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Evaluation Of Soil Fertility Under Industrial, Irrigated And Continuous Sugar Cane Cultivation In The Integrated Agricultural Unit Of SUCRIVOIRE-Zuénoula (Centre West Of Côte d'Ivoire)

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Abstract – This study was carried out to evaluate the soil fertility in continuous and irrigated cultivation of sugar cane. To do this, soil samples were taken from the top 20 centimeters of the soil, in the three different sectors of the sugar cane plantations and on another plot left fallow for nearly 20 years, at the integrated agricultural unit of Zuenoula. These samples underwent physical and chemical analyzes in the laboratory following standard procedures. The results obtained show that the soil texture is of the sandy loam type for the fallow and the pivot P17B, silt and fine silt respectively for the pivots P27B and P20A. For the chemical parameters, apart from the pH, which has acceptable values for sugar cane, on all the plots studied, the other parameters, in particular, organic carbon, organic matter, nitrogen, assimilable phosphorus, potassium, calcium, magnesium and cation exchange capacity, show mixed values. Thus, the soil fertility potential under pivots P17B and P20A can be described as low, while it is medium under fallow and relatively high under pivot P27B. This variability of these physical and chemical characteristics from one plot to another requires specific manure recommendations. However, a strong correlation was found between the rate of fine soil elements (clay + fine silt) and most soil chemical parameters. From the content of fine elements in the soil of the fallow land, the modeling equation for this relationship made it possible to show that the fallow land improves the chemical characteristics of the soil, of the order of 10% for the pH, 22% for assimilable phosphorus, 74% for potassium and more than 100% for organic carbon, nitrogen, cation exchange capacity, calcium, as well as the Ca/Mg ratio. This clearly demonstrates that fallowing allows a restoration of the fertility of soils that would be degraded by the continuous cultivation of sugar cane.

Keywords – continuous cultivation of sugarcane; degraded soils; fallow; restoration of soil fertility.

I. Introduction

Sustainable management of soil fertility and improvement of yields concern all speculations in general. This reality becomes a challenge in a continuous culture condition. This is the case of sugar cane cultivation all over the world and particularly in Côte d'Ivoire, where this speculation has been practiced for a long time, on agricultural units using the same plots.

However, the resulting production must meet the consumption needs of a growing population, with booming urbanization [1]. This need for sugar consumption in Côte d'Ivoire is estimated at around 250,000 tonnes, and is only covered at around 83% by the two sugar companies SUCAF-CI and SUCRIVOIRE [2].

To make up for this deficit, Côte d'Ivoire has resorted to importing sugar. But, the resorption of this deficit by local production would go through, in part, by intensive industrial exploitation [3]. However, the intensive cropping system is well known for its degrading effect on the soil, which could instead lead to a drop in yield during successive cropping seasons, particularly in the humid tropical zone [4]. This soil degradation could lead, in the medium and long term, to a decrease in organic matter content and a drop in biological activity [5].

Yield decline has not been sufficiently documented in the forest-savannah transition zone of West Africa, specifically for continuous sugarcane cultivation. Nevertheless, soil degradation and soil nutrient depletion are known to be among the major factors threatening cane production. This threat is mainly associated with soil compaction and acidification, coupled with the loss of organic matter leading to nutrient depletion in the tropics [6]. Knowledge about the physico-chemical properties of these soils therefore becomes imperative [7], to better understand, among other things, the evolution of soil characteristics, especially in a continuous culture situation.

The objective of this study is to assess the potential for soil fertility in an intensive sugar cane cropping system.

It specifically aims to know the values of soil fertility parameters after several years of cultivation and to assess how natural fallowing could restore the quality of these soils which would be degraded.

It was carried out at the Integrated Agricultural Unit of Zuénoula, in the center west of Côte d'Ivoire.

II. Material And Methods

2.1. Description of the study site

The Integrated Agricultural Unit (UAI) of Zuénoula is located between 7°30 and 7°40 North latitude, and between 6°5 and 6°15 West longitude, and is situated at an altitude of 209 m from the sea [8]. It is located in the Marahoué region in the centre-west of Côte d'Ivoire, precisely between the departments of Zuénoula in the south, Vavoua in the west and Kongasso, in the north. The UAI of Zuénoula is bordered to the east by the right bank of the Marahoué or red Bandama river (Figure 1). It is located 25 kilometers from the town of Zuénoula. It is in the transition zone, between forest and savannah. Over more than three decades (updated to 2020), an average of 1179 mm of water has been recorded. The monthly average temperatures vary between 24°C and 31°C. The Integrated Agricultural Unit of Zuénoula currently covers an area of almost 12,900 ha, divided into three sectors. It uses a sprinkler irrigation system with pivoting booms, hence the name "pivot" for the plots. For this article, one pivot was randomly selected in each sector. As the pivots are subdivided into quarters, the study refers to the Pivot quarters P17B, P20A and P27B. In addition, a 20 year old fallow land, previously cultivated with sugarcane, was used as a reference. Low yields were the main reason for its fallowing.

2.2. Sampling

The soil survey was carried out at a scale of 1:10,000, i.e. observation through open pits every 100 metres. They were 1.20m deep, 1m long and 0.80m wide. The distribution of the pits corresponded to a regular grid pattern. Soil samples were collected from the 0-20 cm horizon.

2.3. Laboratory methods

The collected soil samples were spread out in the shade until completely dry. They were then sieved using a 2 mm mesh sieve. The fine soil obtained was used for physical and chemical analyses. These analyses were carried out on composite samples covering the 0-20 cm horizon, in order to obtain results that reflect the real characteristics of the sugarcane's water and mineral supply sphere, which evolves according to the phenological stages. The Robinson-Köln pipette method [9] was used to determine the different particle size fractions. The pH was determined by the electrometric method, in a soil/water ratio of 1/2.5 [10]. Total organic carbon was determined by the Walkley-Black method [11]. The total nitrogen content was obtained by Kjeldahl distillation [12]. Available phosphorus was determined by Olsen method. Exchangeable bases (Ca2+, Mg2+, K+) were determined by extraction with ammonium acetate buffered at pH 7, followed by saturation with NaCl for the determination of the cation exchange capacity (CEC) and the determination of these different cations.

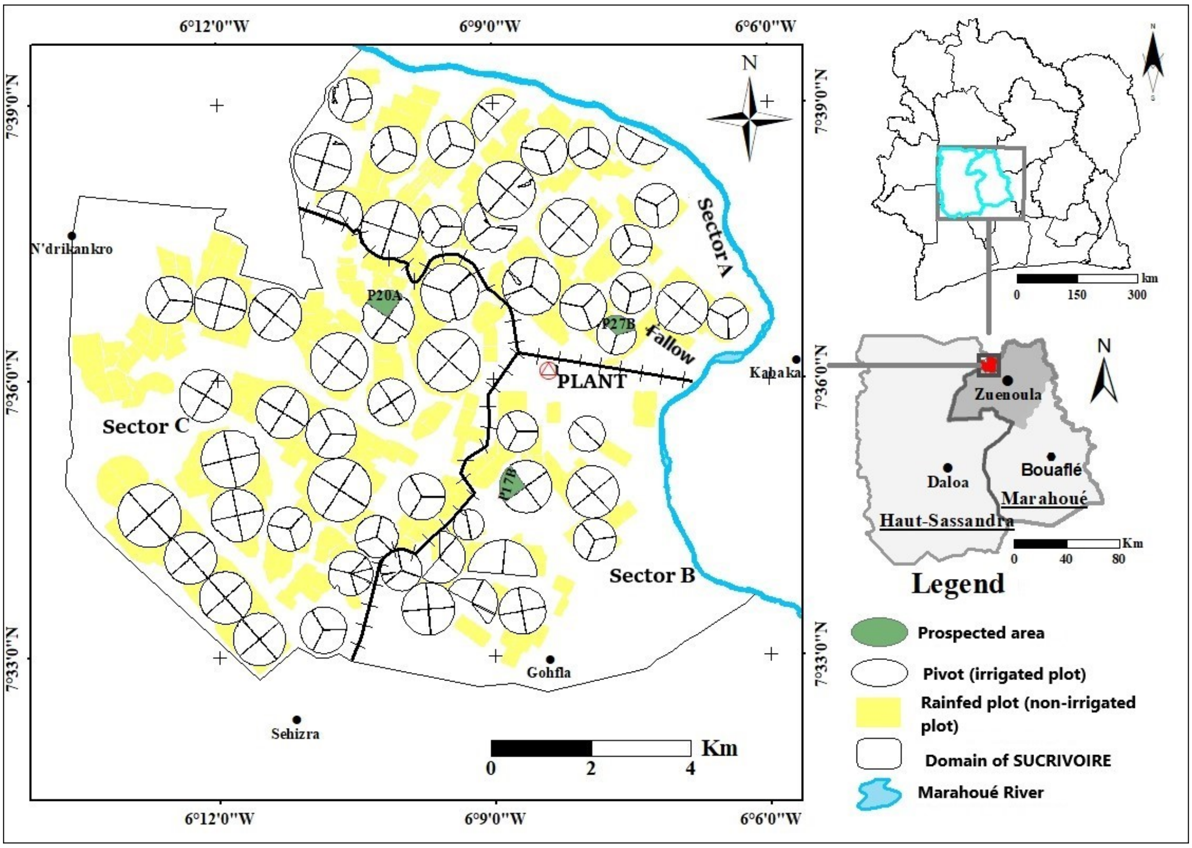

Fig. 1. Location map of the Zuénoula integrated agricultural unit

2.4. Statistical analyses

These concerned the results of the chemical and physical analysis of the soils. They consisted of simple descriptive statistical analyses, with a view to determining the overall average and the coefficient of variation of the physical and chemical soil parameters.

The one-way analysis of variance (ANOVA) was used to test the hypothesis of an influence of depth on soil physical and chemical properties. The Tukey HSD (Honest Significant Differences) post-hoc test was used to perform multiple comparisons of means at the 5% threshold. These analyses were performed using XLSTAT (2016) software. They linked the fallow data with those of pivots P17B, P20A and P27B to identify the impact of continuous sugarcane cultivation on soil fertility.

III. Results

3.1. Assessment of physical characteristics over the depth of the first 20 cm of soil

3.1.1. Granulometry

Table I shows the similar clay content for Pivots P17B, P20A and the fallow land, i.e. rates between 10 and 14 %; this is statistically different from the clay rate at Pivot P27B (24 %). This trend is also observed for the content of fine elements, i.e. the content of clay + fine silt. Indeed, for these fine elements, Pivot P17B, P20A are statistically similar to the fallow, with values ranging from 17 to 21 %, while Pivot P27B contains 41.67 % and is considered statistically different from the first three.

For silt content, pivot P17B and the fallow had statistically identical ratios in the range 28 to 29 %, but were statistically different from pivots P20A and P27B, with values ranging from 41 to 54 %

The same trend was also observed for the sand content. Thus, pivots P20A and P27B are statistically similar, ranging from 32 to 33 %, but are statistically different from pivot P17B in sand content and fallow between 55 and 58 %

However, the ratio of fine silt to clay showed no significant difference between the different plot values, but the ratio of pivot P17B was found to be lower than the other three.

TABLE I: GRANULOMETRIC COMPOSITION OF SOILS ACCORDING TO THE 0-20 CM HORIZON

Depth (cm)	Plots	Clay (%)	Silt (%)	Sand (%)	Clay + fine silt (%)	Fine silt / clay	Textural class
0-20	**P17B**	14,29 ab	28,99 b	55,73 a	19,17 b	0,34 a	Sandy Loam
	P20A	13,50 ab	54,30 a	31,04 b	21,83 b	0,77 a	Silt Loam
	P27B	24,17 a	41,33 ab	31,98 b	41,67 a	1,01 a	Loam
	Fallow	10,83 b	28,10 b	57,90 a	17,50 b	0,70 a	Sandy Loam
MG		**15,70**	**38,18**	**44,17**	**25,04**	**0,70**	**L**
Pr > F		**0,035**	**0,004**	**0,001**	**0,002**	**0,309**	
Significant		**S**	**HS**	**HS**	**HS**	**NS**	

Mean values followed by the same letter in the same column are not significantly different at the 5% threshold. MG: General Mean NS: not significant; S: significant; HS: highly significant; THS: very highly significant; Pr: Probability associated with the ANOVA test.

3.1.2. Texture

The values observe on the table I show three types of texture:

- Sandy Loam for the soils of fallow land and pivot P17B, with similar Clay+Fine Silt rate (respectively 17.500 % and 19.167%) ;
- Silt Loam for the soil of pivot P20A, with Clay+Fine Silt content around 21.833 % ;
- Loam for the soil of pivot P27B with Clay+Fine silt content around 41 %.

3.2. Assessment of chemical characteristics in the top 20 cm of the soil

3.2.1. pH

Pivot P27B, which was statistically different from the other plots in terms of fine element content, still remains so when considering pH values (Table II). Indeed, the P27B plot has the highest pH value in the neutral range, even somewhat alkaline with a value of 7.40.

The soils of the plots P17B and P20A, which were statistically similar to the fallow soil in terms of fine element content, had statistically similar pH values but were statistically different from the pH values observed under the fallow. These two pivots therefore have slightly acidic pH values of 6.44 and 6.47 respectively, compared to a value close to neutrality of 6.96 for the fallow land (Figure 2).

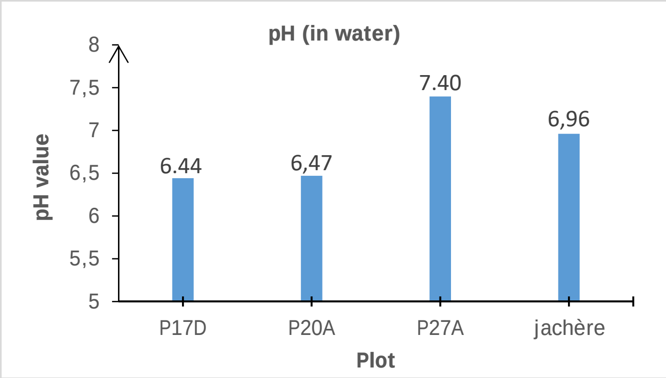

Fig. 2. Evolution of pH (in water) according to pivots and fallow (horizon 0-20cm)

TABLE II: SOIL PH, ORGANIC MATTER AND PHOSPHORUS ACCORDING TO THE 0-20 CM HORIZON

Depth (cm)	Plots	pH (in water)	N	C	MO	C/N	Available P
				(g.kg^{-1})			(mg.kg-1)
	P17B	6,44 c	0,56 a	5,34 a	9,19 a	9,55 a	19,83 a
0-20	**P20A**	6,47 c	0,69 a	7,04 a	12,11 a	10,14 a	20,80 a
	P27B	7,40 a	1,42 a	13,91 a	23,93 a	9,71 a	28,33 a
	Fallow	6,96 b	1,27 a	12,81 a	22,03a	10,08 a	23,33 a
MG		**6,82**	**0,98**	**9,78**	**16,85**	**9,85**	**23,08**
PR > F		**0,0001**	**0,111**	**0,120**	**0,120**	**0,386**	**0,953**
SIGNIFICANT		**THS**	**NS**	**NS**	**NS**	**NS**	**NS**

Mean values followed by the same letter in the same column are not significantly different at the 5% threshold. MG: General Mean NS: not significant; S: significant; HS: highly significant; THS: very highly significant; %: percent; Pr: Probability associated with the ANOVA test.

3.2.2. Organic carbon, organic matter and total nitrogen

No significant differences were observed between the organic carbon and organic matter contents of the different plots studied (Table II). However, the highest organic matter and organic carbon contents were observed under pivot P27B, which also had the highest fine element content. Also, the lowest organic matter and organic carbon contents were observed under pivots P17B and P20A, with organic carbon and organic matter values of 5.34 and 9.19 g.kg-1 for P17B, 7.04 and 12.11 g.kg-1 for P20A respectively. Almost double these values were obtained under fallow, i.e. 12.81 g.kg-1 for organic carbon and 22.03 g.kg-1 for organic matter (Figure 3).

The total nitrogen contents under the three pivots considered and the fallow land show the same trends as those of organic carbon and organic matter.

Indeed, pivot P27B has the highest nitrogen content with 1.42 g.kg-1. This value is slightly higher than that of the fallow, which is 1.27 g.kg-1. The latter value is approximately double that of pivots P17B and P20A, i.e. 0.56 g.kg-1 and 0.69 g.kg-1 respectively (Figure 3).

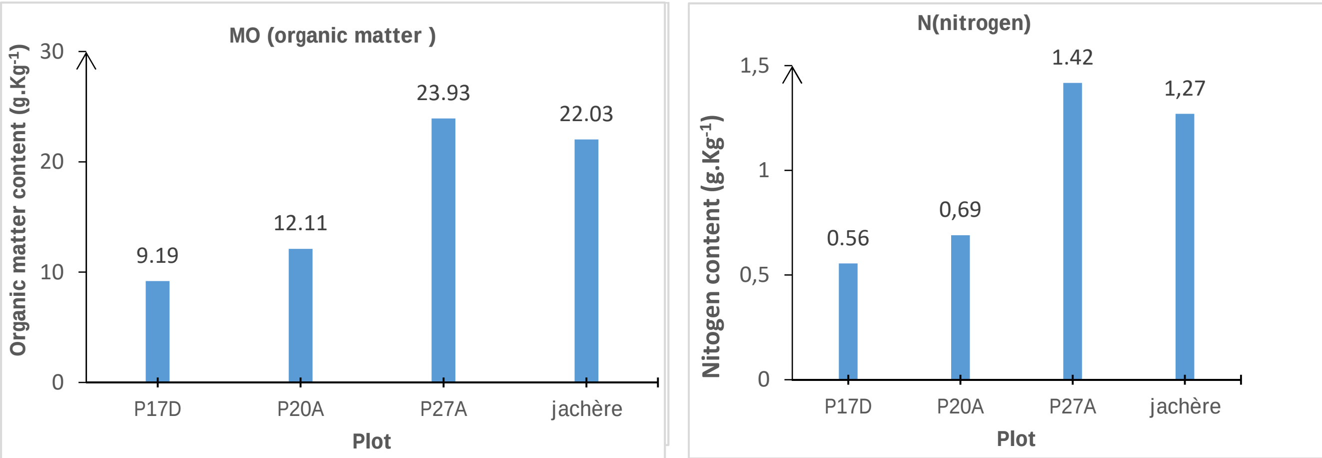

Fig. 3. Evolution of organic matter and nitrogen according to pivots and fallow (horizon 0-20cm)

3.2.3. Available phosphorus

Although there was no significant difference between the different values, it was found that the P27B soils had the highest levels of available phosphorus with 28.33 mg.kg-1. Once again, this value is somewhat higher than the levels observed in the fallow soil (23.33 mg.kg-1). Again the values under pivots P17B and P20A are very close (respectively 19.83 mg.kg-1 and 20.80 mg.kg-1), indicating that these plots are relatively the least supplied with available phosphorus (Figure 4).

3.2.4. Cation exchange capacity (CEC)

The CEC of pivot P27B is statistically different from the other plots (Table III). Indeed, the pivot P27B plot has the highest CEC value of 16.96. As for the soils of the pivots P17B and P20A plots, which were statistically similar to the fallow soil, the respective values were 3.86 and 4.17 cmol.kg-1 for the pivots against a value of 6.40 cmol.kg-1 for the fallow.

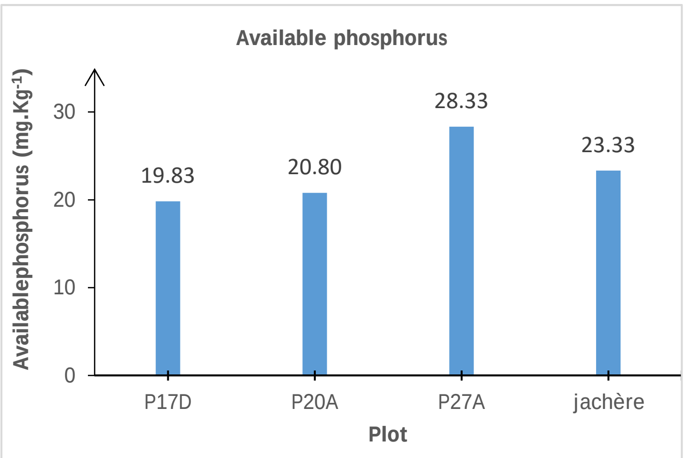

Fig. 4. Evolution of available phosphorus according to pivots and fallow (horizon 0-20cm)

3.2.5. Exchangeable bases and base saturation rate (V)

Potassium (K) and magnesium (Mg) contents were not statistically different in the different plots studied (Table III). However, the highest potassium (K) and magnesium (Mg) contents were observed under pivot P27B, with values of 0.52 and 1.14 cmol.kg-1 respectively. Also, the lowest levels of potassium (K) and magnesium (Mg) were observed under pivots P17B and P20A, with respective values of 0.16 and 0.86 cmol.kg-1 for P17B and 0.27 and 0.99 cmol.kg-1 for P20A. The values obtained under the fallow were 0.30 for potassium (K) and 0.77 cmol.kg-1 for magnesium (Mg).

However, when exchangeable calcium (Ca) levels are considered, pivots P17B and P20A have similar levels to the fallow, i.e. values between 1.8 and 3 cmol.kg-1 which is statistically different from the Ca level (6.83 cmol.kg-1) under pivot P27B.

No significant difference was observed between the base saturation rate (V) of the different plots studied. However, the highest base saturation rate was observed under pivot P20A. However, the base saturation (V) of the different plots studied are all more than 50 %.

3.3. Nutritional balance in the different plots studied

With no significant difference between the different values, it is nevertheless noted that the soils of P27B have the highest nutritional balances with 4.75 for the Ca/Mg ratio and 10.90 for Mg/K. The results (Table III) show a ratio of more than 4 for the pivot soils and less than 4 for the fallow soils for Mg/K.

TABLE III: CHEMICAL PROPERTIES OF SOILS ACCORDING TO THE 0-20 CM HORIZON

Depth (cm)	Plots	CEC	K	Mg	Ca	V	Ca/Mg	Mg/K
				(cmol.kg^{-1})		(%)		
0-20	**P17B**	3,87 b	0,16 a	0,86 a	1,86 b	76,83 a	2,11 a	6,39 a
	P20A	4,17 b	0,28 a	1,00 a	2,25 b	85,10 a	2,23 a	4,66 a
	P27B	16,97 a	0,53 a	1,15 a	6,83 a	52,33 a	4,75 a	10,90 a
	Fallow	6,40 b	0,30 a	0,77 a	2,96 b	62,91 a	3,90 a	2,950 a
MG		**7,85**	**0,32**	**0,95**	**3,48**	**69,29**	**3,25**	**6,23**
Pr > F		**0,0003**	**0,205**	**0,748**	**0,010**	**0,232**	**0,177**	**0,649**
Significant		**THS**	**NS**	**NS**	**S**	**NS**	**NS**	**NS**

Mean values followed by the same letter in the same column are not significantly different at the 5% threshold. MG: General Mean NS: not significant; S: significant; HS: highly significant; THS: very highly significant; Pr: Probability associated with the ANOVA test.

3.4. Improvement of soil characteristics through fallowing

At the level of pivots P17B, P20A and P27B, the analysis of the values of the physical and chemical parameters of the soils showed strong correlations between the rate of fine elements (Clay + Fine silt) and the pH, organic carbon, total nitrogen, available phosphorus, calcium, magnesium, potassium, cation exchange capacity (CEC) and Ca/Mg ratio (Figure). These correlations, which are modeled by linear regressions, show that, with the rate of clay+fine silt of the fallow soil, it's possible to predict values (estimated values) for the chemical parameters of the soil mentioned above (Figure 5a,b,c,d,e,f,g).

The comparison of these estimated values with the real values (observed after chemical analysis), shows that, except the rate of magnesium, the estimated values are all lower than the observed values. This proves that natural fallow would improve the chemical characteristics of the soil, at different rates, depending on the parameter considered. This rate would be 10% for pH, 22% for available phosphorus, 74% for potassium and over 100% for organic carbon, total nitrogen, CEC, calcium and the Ca/Mg ratio (Table IV).

TABLE IV : IMPROVEMENT OF SOIL CHARACTERISTICS THROUGH FALLOWING

Soil parameter	Modeling of soil parameters relative to the clay and fine silt rate	Clay + Fine Silt (%)	a	B	R²	Estimate value	Observed value	Gap	Evolution rate due to fallow (%)
pH	Y = a*X+b	17.5	0.0441	5.5557	0.9931	6.33	6.96	0.63	10
C	Y = a*X+b	17.5	0.368	-1.3758	0.9937	5.06	12.88	7.74	153
N	Y = a*X+b	17.5	0.0377	-0.1512	0.9986	0.51	1.27	0.76	150
Available Phosphorus	Y = a*X+b	17.5	0.3785	12.558	1	19.18	23.33	4.15	22
CEC	Y = a*X+b	17.5	0.6059	-8.3628	0.9922	2.24	6.40	4.16	186
Ca	Y = a*X+b	17.5	0.2249	-2.5512	0.9986	1.39	2.96	1.58	114
Mg	Y = a*X+b	17.5	0.0107	0.7069	0.8607	0.89	0.77	0.12	-13
K	Y = a*X+b	17.5	0.0149	-0.0883	0.9611	0.17	0.30	0.13	74
Ca/Mg	Y = a*X+b	17.5	0.1212	-0.3117	0.9954	1.81	3.90	2.09	115

TABLE V: RATINGS FOR SOIL FERTILI!Y CLASSES [13]

Parameters	Low	Medium	High
organic matter (MO) ($g.kg^{-1}$)	<10	10-15	>15
nitrogen (N) ($g.kg^{-1}$)	<1.5	1.5-2.0	>2.0
Organic carbon (C) ($g.kg^{-1}$)	<10	10-15	>15
C/N	<8	8-12	12-15
Available phosphorus (P) ($mg\ Kg^{-1}$)	<10	10-20	>20
Exch (K) ($cmol.kg^{-1}$)	<0.15	0.15-0.40	>0.40
Exch (Ca) ($cmol.kg^{-1}$)	<2	2-5	>5
Exch (Mg) ($cmol.kg^{-1}$)	<0.3	0.3-1.0	>1.0
CEC ($cmol.kg^{-1}$)	<6	6-12	>12

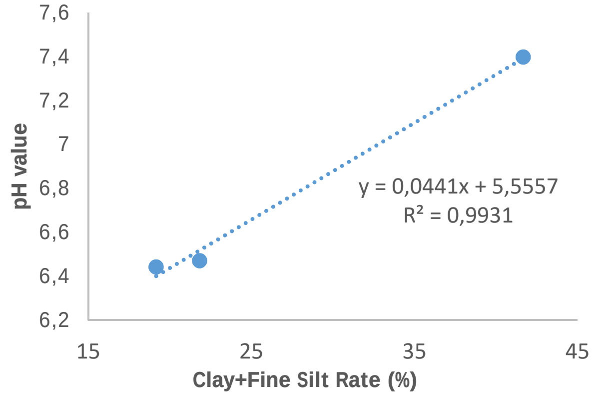

Fig. 5a. pH according to the content of fine elements

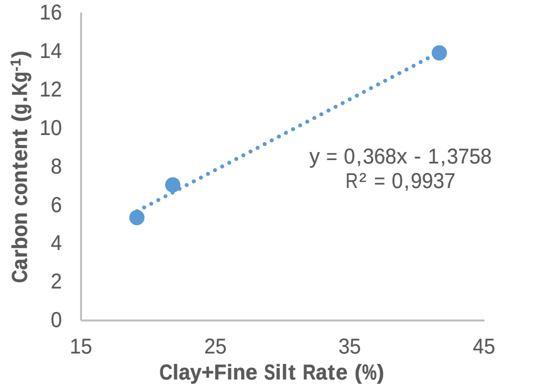

Fig. 5b. Carbon according to the content of fine elements

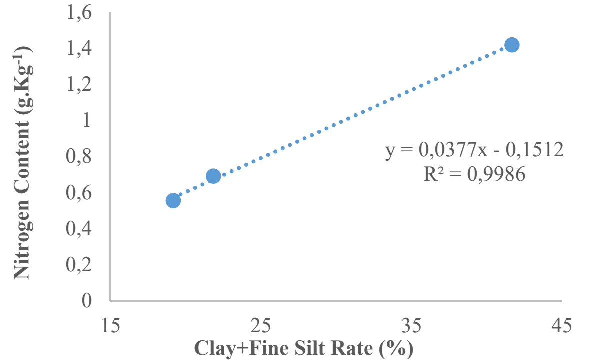

Fig. 5c. Nitrogen according to the content of fine elements

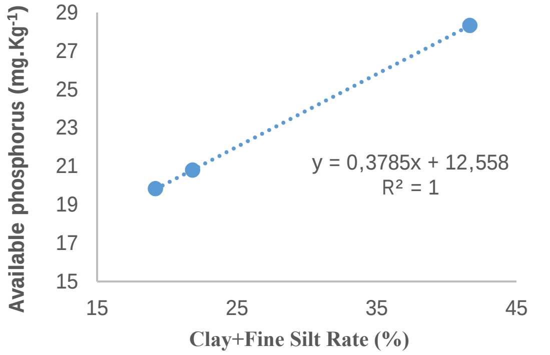

Fig. 5d. Available Phosphorus according to the content of fine elements

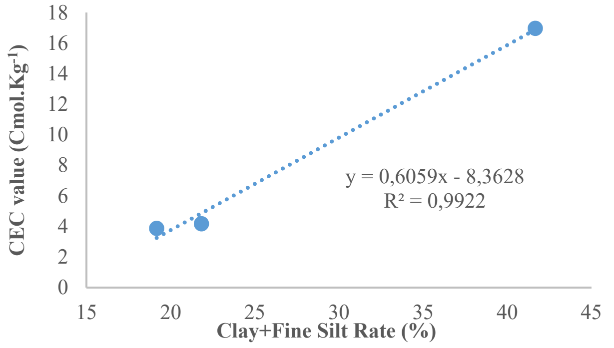

Fig. 5e. CEC according to the content of fine elements

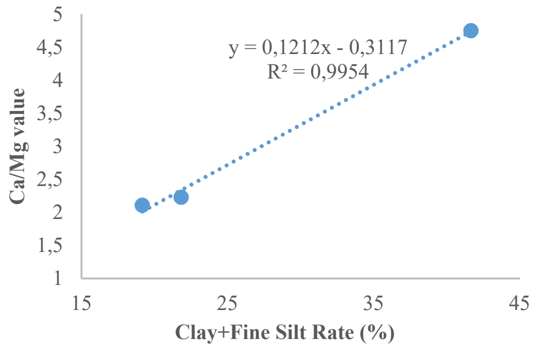

Fig. 5f. Ca/Mg according to the content of fine elements

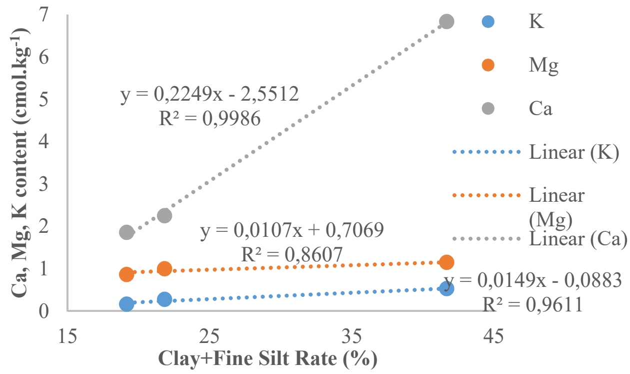

Fig. 5g. Ca, Mg, K according to the content of fine elements

Fig. 5. Correlation between fine element content and soil chemical parameters

IV. Discussion

Soil texture is the most stable physical characteristic of soils that influences some of soil properties, such as structure, moisture, root penetration and soil fertility [14], [15]. Coarse-textured soils (sandy loam under pivot P17B and fallow) lack both nutrients and water retention capacity, while fine-textured soils (loam under pivot P20A) often have problems with structure and water infiltration [16]. This indicates a low level of physical fertility. As for soils with a moderately fine texture (pivot P27B), with a relatively high clay content (>20%), more or less significant retentions of nutrients and water are favored. but high clay content can cause very poor physical properties, including an impermeable environment, poor soil aeration preventing harmonious root penetration, soil compactness in dry conditions and high plasticity in wet conditions. This could make tillage difficult. This implies a medium level of physical fertility, as observed in the work of [17]. The fine silt/clay ratio values were on average above 0.15. This indicates that the soils are relatively young and have a high degree of weathering potential [18]. Soil pH is the most important chemical characteristic of the soil solution. The results showed that the horizon (0-20cm) was slightly acidic for the pivots P17B and P20A pivots and neutral for the fallow. This demonstrates the impact of continuous cropping on the environmental conditions, compared to the fallow plot with the same physical properties.

Organic matter (OM) levels were on average low (< 10 g.kg-1), medium (10-15 g.kg-1) and good (> 15 g.kg-1) (Table IV) for the different pivots surveyed and the fallow [13]. According to this standard, the organic carbon content in the soils was low (< 10 g.kg-1) for pivots P17B and P20A, medium (10-15 g.kg-1) for the fallow and pivot P27B for the 0-20 cm horizon [13]. Similar results were obtained in previous work by [19] and [1]. The organic matter (OM) level of the fallow for the 0-20cm horizon was higher than that of the pivots P17B and P20A.

Total nitrogen (N) evolved in accordance with the level of organic matter (OM) in the different soil horizons (0-20cm), suggesting a strong correlation between these two soil parameters. The very low to low level of total nitrogen (N) indicates that the soils in the study area are deficient in N, witch could not support harmonious growth and development of the sugarcane crop.

This implies the need for fertilisation with external N inputs and a progressive increase in their organic matter (OM) levels to ensure sustainable productivity. This corroborates the work of [19] and [1]. However, the level of nitrogen in the 0-20cm horizon of the fallow was almost double for pivots 17A and P20A.

The C/N ratio of the soils of the fallow and pivots P17B, P20A, P27B were on average between 8 and 12. This indicates a good level of mineralization of organic matter. However, [20] had found high values for the C/N ratio under fallow in another study area. However, the C/N values recorded on the Zuénoula agro-industrial unit are in line with the pH value observed. Indeed, according to [15], a pH higher than 5.5 would be favorable to good nitrification of organic matter.

The available phosphorus (P) content in the studied soils were qualified as medium (10-20 mg.kg-1) for P17B and good (>20 mg.kg-1) for P20A, P27B and the fallow, according to the assessment [13] in the horizon (0-20cm). An available P concentration of 15 mg.kg-1 is generally considered as the critical limit below which phosphorus deficiency symptoms are likely to occur in many crops [15], [21]. Phosphorus is an important nutrient for root development and nodulation which is important for the nitrogen fixation process [22].

The exchangeable bases (Ca, Mg and K) showed low calcium (Ca) contents under pivot P17B, medium for pivot P20A and fallow, good under pivot P27B. The low Ca content of the soils would be the consequence of the practice of burning at each sugarcane harvest. This cultural practice would lead to the availability of mineral elements through the ash, which accumulates on the surface, but is limited in depth [19]. While exchangeable K and Mg values observed were average for the fallow, the pivots P17B, P20A, and good for pivot P27B.

CEC is also considered low (<6 cmol.kg-1) for pivot P17B and P20A, but good (>12 cmol.kg-1) for pivot P27B. The level of CEC in the fallow land was medium. The level of exchangeable bases in soils is a measure of the availability of absorption bases for sugarcane. The low CEC concentrations observed in these soils of pivots P17B and P20A indicate that these soils have low nutrient content, as reported by [1]. The variation in organic carbon in these soils indicates a relationship with CEC values in which low organic carbon levels correspond to low CEC values explaining the contribution of Organic Matter to soil CEC improvement. The low levels of CEC observed under pivots P17B and P20A of the soils of the pivots studied could also be attributed to the strong leaching of exchangeable bases in these soils, as indicated by [14] as well as low clay content (<20 %) of the soil [23].

The base saturation rate (V) can be qualified as good (>50 %). The low levels of exchangeable bases and CEC of the pivots P17B, and P20A indicate the presence of acid cations (H^+ and Al^{3+}) indirectly allowing to assess the anion exchange capacity, as indicated by [24]. The availability of nutrients for plant uptake depends not only on absolute nutrient levels, but also on the ratios between nutrient [25]. Nutrient imbalances affect nutrient uptake by inducing deficiencies of certain mineral elements that may be present in the soil in sufficient amounts [25]. It is therefore important to consider theses ratios, namely Ca/Mg and Mg/K, which are indicators of nutrient uptake [21].

Ca/Mg ratios of 2 to 4 and Mg/K of 1 to 4 are considered favourable for most tropical crops [14]. In this study, Ca/Mg ratios are relatively at the good level.

However the Mg/K ratios under pivots are above the optimal range. This implies that potassium uptake may be inhibited with Mg deficiency. In contrast to the fallow, it is in the optimal range. From these results, it appears that the nutrient imbalances observed in this study will influence nutrient availability. Nutrient availability determines the yield potential of the sugarcane crop and can be improved by the application of fertilizers [26]. All these deficiencies are the basis of the drop in sugarcane yield and sugar production [19]. Indeed, it is recognised that nutrients present in the soil in smaller quantities, whether major, secondary or trace elements, limit yield and/or affect the quantity and/or quality of the crop [27]. Also, a single nutrient, at low levels in the soil, reduces yield, even if the others are not at limiting values. Fertilisation, in this case, must be balanced to correct all soil deficiencies [28]. In addition, the low values of the physico-chemical parameters observed in the soils of pivots P17B and P20A, compared to the fallow which has good values, shows that the fallow made it possible to restore the bioavailability of soil nutrients for the plant. However, the medium and good values of the physico-chemical parameters in the soil of the pivot P27B, justifies an medium fertility potential for the cultivation of sugar cane. This would result from the the acceptable rate of clay in the soil granulometry on this plot.

The rate of improvement of the chemical characteristics of the soil by fallowing, which could go to more than 100% for certain elements, is in line with the work of [29]. Indeed, it mentioned annual recycling rates of around 10% for certain mineral elements. The surface horizon (first 20 centimeters of the soil profile) explored in this study shows that the essential factor in the improvement of the chemical properties of the soil induced by fallow would be much more linked to vegetation and precipitation than to a geochemical origin [29].

V. Conclusion

The results of the study showed that for the horizon (0-20cm) preferential nutrition zone of sugarcane, the soils of pivots P17B, P20A and fallow had approximately the same physical properties, unlike pivot P27B due to its clay content (>20p.c). As for chemical parameters, unsatisfactory levels of CO, OM, N, P, K, Ca, Mg, and CEC were observed, illustrating the low fertility potential of the soils under pivots P17B and P20A. As for the fallow, it showed a good content of available CO, OM, P and an average content of K, Ca, Mg and CEC. This implies that continuous cultivation over several decades exposed the soil to nutrient stock depletion and led to reduced bioavailability of primary nutrients (N, P and K) for sugarcane cultivation.

This clearly demonstrates that fallow allows for a reconstitution of the soil-geological environment and bioavailability of nutrients for sugarcane. Moreover this variability of physical and chemical properties from one pivot to another requires a specific fertilization plan for each situation, hence fertilization à la carte.

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References

[1] Yao, K. (2017) Effets de la dynamique de l'écume sur le rendement de la canne a sucre (saccharum officinarum L.) dans les complexes sucriers de borotou-koro (nord-ouest) et de Zuenoula (centre-ouest), en côte d'ivoire. Thèse de Doctorat d'état es Sciences naturelles, Université FHB /UFR STRM, 245 p.

[2] Anonymous (2019) Study of the competitiveness of Ivorian sugar, Executive summary and Matrix of priority actions economic policy analysis cell of wax (capec), 23p.

[3] Milleville, P. et Serpantie, G. (1994) Intensification et durabilité des systèmes agricoles en Afrique Soudano-Sahélienne. Actes du Séminaire International, Dakar, Sénégal, 1014/01/1994.Benoit-Cattin M.Juan-Carlos D (éds), Paris,France. pp.33-45.

[4] Beets, W.C. (1989) Sustainable continuous crop production in a tropical environment. ILEIA Newsletter, 5 (2): 3 – 9.

[5] Cattan, P., Letourmy P., Zague, B., Minougou, A. et Compaoré, E. (2001) Rendement del'arachide et du sorgho en rotation sous différents itinéraires technique au Burkina Faso. Cahiers Agricultures, 10 : 159-172.

[6] Campo, J. and Va´zquez-Yanes, C. (2004) Effects of Nutrient Limitation onAboveground Carbon Dynamicsduring Tropical Dry ForestRegeneration in Yucata´n, Mexico. Ecosystems 7: 311–319.

[7] Mustapha, S., Gwararn, M.Y. and Ahmed, B.L. (2005) Fertility and salinity/sodicity status of the microtopographicalland features of river Yelwa fadarna at Bauchi, Nigeria. Biol. Environ. Sci. 1. Tropics, 2: 56-61

[8] Péné, B.C. et Assa, A.D. (2003) Variations interannuelles de la pluviométrie et de l'alimentation hydrique de la canne à sucre en Côte d'Ivoire. Science et Changements planetaire/Secheresse. 14,1, pp. 43-52.

[9] Fournier, J., Bonnot-Courtois, C., Paris, R., Voldoire, O. and Le Vot, M. (2012) Analyses granulométriques, principes et méthodes. CNRS, Dinard. 99 p.

[10] Mathieu, C. and Pieltain, F. (2003) Analyse chimique des sols méthodes choisies. Lavoisier ed, Paris.387 p.[11] Nelson, D.W. and Sommer, L.E. (1982) Total Carbon, Organic Carbon and Organic Matter. Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2nd Edition. ASA-SSSA, Madison, 595-579.

[12] Bremner, J. and Mulvaney, C. (1982) Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Madison: ASA, SSSA. Nitrogen Total and Total P, Agronomy 9 Second edition. pp. 403-430.

[13] Esu, I. E. (1991) Detailed soil Survey of NIHORT Farm at Bunkure, Kano State, Nigeria. Institute for Agricultural Research, ABU, Zaria.

[14] Msanya, B.M., Kaaya, A.K., Araki, S., Otsuka, H., Nyadzi, G. I. (2003) Pedological characteristics, general fertility and classification of some benchmark soils of Morogoro District,Tanzania. African Journal of Science and Technology, Science and Engineering Series 4(2):101-112.

[15] Landon, J.R., (1991) Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific and Technical Publishers, Essex. 474 p.

[16] Malgwi, W.B., and Abu, S.T. (2011) Variation in somephysical properties of soils formed on a hilly terrain under diferrent land use types in Nigeria Savanna pp150-163.

[17] Zro, B.G.F., Yao-Kouamé, A. and Kouamé, K.F. (2012) Évaluation statistique et spatiale de la fertilité rizicole des sols hydromorphes (gleysols) de la région du Bélier (Côte d'Ivoire), TROPICULTURA, 30, 4, 236-242.

[18] Van Wambeke, R. (1991) Criteria for classifying tropical soils by age. Journal of Soil Science 13(1):124 – 132.

[19] Bouadou, F. (2014) Effets de l'écume et de la mélasse (sous-produits organiques) sur les propriétés des sols et le rendement de la canne à sucre (saccharum officinarum l.) au complexe sucrier de Zuénoula (Centre-ouest de la Côte d'Ivoire), Thèse de Doctorat, UFR-STRM,Université FHB (Abidjan/ Côte d'Ivoire), 212 p.

[20] Alongo, S., Visser, M., Kombele, F., Colinet, G., Bogaert, J. (2013) Propriétés et diagnostic de l'état agropedologique du sol de la serie yakonde après fragmentation de la forêt a yangambi, R.D. congo. Annales des instituts supérieurs d'études agronomiques 5 (1), pp.36-51. hal-00875748.

[21] Hodges, S.C. (2010) Soil fertility basics. Soil extension North Carolina State University, North Carolina, USA, 75p.

[22] Marschner, H. (1995) Mineral Nutrition of Higher Plants. 2nd Edition, Academic Press, Amsterdam, Netherlands. 889 p.

[23] Gachene, C.K.K., Kimaru, G. (2003) Soilfertility and Land productivity: A guide for extension workers in the Eastern Africa Region. RELMA Technical handout Series 30. Nairobi, Kenya: Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (SIDA), 164 p.

[24] Assa, A. (2005) Précis de pédologie, à l'usage des étudiants du second cycle des études universitaires.EDUCI, 100 p.

[25] Edem, S.O., Ndaeyo, N.U. (2009) Fertility status and management implications of wetland soils for sustainable crop production in Akwa Ibom State, Nigeria. Environmental Development Sustainability. 11:393 -406.

[26] Jones, A, Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallet, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., Van Ranst, E., Yemefack, M., Zougmore, R. (2013). Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxemborg. 176 p.

[27] Dugué, P., et Gigou, J. (2002) La gestion de la fertilité. Edition CIRAD GRET, Paris, France, pp.53-74.

[28] Akanza, K.P. and Yao-Kouamé, A. (2011) Organo-mineral fertilization of cassava (Manihot esculenta Crantz) and soil deficiency diagnosis. Journal of Applied Biosciences 46: 3163-3172.

[29] Boyer, J., (1978), Le calcium et le magnésium dans les sols des régions tropicales humides et sub-humides. Paris : ORSTOM, 173 p.