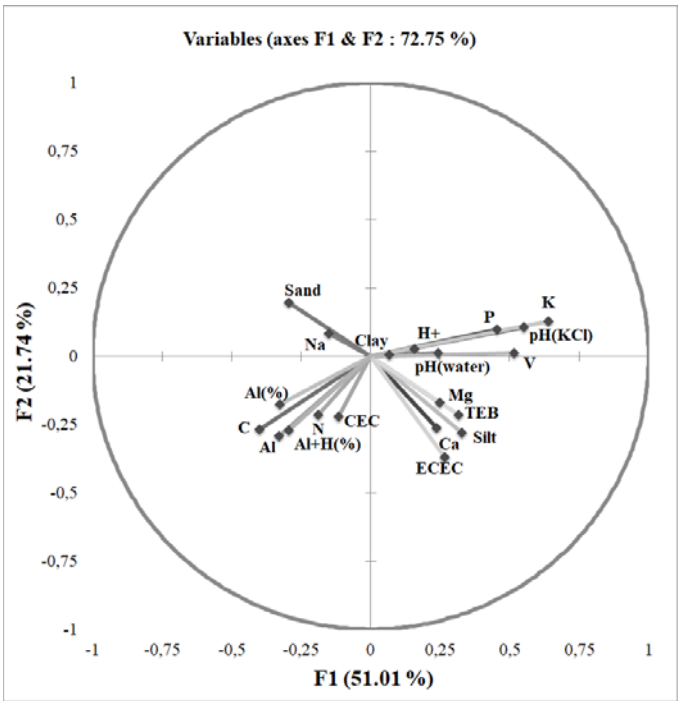

Fig. 2. Correlation between variables and factors (F1 and F2)

Factorial Discriminant Analysis or FDA of pedophysical and pedochemical is showed in figure 3. The confidence ellipse of the soils under grassy savanna and that of the fallow rainfed soils overlap almost completely. Only barycenter distinguishes samples on the graph according to land use. The Wilks' Lambda test is used to confirm the existence of significant differences between the vectors. In other words, the difference between the barycenter of these five groups of soil individuals is significant

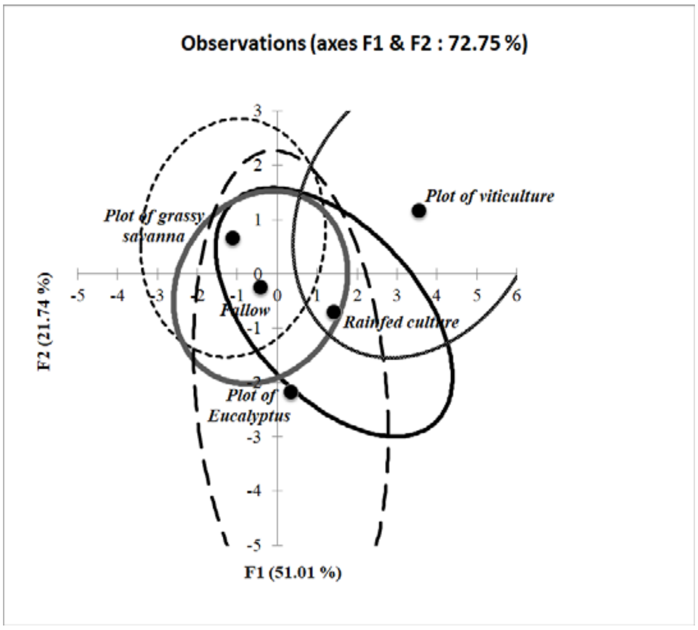

Fig. 3. Factorial Discriminant Analysis or FDA of pedophysical and pedochemical variables (barycenter and confidence ellipses)

Table4 shows the confusion matrix when classifying à priori and à posteriori the studied samples. Confusion risk during the differentiation of one land use category to another category ranges from 41% to 66,7%.

TABLE 4. Confusion Matrix for the results of the crossed validation: A priori and à posteriori classification of humus horizon samples according to soil use

From \ To	**Grassy savanna**	**Rainfed Culture**	**Fallow**	**Eucalyptus**	**Viticulture**	**Total**	**Correct %**
Grassy savanna	13	0	8	0	1	22	**59,09%**
Rainfed Culture	0	3	3	0	0	6	**50,00%**
Fallow	7	2	8	0	1	18	**44,44%**
Eucalyptus	2	0	2	2	0	6	**33,33%**
Viticulture	0	1	1	1	3	6	**50,00%**
Total	***22***	***6***	***22***	***3***	***5***	***58***	**50,00%**

It is the classification of the plots under Eucalyptus that increases confusion because, out of the six profiles under eucalyptus studied, two profiles merge with the profiles under grassy savanna and other two have similar results to profiles of fallow crops plots. Then, it is observed that, the fallow crop plots are the second modality of land use that is causing problems in differentiation. Out of the 18 fallow profiles, 7 profiles were treated as profiles under grassy savanna, two profiles were considered as plots under rainfed cultures and 1 profile merges with the profiles under viticulture.All this suggests the limits of statistical analysis in the differentiation of the tanety lateritic soils whose fertility levels are not only low, but the absolute values are quite close to each other. For all observations, the total of « % correct » is only 50%.

Table 5 shows the mean values of chemical and physical variables of Ah according to the type of soil use.

TABLE 5. Mean Values of chemical and physical variables of Ah by type of soil use

	Grassy savanna (N = 17)	**Rainfed culture** (N = 6)	**Fallow** (N=12)	**Eucalyptus** (N = 5)	**Viticulture** (N= 5)
pH_{eau}	4,9 ± 0,3	4,7 ± 0,2	4,7 ± 0,3	5,1 ± 0,4	5,1 ± 0,4
pH_{KCl}	4,6 ± 0,2	4,5 ± 0,1	4,6 ± 0,4	4,9 ± 0,5	5,3 ± 0,3
C (g.kg^{-1})	20,81 ± 3,89	18,48 ± 4,28	16,91 ± 3,43	23,36 ± 6,17	10,48 ± 3,17
MO (g.kg^{-1})	36,05 ± 6,74	32,01± 8,33	29,29 ± 5,93	40,46 ± 10,69	18,15 ± 5,50
N (g.kg^{-1})	1,45 ± 0,46	1,42 ± 0,26	1,32 ± 0,27	1,64 ± 0,04	0,98 ± 0,45
P (mg.kg^{-1})	4,53 ± 2,96	7,23 ± 4,54	5,46 ± 3,66	5,28 ± 4,01	12,86 ± 13,34
Al^{3+} (cmol.kg^{-1})	0,39 ± 0,27	0,52 ± 0,29	0,48 ± 0,33	0,46 ± 0,59	0,07 ± 0,02
H^{+} (cmol.kg^{-1})	0,27 ± 0,41	0,30 ± 0,23	0,49 ± 0,56	0,27 ± 0,27	0,60 ± 1,05
Ca^{++} (cmol.kg^{-1})	0,93 ± 0,52	0,84 ± 0,34	0,85 ± 0,62	2,68 ± 3,07	1,80 ± 0,65
Mg^{++} (cmol.kg^{-1})	0,68 ± 0,36	0,48 ± 0,17	0,66 ± 0,33	0,93 ± 0,45	0,91 ± 0,24
K^{+} (cmol.kg^{-1})	0,18 ± 0,11	0,18 ± 0,12	0,17 ± 0,17	0,35 ± 0,20	0,63 ± 0,32
Na^{+} (cmol.kg^{-1})	0,11 ± 0,09	0,08 ± 0,03	0,07 ± 0,03	0,09 ± 0,05	0,08 ± 0,02
TEB (cmol.kg^{-1})	1,92 ± 0,90	1,59 ± 0,58	1,91 ± 0,92	4,06 ± 3,60	3,42 ± 1,19
ECEC (cmol.kg^{-1})	2,44 ± 0,85	2,36 ± 0,44	2,55 ± 0,83	4,74 ± 3,22	3,56 ± 1,15
CEC (cmol.kg^{-1})	5,19 ± 1,50	4,36 ± 1,01	4,54 ± 1,09	6,50 ± 1,84	4,42 ± 1,501
Al% (%)	20,01 ± 19,41	24,15 ± 14,53	24,68 ± 23,01	20,06 ± 32,15	2,42 ± 1,48
Al+H (%)	25,23 ± 20,00	34,62 ± 12,47	35,68 ± 25,16	26,72 ± 31,70	4,72 ± 2,35
V (%)	38,11 ± 17,31	39,44 ± 18,80	39,79 ± 24,34	55,60 ± 34,79	77,62 ± 6,94
Silt (g.kg^{-1})	190 ± 66	185 ± 91	189 ± 59	242 ± 54	220 ± 45
Clay (g.kg^{-1})	230 ± 50	193 ± 88	255 ± 52	238 ± 54	274 ± 83
Sand (g.kg^{-1})	570 ± 94	548± 29	555 ± 71	520 ± 72	506 ± 52

3.4 Comparative analysis of some pedochemical indicators across observation sites

With a view to a rational management of the chemical fertility of the soil, it is necessary to have relevant and precise information on the importance of the modifications of the physico-chemical characteristics of the soil according to the type of use recommended by farmers. The purpose of this analysis thus consists in evaluating the importance of the correlations which exist between the pedochemical parameters and the types of land use. The aim is to determine for each type of land use the most relevant pedochemical indicators of the state of soil fertility. Consequently, a better knowledge of the impacts of soil use on its chemical state makes it possible to better identify the problem relating to the improvement and maintenance of the chemical fertility of cultivated soils.

In this analysis, profiles under natural grassland (savannah) and never cultivated are considered as control sites. The analysis is limited to the pedochemical parameters of the surface humus horizon insofar as it constitutes the most dynamic horizon in terms of chemical evolution. The pedochemical characteristics of the cultivated profiles were thus compared with those of the control profiles in order to assess the importance of the changes caused by the uses of the soil on the state of soil fertility. Indeed, for each pedochemical parameter, the "calculated difference" between the average value of the control profiles and that of the cultivated profiles is expressed as a percentage (mean value of the controls taken as a reference).

3.4.1 Soil acidity

Only the plots subject to viticulture show increased pH. For all observation sites, the change rate of registered pH_{KCl} range from (-16% or 0,16 units) and (+28% or + 0,28 units).

The plots of fallow crops experience the highest average rate of negative development. Indeed, the average value of the negative development of pH_{KCl} is about -6% for fallow plots against -3% for plots under rainfed culture and -1% for plots of eucalyptus afforestation.

Figure 4 shows the importance of the average change in the acidity of exchange. It was confirmed by the negative impacts of traditional modes of land use on the fertility status of ferralsols on tanety. Indeed, among the four groups of soils studied only soils under viticulture have an average rate of negative development (-17%) compared to the control sample.

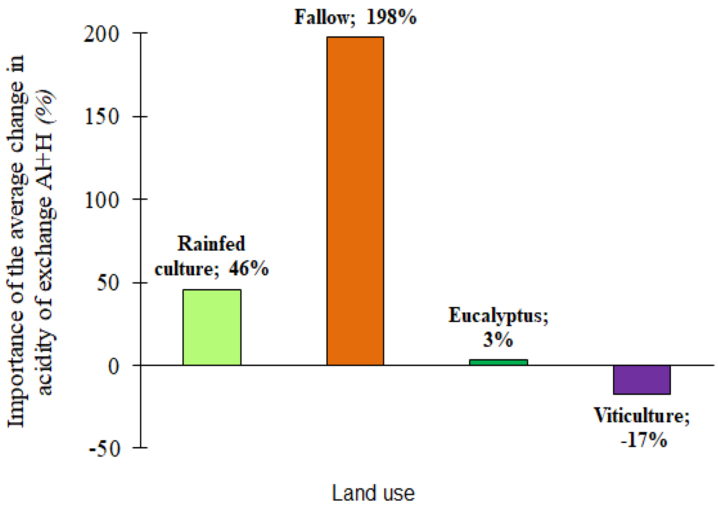

Fig. 4. Importance of the average change in acidity of exchange Al+H *(expressed in %)*

The acidification process is more or less controlled for plots in wine cultures through regular contributions from organo-mineral fertilizers. Fallow agricultural plots increases soil acidification. Indeed, the importances of the average change in the acidity exchange reaches +198%. Almost all plots of rainfed fallow show a positive change of Al+H well over 100 %. It seems that cultivation helps mitigate acidification insofar plots under rainfed records only an average rate of 46% positive development. Besides, the eucalyptus afforestations record only an average increase of +3%.

3.4.2. The total organic matter

In general, the cultivation causes a decrease in the content of soil organic matter: five grown of 23 studied profiles show a positive change. However, under rainfed plots are marked by an average rate of positive change (Figure 5). Among the five types of land use studied viticulture seems to affect much the organic status of the soil. On average, the vineyard parcels are characterized by an average rate of negative change in the order of -24%. Plots under fallow cultivation and eucalyptus afforestation displayed -19% and -15% respectively. The study by Razafindramanana team on the Malagasy Highlands in the Upper-Matsiatra Region showed that compared to the grassy savanna considered as control sample the C stocks of plantations and crops soils show a decrease.

Indeed, on a layer of 0-40 cm, the decrease is about 19% for temporary rainfed culture and up to 27% for eucalyptus. In soils of plots under afforestation, mineralization of soil organic stocks is favored by the presence of mycorrhizae that live in symbiosis with tree roots [14]. The mineralization of organic matter is activated on an uncovered ground and exposed to rain. The destruction of aggregates leads to a « deprotection » of the organic matter and a carbon loss by erosion due to the low soil cover [15].

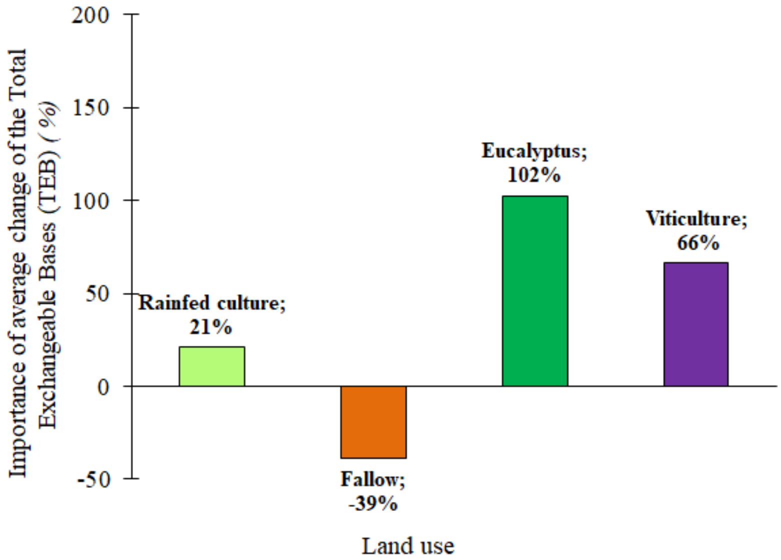

Fig. 5. Importance of the average change of the organic matter *(expressed in %)*

3.4.3. The status of the exchange complex: ECEC and TEB

Figure 6 illustrates the negative impact of the traditional fallow on the effective cation exchange capacity of the soils. Indeed, the importance of the average change of the ECEC fallow plots is -27 %. Almost all parcels of fallow crops recorded a negative rate change with values ranging between

-60% and -10%.

However, under rainfed profiles show some improvement in the CECE; the evolutionary rates vary between -12% and +70% with an average of 22%. Compared to the three other types of use, reforestation with eucalyptus seems most favorable to the improvement of the effective cation exchange capacity. For the reforestation sites studied, the evolution of the CECE rates is between 4% and + 500% with an average of 128% +. Profiles in vineyard cultures also show a clear improvement in the ability of effective cation exchange with an average of 59% The rates there range from -1% to 173%.

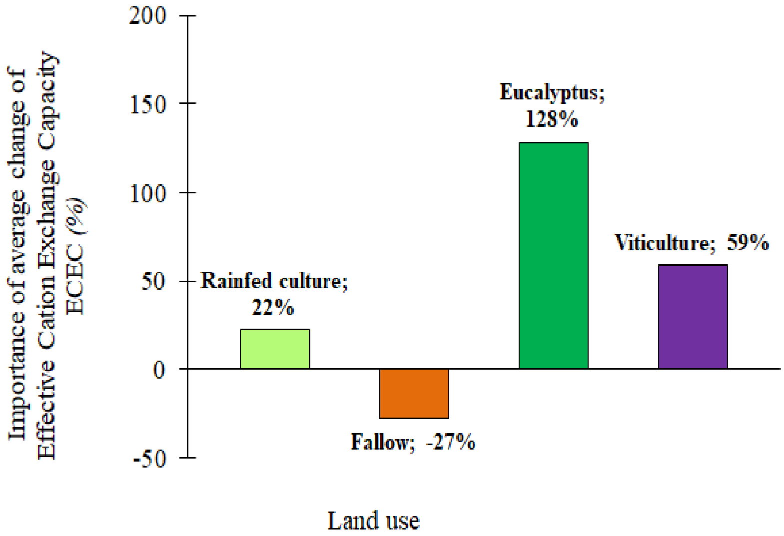

Fig. 6. Importance of average change of ECEC *(expressed in %)*

The Importance of average change of the total exchangeable bases (TEB) is showed in figure 7 below**.** The comparative analysis with respect to exchangeable bases, again confirms the negative impact of traditional fallow on chemical soil fertility. Almost all parcels of fallow crops show a significantly negative trend in terms of saturation rate base, ranging from -17% to -68%. However, for profiles under rainfed crops under viticulture and under eucalyptus afforestation, the general trend is dominated by the increasing rate of base saturation which is between 37% and 110%. In profiles in wine cultures, improvement of the rate base saturation ranges from + 66% to + 151%. The enhancement rate of profiles in afforestation is between +18% and +690%.

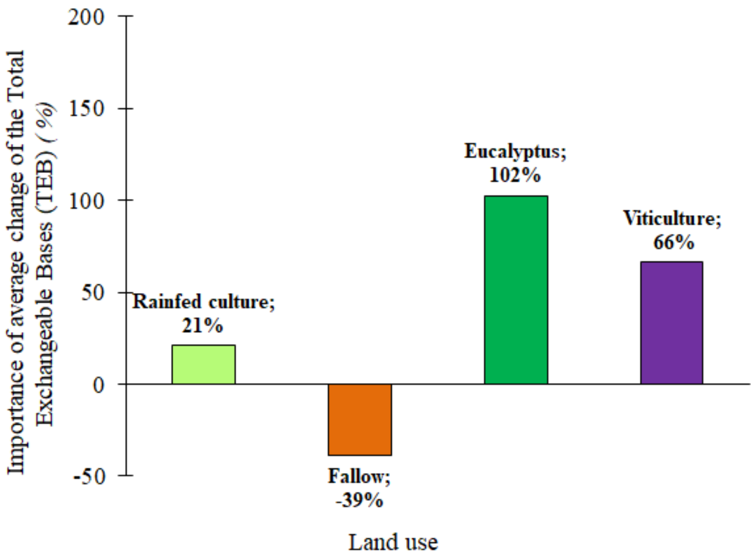

Fig. 7. Importance of average change of the Total exchangeable Bases (TEB) *(expressed in %)*

If we refer to the sum of exchangeable bases TEB, average rates of evolution are clearly positive for plots under cultivation or under afforestation. Plots under eucalyptus afforestation show the highest improvement; the average increase of the TEB is (+102%). The average value of the TEB evolution rate is (+ 21%) for plots under rainfed and (+ 66%) for plots in wine culture. On the contrary, cultivation plots fallow record clearly negative trend rates whose average value is (-39%).

For all four cations, only the plots of rainfed fallow show a clear trend showing almost negative rates of change except for a few plots. The comparative analysis confirms that there is some improvement in mean levels of magnesium and exchangeable potassium of plots under cultivation or under eucalyptus afforestation compared to control plots under grassy savanna.

Aside from the exchangeable sodium, the other three cations are characterized by average rates of positive development for the plots under rainfed and wine culture. The average change rates are particularly important for contents of exchangeable potassium and magnesium plots under eucalyptus afforestation. A plot under eucalyptus afforestation can record over (+2000%) rate of change in exchangeable potassium. We realize that in these rainfed, the average rate of positive changes in levels of exchangeable magnesium is also quite high.; Table 6 shows the importance (in %) of the average change in the levels of exchangeable cations by type of land use.

TABLE 6. Importance of average change in exchangeable cation contents (expressed in %) according to the type of land use

Types of uses	**Exchangeable Cations**			
	Ca	Mg	K	Na
Rainfed culture	+40	+127	+32	-17
Fallow	-39	-27	-22	-4
Eucalyptus	-21	+406	+570	+75
Viticulture	+92	+54	+132	-26

IV. Conclusion

The analytical results have shown chemical «poverty» of all soils studied. The nature of the parent materials primarily explains the chemical deficiency of these soils to the extent that they developed directly from the ancient regolith strongly leached unable to generate but desaturated acid soils [16]. Then the existing cropping systems, accentuate the deterioration of the chemical fertility of these already poor soils. Indeed, due to lack of financial and material resources, the plots of rainfed crops do not sufficiently benefit from fertilization. Moreover, no appropriate technical measures are taken to mitigate the loss of nutrients and organic by erosion and leaching. Finally, the rate of degradation is growing worse because of the intensive use linked to population pressure. As in many African countries, population pressure is a major factor in the deterioration of Malagasy soil [17].

In order to restore the fertility of depleted plots, only fallow is the most practiced means, by farmers but the system remains ridiculous as the plots involved receive neither input nor specific maintenance.

The use of discriminant analysis coupled with the comparative analysis of the profiles across the site allows us to better differentiate the status of soil fertility by type of use in evaluating the effectiveness of the traditional fallow in maintaining soil fertility. Thus, contrary to what farmers expected, fallow plots of rainfed do not allow reconstructing the chemical soil fertility. Referring to the analytical data of control sample profiles under grassy savanna profiles, there is a degradation of the chemical fertility of rainfed plots fallow: worsening soil acidification, loss of total organic matter content and decreased saturation of exchangeable bases.

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