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Contribution to the Assessment of the Fertility Status of the Soils of Kouh-East in the Eastern Logone in Southern Chad

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Abstract— *Agriculture is the main source of income and survival for the population of East Kush. Population growth has led to an increase in the area available for cultivation, a reduction in set-aside time, migrations in search of cultivable soils, with the corollary of soil degradation and a reduction in fertility levels. The objective of the study is to assess the fertility status of soils in Kouh-East. Physicochemical characterization of soils from twenty-five localities has shown that soils are clay-sandy to sandy-clay with a clay content of 7 to 47.50%, MO ranges from 0.41 to 4.62%, pH ranges from 5.10 to 7.60, nitrogen content ranges from 0.00 to 0.11%, Ca^{2+} content ranges from 0.72 to 28.88 $cmol^+/kg$, Mg^{2+} content ranges from 0.2 8 to 6.56 $cmol^+/kg$, K^+ ranges from 0.01 to 20.09 $cmol^+/kg$, Pass ranges from 0.02 to 212.83 ppm, Na^+ ranges from 0.03 to 0.24 $cmol^+/kg$, CEC ranges from 11.20 to 42.32 $cmol^+/kg$, SBE ranges from 1.44 to 39.82 $cmol^+/kg$, V ranges from 11.02 to 1.02 16, 29%. Statistical treatment correlated soil fertility variables. Thus, a bilateral relationship is observed between clay and CEC (R^2=0.711), between Limon and CEC (R^2=0.707), nMO and Ca (R^2=0.564), between SBE and MO (R^2=0.429), between SBE and silt (R^2=0.520), between SBE and Ca (R^2=0.812), between SBE and Mg (R^2=0.542), between SBE and K (R^2=0.720), between SBE and Na (R^2=0.689), between V and Ca (R^2=0.713), between V and K (R^2=0.748), between V and Na (R^2=0.687) and between V and SBE (R^2=0.949). Four soil fertility classes are identified. Soils have good physical properties but organic and mineral soil improvers are essential for chemical fertility*.

Keywords— *Fertility, Soils, Kouh East, Eastern Logone, Amendment*.

I. Introduction

Central Africa, and in particular the Sahel, are recognized as very vulnerable to climate change and land degradation with land use change as the main threat [12] [20].

Agriculture is a vital part of the economy of all African countries. It therefore has a role to play in addressing our continental priorities of eradicating poverty and hunger, boosting intra-African trade and investment, rapid industrialization and economic diversification, sustainable resource and environmental management, job creation and food security [35].

Chad is an agro-pastoral country where more than 75% of the population lives on agriculture. The largest contribution of Chadian agriculture to the economy is its large share in the Gross Domestic Product (GDP) estimated at 23%, of which 20% comes from food production and 3% from cash crops [32]. It is also a major job provider that occupies 2/3 of the workforce. In recent decades, Chad has experienced a rapid increase in population, for example in the Eastern Logone, where the population was estimated at 44,300 in 1993 [22] and 796,453 in 2009 [23]. This demographic increase is automatically accompanied by an increase in food requirements, which leads to overexploitation of agricultural plots, a decline in soil fertility, and migration in search of good soil, leading to food insecurity.

In sub-Saharan Africa, soil fertility depletion has reached a critical level, particularly with small-scale land use. Soil fertility is the quality of soil that allows it to provide nutrients in adequate and balanced amounts to support the growth of specific plants or crops [20].

The degradation of cultivated soils is one of the main constraints of agriculture in Chad, as everywhere in the Sudano-Sahelian zone. Numerous works over the last few decades show very significant soil degradation in the Logone-Oriental: Decreased organic soil stock and erosion [41], depletion of cultivable soils due to a shortening of set-aside time due to population pressure that generates an increase in food demand [10], recurrent droughts.

In order to maintain soil fertility in order to ensure its feeding function, several studies have been carried out: [14][41][17][15][30][44][40][31][18][5][8][4][36][37][2][3].

The department of Kouh-Est is located in the Sudanian zone of Chad, a strip that experiences rain for five to six months from May to October, with an average rainfall of more than 800 mm. In August, the humidity of the rainy season causes the temperature to drop below 30 degrees [13].

This distributed rainfall and a whole range of soils required by the department of Kouh-Est, makes it an agricultural zone.

The main objective of this study is to assess the chemical fertility status of soils in Kouh-est. Specifically, these are:

- Statistical data processing of soil physicochemical parameters ;
- Interpret and discuss the results ;
- Determine soil fertility level
- Evaluate the amount of inputs for fertility restoration.

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II. Materials and Methods

The physico-chemical characterization of soil samples taken in the field and analyzed in the laboratory made it possible to determine the fertility status of the different soils of the department of Kouh-East. The materials were removed from the topsoil (0-30 cm. A composite soil sample from each site was then obtained by mixing all the samples and then air-dried and sieved through a 2 mm sieve. Then 1 kg of fine earth obtained after screening was taken during screening and packaged in a plastic bag labeled for laboratory analysis.

A. Selection of study areas

The department of Kouh-East has a whole range of soils, but the most used are ferrallitic and ferruginous soils. A total of 25 Localities in the Head of Department Bodo were chosen. These twenty-five localities were chosen because they are the large agricultural areas of the department of Kouh-East, they require soils that have a great geographical extension, a strong agricultural exploitation because they form exempt land during the rainy season.

B. Location of the study area

The department of Kouh-East is located in the Sudanian zone of Chad, a strip that experiences rain for five to six months from May to October, with an average rainfall of more than 800 mm. In August, the humidity of the rainy season causes the temperature to drop below 30 degrees [6][36][13].

The department of Kouh-East covers an area of 1017.3 km2. It is located between 8°08' and 8°20' of latitude North and between 16°80' and 17°20' of longitude East (Fig 1).

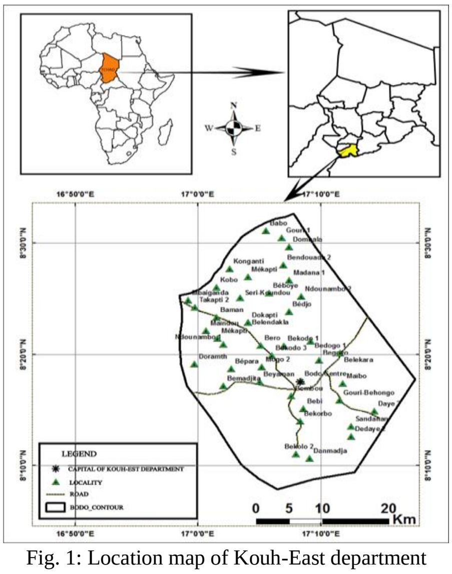

Fig. 1: Location map of Kouh-East department

Two considerations should always be kept in mind [29].

- field sampling is an essential phase given the high variability of the terrain; the sampling error may affect the representativeness of the sample taken;
- in the majority of cases, samples are not collected randomly or systematically (Fig. 1) but are selected as best as possible On the basis of knowledge or field testing, rather arbitrarily.

Sampling is primarily intended to produce small and medium-scale soil maps of eastern Kouh, simple inventories for regional planning. The method of prospecting and sampling is then based on the recognition of homogeneous soil units, defined most often from existing base maps (soil maps), aerial photos, satellite images and directly from the terrain. These homogeneous units are represented by twenty-six (26) samples which characterize one or more representative profiles of the soil type, the description of which, the results of the physico-chemical and mineralogical analyzes, generally serve as a reference profile.

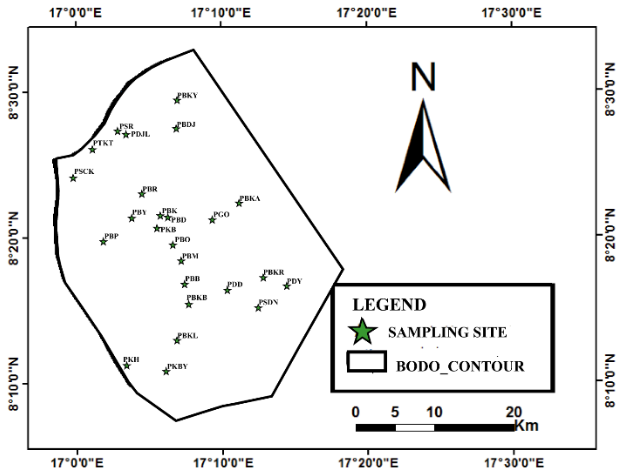

Fig. 2: Sampling map of the department of Kouh-Est

C. Method for assessing soil fertility levels

The fertility of the soils studied was defined from the chemical fertility classes (table 1).

Classification of soil chemical fertility levels

Class I, high fertility: Soils are of this class when the characteristics do not have or have only small limitations.

Class II, average fertility: Soils are of this class when the characteristics have no more than 3 moderate limitations possibly associated with low limitations.

Class III, low fertility: Soils are of this class when their characteristics have more than 3 moderate limitations associated with a single severe limitation.

Class IV, very low fertility: Soils are of this class when their characteristics have more than one severe limitation.

The table below clarifies the criteria for assessing soil fertility classes.

D. Statistical analyzes of data

The collected data were subjected to a software analysis of variance XLSTAT 2022.3.1 and SPSS software. Fisher's test was used for the separation of means when analysis of variance revealed significant differences between treatments at the 5% probability threshold.

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TABLE 1: Assessment criteria for soil fertility classes.

Elements	Fertility level				
	Very high (without limitations)	High (limitation low)	means (limitations averages)	low (limitations severe)	very low (limitations very severe)
	Degree 0	Degree 1	Degree 2	Degree 3	Degree 4
MO (%)	> 2	2-1,5	1,5-1	1-0,5	< 0,5
N (%)	> 0,08	0,08-0,06	0,06-0,045	0,045-0,03	< 0,03
P_{ass} (cmol+/kg)	> 20	20-15	15-oct		< 5
K^+ ($cmol^+$/kg)	> 0,4	0,4-0,3	0,3-0,2	0,2-0,1	< 0,1
Sum of bases ($cmol^+$/kg)	> 10	10-7,5	7,5-5	5-2	< 2
V (%)	> 60	60-50	50-30	30-15	< 15
CEC ($cmol^+$/kg)	> 25	25-15	15-10	10-5	< 5
pH	5,5-6,5 6,5-8,2	5,5-6,0 6,5-7,8	5,5-5,3 7,8-8,3	5,3-5,2 8,3-8,5	< 5,2 >8,5

Sources : Dabin (1970)

Soil analysis

Physico-chemical analyzes of the fine fraction (less than 2 mm) were carried out at the Laboratory of Soil Analysis and Environmental Chemistry (LABASCE) of the University of Dschang in Cameroon. They covered particle size, determination of pHeau, organic carbon, total nitrogen, exchangeable bases (Ca, Mg, K, Na), assimilable phosphorus and CEC.

These analyzes consisted of the determination of the particle size (5 fractions), carried out by the international method modified by the use of the Robinson pipette, of the organic carbon, determined by the method of (Walkley and Black, 1934); total nitrogen as determined by the Kjeldahl method; pHeau, using a pH meter with (1/2.5) as the soil-water ratio; assimilable phosphorus by the Bray1 method; cationic exchange capacity (CEC), by extraction with 10% KCl and then distillation by the Kjeldahl method; exchangeable cations (Ca, Mg and K), determined by Atomic Absorption Spectrophotometry and exchangeable aluminum.

III. RESULTS

The results of the analysis of the physico-chemical parameters analyzed made it possible to evaluate the fertility state of the soils of Kouh-East.

A. Granulometry of the soils studied

Clay content varies from 7 to 47.50% (average = 33.86%); ET = 11.32%), Kaba soils (PKB) have the highest percentage of clay and the lowest percentage is Bekodo II soils (PBK). The silt content ranges from 4 to 42.50% (mean = 22.77% ; ET = 10.83%), the highest percentage of silt is that of Bekorobe soils (PBKB) and the lowest percentage is that of Bekodo II soils (PBK). The percentage of sand varies from 25,00 % to 88 % (average = 43,65 %) ; ET = 18.81%), Bekodo II (PBK) soils had the highest percentage and the lowest percentage was Bekorobe (PBKB) soils.

Overall, the soils studied have a sandy-clay texture with the exception of Bodo, Bekodo II, Beyama and Gouri soils, which have a sandy-clay texture.

B. Organic matter and fertility

Soil organic matter ranged from 0.41 to 4.62% (mean = 1.63%) ; ET = 1.06%). The highest value of organic matter is found in Beleckara (PBKA) soils and the lowest in Seri (PSR) and Kobetey (PKBY) soils. The organic matter content is very high in the soils of Bekorobe, Kouh, Sacko, Takapti, Beleckara and Kaba; the organic matter content of the soils of Sandana, Békoye, Daye, Bépara and Békodo II is high; the organic matter is medium in the soils of Dédaye, Djoli, Békori, Bémou, Bédouada, Béyama and Gouri; the soils of Békolo, Bédjo, Béro and Bébara have low levels of organic matter and the very low levels are observed in the soils of Kobetey, Séri and Bodo.

C. pH and fertility of soils studied

The pH values studied range from 5.10 to 7.60 (Mean=6.22 ; ET=0.59) versus the standard ranging from 6.5 to 7.5 The highest pH is observed in Beleckara soils (PBKA) and the lowest is in Kaba soils (PKB). Very high pH values are observed in the soils of Békorobe, Békolo, Dédaye, Sandana, Bédjo, Békoye, Sérìe, Djoli, Békori, Sacko, Takapti, Béro, Bémou and Béyama ; the high pH values are those of the soils of Kobetey, Bélkara, Bépara, Bébara, Bodo, Bédouada, Békodo II and Gouri ; Kouh soils have a medium pH ; those of Daye have a low pH and those of Kaba have a very low pH.

D. Nitrogen and soil fertility studied

The nitrogen content varies from 0.00 to 0.11% (Mean=0.07% ; ET=0.02%) (Table 3) versus the standard of 0.1 to 0.15%. The highest nitrogen values are observed on Bekorobe soils (PBKB) and the low values are Belekara soils (PBKA). These values show that the soils of Békoye, Djoli, Sacko and Takapti have very high concentrations ; the soils of Kobetey, Sandana, Bédjo, Béro, Kaba and Bébara have high nitrogen content ; the soils of Kouh, Dedaye, Séri, Daye, Bémou and Bodo have average nitrogen contents ; the soils of Békolo, Békodo II, Béyama and Gouri have low nitrogen contents and the soils of Bélkara, Bépara and Bédouada are very low in nitrogen (table 2).

E. Calcium and fertility of soils studied

Calcium content ranges from 0.72 to 28.88 cmol+/kg (Mean=6.12% ; ET=5.51%) against the standard of 2.3 to 3.5 $cmol^+$/kg. Belecara soils (PBKA) have the highest magnesium content and Gouri soils (GGO) have the lowest content. Apart from the soils of Békolo, Dédaye, Bédjo, Békoye, Daye, Békori, Sacko, Takapti, Kaba, Bodo, Békodo II, Béyama and Gouri, the other soils are provided with Calcium (table 2).

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F. Magnesium and fertility of soils studied

The magnesium concentration varies from 0.28 to 6.56 cmol+/kg (Mean=2.33% ; ET=1.49%) versus the reference ranging from 1 to 1.5 cmol+/kg. The highest amount of magnesium is in Kobetey (PKBY) soils and the smallest is in Beyama (PBY) soils. The soils studied are predominantly magnesium-containing, with the exception of the soils of Bekolo, Seri, Takapti, Bodo, Bedouada, Bekodo II, Beyama and Gouri.

G. Potassium and fertility of soils studied

The potassium concentration ranges from 0.01 to 20.09 cmol+/kg (Mean=3.44% ; ET=4.92%) against the standard ranging from 0.2 to 0.4 cmol+/kg. The highest potassium values are for Djoli soils (PDJL) and the lowest are for Béyama soils (PBY). Very high levels of potassium are observed in the soils of Bekorobe, Bekolo, Kobetey, Kouh, Dédaye, Sandana, Bédjo, Békoye, Série, Djoli, Daye, Békori, Sacko, Takapti, Béro, Bélkara, Kaba, Bémou and Bébara ; the average soil concentrations are observed in Bedouada soils ; Bodo and Gouri soils have low potassium levels ; the soils of Bépara, Békodo II and Béyama have very low levels of potassium.

H. Assimilable phosphorus and soil fertility

The concentration of assimilable phosphorus varies from 0.02 to 212.83 ppm (Mean=31.59% ; ET=44.05%) versus reference ranging from 10 to 15 ppm. Seri soils (SRP) have the highest assimilable phosphorus levels and Kouh soils (PKH) have the lowest. The values of very high contents compared to the standard are those of the soils of Békorobe, Sandana, Bédjo, Békoye, Série, Djoli, Takapti, Bélkara, Bémou, Bépara and Béyama ; high phosphorus levels are observed in the soils of Békolo and Daye ; the low concentrations are those of the soils of Kobetey, Dédaye, Békori, Sacko, Kaba, Bebara, Béro, Bodo, Bédouada, Bekodo II and Gouri and the soils of Kouh have very low values of assimilable phosphorus.

I. Sodium and fertility of soils studied

The sodium concentration ranges from 0.03 to 0.24 cmol$^+$/kg (Mean=1.66% ; ET=1.18%) versus the reference of 0.3 to 0.7 cmol+/kg. The highest amount of sodium is observed in Daye (PDY) soils and the lowest in Beyama (PBY) soils. Soils studied are predominantly sodium-containing except for Bodo, Bedouada, Bekodo II, Beyama and Gouri soils.

TABLE 2: Physico-chemical characteristics of soils in different localities.

Locality code	**A (%)**	**L (%)**	**S (%)**	**pHeau**	**OM (%)**	**N (cmol+/kg)**	**C/N (cmol+/kg)**	**Ca (cmol+/k)**	**Mg (cmol+/kg)**	**K (cmol+/kg)**	**Na (cmol+/kg)**	**SBE (cmol+/kg)**	**CEC (cmol+/kg)**	**V %**	**P_{ass} PPm**
PBKB	32,50	42,50	25,00	5,90	2,63	0,44	39,62	8,32	4,72	1,28	2,34	16,66	28,00	59,51	29,86
PBKL	38,50	24,00	37,50	6,20	0,88	0,04	14,53	0,96	1,04	0,91	0,36	3,27	29,20	11,21	17,55
PKBY	32,00	25,50	42,50	5,80	0,41	0,06	4,24	7,12	6,56	2,00	2,34	18,03	26,24	68,70	8,08
PKH	37,25	33,00	39,75	5,40	2,28	0,05	25,18	6,80	3,28	1,15	1,88	13,11	29,20	44,91	0,02
PDD	27,50	42,00	30,50	6,60	1,46	0,05	17,30	9,60	1,44	6,49	2,67	20,21	33,40	60,50	8,43
PSDN	47,50	14,50	38,00	5,60	1,81	0,07	15,48	7,76	2,96	13,32	3,58	27,63	23,80	116,07	113,57
PBDJ	43,00	22,25	34,75	6,90	0,53	0,07	4,36	3,36	1,28	1,03	1,08	6,75	25,60	26,37	59,83
PBKY	44,25	23,00	32,75	6,50	1,69	0,09	11,33	3,92	1,36	2,33	1,46	9,07	39,80	22,79	20,59
PDJL	39,50	19,25	41,25	6,40	0,41	0,06	3,94	3,04	2,96	0,69	0,85	7,54	40,60	18,58	212,83
PSR	33,25	23,25	43,50	6,30	1,46	0,09	8,97	7,20	3,12	20,09	0,85	31,27	33,40	93,62	51,70
PDY	34,25	24,25	41,50	5,20	1,69	0,06	16,52	5,20	2,08	13,32	3,98	24,58	32,20	76,34	16,78
PBKR	37,25	24,75	38,00	5,60	1,23	0,07	9,69	5,60	2,08	4,06	3,78	15,52	31,40	49,44	9,57
PSCK	32,50	30,00	37,50	5,60	2,05	0,11	10,86	4,96	1,52	4,06	1,88	12,42	23,16	53,65	9,07
PTKT	36,50	24,50	39,00	6,30	2,98	0,09	19,00	1,68	2,24	0,59	1,74	6,24	27,56	22,65	20,17
PBR	44,75	24,75	30,50	6,60	0,53	0,07	4,45	7,04	2,88	1,41	2,67	14,01	34,12	41,06	14,59
PBKA	31,25	30,75	38,00	7,60	4,62	0,00	1912,83	28,88	3,12	4,97	2,85	39,82	34,24	116,29	22,79
PKB	47,50	27,25	25,25	5,10	4,15	0,07	32,12	5,76	1,52	3,64	2,03	12,95	33,20	39,01	13,74
PBM	41,50	32,50	26,00	6,10	1,46	0,05	15,93	6,72	3,36	0,59	1,20	11,87	38,80	30,60	22,01
PBP	45,00	29,00	26,00	6,90	1,93	0,01	199,76	12,48	3,68	0,02	0,97	17,15	42,32	40,53	51,21
PBB	36,75	29,25	34,00	7,00	0,88	0,07	7,73	8,16	4,32	3,44	2,34	18,26	34,80	52,48	11,47
PBO	8,00	4,00	87,00	6,60	0,42	0,05	4,80	2,16	0,56	0,13	0,10	2,95	11,20	26,33	6,62
PBD	38,00	6,00	56,00	6,40	1,00	0,04	14,50	2,96	0,56	0,22	0,10	3,84	15,68	24,48	13,80
PBK	7,00	4,00	88,00	6,00	1,90	0,03	36,60	1,28	0,56	0,05	0,06	1,95	15,68	12,43	6,25
PBY	8,00	4,00	87,00	6,30	1,19	0,03	23,00	1,20	0,28	0,01	0,03	1,44	12,00	20,33	43,87
PGO	23,00	5,00	72,00	6,60	1,06	0,04	15,50	0,72	0,88	0,10	0,24	1,94	17,60	11,02	5,38
MOY	33,86	22,77	43,65	6,22	1,63	0,06	98,73	6,12	2,33	3,44	1,66	13,54	28,53	45,56	31,59
ET	11,32	10,83	18,81	0,59	1,06	0,02	372,18	5,51	1,49	4,92	1,18	9,65	8,61	29,45	44,05
Max	**47,50**	42,50	88,00	7,60	4,62	0,11	1912,83	28,88	6,56	20,09	3,98	39,82	42,32	116,29	212,83
Min	7,00	4,00	25,00	5,10	0,41	0,00	3,94	0,72	0,28	0,01	0,03	1,44	11,20	11,02	0,02
Var	133,55	122,19	368,67	0,36	1,17	0,00	144287,60	31,64	2,31	25,24	1,45	96,92	77,20	903,61	2021,07

S: sand; L: Limon; A: Clay; MO: Organic Matter; N: Total nitrogen; K^+: Potassium; Na^+: Sodium; Ca^{2+}: calcium; Mg^{2+}: Magnesium; SBE: Sum of Exchangeable Bases; CEC: Cationic Exchange Capacity; P: Phosphorus; V: Saturation; MOY: Medium; ET: Standard deviation; Max: Maximum; Min: Minimum; Var: Variance.

TABLE 3: Correlation between physico-chemical soil parameters

Corrélations														
	A	L	S	pHwater	MO	N	Ca	Mg	K	Na	SBE	CEC	V	P
A	1													
L	,514**	1												
S	-,877**	-,854**	1											
pHwater	-,115	-,068	,078	1										
MO	,140	,355	-,273	-,115	1									
N	,328	,134	-,275	-,379	-,167	1								
Ca	,210	,496*	-,404*	,394	,564**	-,405*	1							
Mg	,380	,575**	-,538**	-,032	,047	,012	,446*	1						
K	,176	,151	-,198	-,241	,126	,340	,227	,149	1					
Na	,440*	,568**	-,579**	-,311	,291	,243	,459*	,455*	,457*	1				
SBE	,323	,520**	-,487*	,059	,429*	-,026	,813**	,542**	,720**	,689**	1			
CEC	,711**	,707**	-,822**	,103	,192	,120	,431*	,497*	,195	,420*	,475*	1		
V	,223	,377	-,346	-,056	,375	,025	,713**	,491*	,748**	,687**	,949**	,230	1	
P	,250	-,106	-,103	,082	-,192	,043	-,030	,125	,143	-,053	,068	,264	,076	1
**. The correlation is significant at level 0.01 (bilateral)).														
*. The correlation is significant at 0.05 (bilateral)														

J. Saturation rate and fertility of soils studied

The saturation rate of the soils studied generally ranges from 11.02 to 116.29% (Mean=45.56% ; ET=29.45%) versus the standard of 40-60%. The highest rate of saturation is observed in Beleckara (PBKA) soils and the lowest is in Gouri soils. Very high saturation rates are observed in the soils of Kobetey, Dédaye, Sandana, Djoli, Daye and Bélekara; the high saturation rates are those of the soils of Bekorobe, Sacko and Bebara; average saturation values are observed in the soils of Kouh, Békori, Béro, Kaba, Bémou and Bépara; the soils of Bédjo, Békoye, Série, Takapti, Bodo, Bédouada and Béyama contain low saturations; the very low saturation rates are those of the soils of Bekolo, Bekodo II and Gouri.

K. Cationic Exchange Capacity (CEC) and fertility of soils studied

The Cationic Exchange Capacity content of the soils studied ranges from 11.20 to 42.32 $cmol^+/kg$ (Mean=28.53% ; ET=8.61%) (Table 3) versus the reference of 10 to 25 $cmol^+/kg$. The highest concentrations of CEC are in Bépara soils (BBP) and the low values are in Bodo soils (PBO). Very high levels of CEC are observed in the soils of Békorobe, Békolo, Kobetey, Kouh, Dédaye, Bédjo, Békoye, Djoli, Seri, Daye, Békori, Takapti, Béro, Bélkara, Kaba, Bémou, Bépara and Bébara; high CECs are observed in the soils of Sandana, Sacko, Bekodo II and Gouri; the average CfD values are those of Bodo, Bedouada and Béyama soils.

L. Sum of exchangeable bases (SBEs) and soil fertility studied

The sum of the exchangeable bases of the soils studied ranges from 1.44 to 39.82 $cmol^+/kg$ (Mean=13.54% ; ET=9.65%) against the reference of 5 to 10 $cmol^+/kg$. The highest sum of tradable soils is that of Belecara soils (PBKA) and the lowest value is observed in Beyama soils (PBY). The very high values of the sums of the exchangeable bases are observed in the soils of Békorobe, Kobetey, Kouh, Dédaye, Sandana, Djoli, Daye, Békori, Sacko, Béro, Bélkara, Kaba, Bémou, Bépara and Bébara; the sums of the high exchangeable bases are observed in the soils of Békoye and Seri; Bédjo and Takapti soils have the average EBS; the Békolo, Bodo, Bédouada SBE and the soils of Bekodo II, Beyama and Gouri have very low SBEs.

The table below summarizes the physico-chemical characteristics of the soils studied.

M. Correlation result between parameters

A significant and positive bilateral correlation at the 0.01 level was observed between clay and CEC (R^2 = 0.711), between Limon and CEC (R^2 = 0.707) (Fig. 3 and table 4). As soil clay and silt content increases, the CEC becomes important. This relationship is antagonistic between CEC and sand, which has a strong bilateral correlation that is significant and negative at the 0.01 level (R^2=-0, 822). The higher the soil sand level, the lower the CEC.

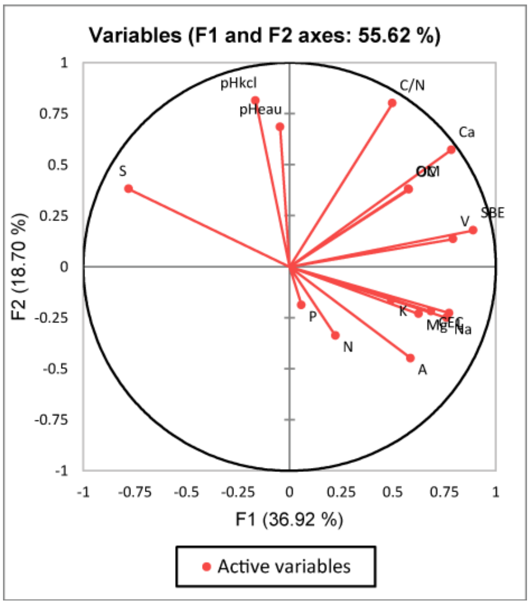

Fig. 3. Correlation circle of physico-chemical parameters

A significant and positive bilateral correlation at 0.01 and 0.05 was observed between MO and Ca (R^2 = 0.564), SBE and MO, respectively (R^2 = 0.429). Increasing MO results in increased Ca and SBE and vice versa. A significant and positive bilateral correlation at 0.01 was observed between SBE and the

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following parameters: silt (R2 = 0.520), Ca (R2 = 0.812), Mg (R^2 = 0.542), K (R^2 = 0.720), Na (R^2 = 0.689). The increase in the content of these elements also leads to the increase in the SBE. The same trend was observed between the saturation rate V at the threshold of 0.01 with the following chemical parameters Ca (R^2=0.713), K (R^2=0.748), Na (R^2=0.687) and SBE (R^2=0.949).

IV. Discussion

A. CEC and particle size distribution

The CEC is an indicator of potential soil fertility (table 4). The cationic exchange capacity of the soil represents the size of the reservoir allowing certain cationic fertilizing elements (potassium, magnesium, calcium, etc.) to be stored in a reversible manner. It is related to the humic clay complex. The Cationic Exchange Capacity content of the soils studied ranges from 11.20 to 42.32 $cmol^+$/kg against the reference of 10 to 25 $cmol^+$/kg. The proportions of clay and silt largely dominate that of sand in all localities (88%). The soils are clay-sandy to sandy-clay in texture. Clay is the most active particle size fraction because it has multiple functions (association with organic matter, aggregate cohesion, cation and anion fixation at exchange sites, water retention) [7][46][27]. Similar results were found by [25][8].

B. Exchangeable cations and saturation of soil cations

Soils in different localities have calcium levels ranging from 0.72 to 28.88 $cmol^+$/kg, compared to the standard of 2.3 to 3.5 $cmol^+$/kg. More than 52% of soils have a calcium content below the reference. Replaceable calcium deficiencies normally occur only in soils with a low pH $\leq$ 5.5, which is the case for the sites studied [28]. Magnesium ranges from 0.28 to 6.56 $cmol^+$/kg, compared with the reference of 1 to 1.5 $cmol^+$/kg. More than 32% of the soils studied are free of magnesium. Potassium concentration ranges from 0.01 to 20.09 $cmol^+$/kg versus the reference of 0.2 to 0.4 $cmol^+$/kg. More than 20% of the soils studied are below the accepted threshold. Alkaline and alkaline-earth elements play a major role in plant nutrition, and their deficits are not without problems [34].

The nitrogen content varies from 0.00 to 0.11% against the standard of 0.1 to 0.15%. More than 28% of soils are nitrogen deficient.

The saturation rate of the soils studied generally ranges from 11.02 to 116.29%. These values show that more than 40% of the soils studied are below the saturation threshold. These findings are consistent with those of [36].

C. Organic matter

Organic matter is a good indicator of plant health. It contributes to soil fertility. In this study, soil organic matter ranges from 0.41% to 4.62%. More than 72% of the soils studied have organic matter, 28% are low, which could be an obstacle to good productivity [42][3]. This could be explained by the lack of organic amendment and chemical inputs and the overexploitation of soils [7][36].

D. Soil pH

The pH values studied range from 5.10 to 7.60. The soils studied are slightly acidic to neutral. These pH values are characteristic of the nature of the ferrallitic and ferruginous soils of the Sahel [24][11][26]. For pH values below 5,5 as for the local ferrallitic and ferruginous soils, an addition of organic matter is necessary to increase the pH, but if not, it will be a limiting factor for plant feeding.

E. Assimilable phosphorus

More than 48% of the soils studied have assimilable phosphorus contents below the permitted threshold (table 4). Many authors have shown the role of phosphorus in plant nutrition. These studies reveal the importance of organic matter in the availability of assimilable phosphorus [43]. Organic matter is an important source of phosphorus in organic form but also contributes to the reversible storage of nutrients through mineralization/immobilization by microorganisms [9].

TABLE 4: Degree of limitation of physico-chemical parameters and soil fertility level

Caractéristiques	Békorobe	Békolo	Kobetey	Kouh	Dédaye	Sandana	Bédjo	Békoye	Séri	Djoli	Daye	PBKR
MO (%)	Unlimited	Severe Limitation	Very severe limitation	Unlimited	Average Limitation	Low Limitation	Severe Limitation	Low Limitation	Very severe limitation	Average Limitation	Low Limitation	Average Limitation
N (%)	Unlimited	Severe Limitation	Low Limitation	Average Limitation	Average Limitation	Low Limitation	Low Limitation	Unlimited	Average Limitation	Unlimited	Average Limitation	Low Limitation
P_{ass} ($cmol^+$/kg)	Unlimited	Low Limitation	Severe Limitation	Very severe limitation	Severe Limitation	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Low Limitation	Severe Limitation
K+ ($cmol^+$/kg)	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
SBE ($cmol^+$/kg)	Unlimited	Severe Limitation	Unlimited	Unlimited	Unlimited	Unlimited	Average Limitation	Low Limitation	Low Limitation	Unlimited	Unlimited	Unlimited
CEC ($cmol^+$/kg)	Low Limitation	Unlimited	Unlimited	Unlimited	Unlimited	Low Limitation	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
V (%)	Very severe limitation	Very severe limitation	Unlimited	Average Limitation	Unlimited	Unlimited	Severe Limitation	Severe Limitation	Severe Limitation	Unlimited	Unlimited	Average Limitation
pH	Unlimited	Unlimited	Low Limitation	Average Limitation	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Severe Limitation	Unlimited
Limiting factors	V	**MO, N, P, SBE, CEC**, V	**MO, N, P, pH**	**N, P, V, pH**	**MO, N, P**	**MO, N, CEC**	**MO, N, SBE, V**	**MO, SBE, V**	**MO, N, SBE, V**	**MO**	**MO, N, P, pH**	**MO, N, P, V**
Soil class	I	IV	IV	III	III	II	IV	III	IV	II	III	III
Fertility level	High fertility level	Very low fertility	Very low fertility	Low fertility	Low fertility	Average fertility level	Very low fertility	Low fertility	Very low fertility	Average fertility level	Low fertility	Low fertility

Caractéristiques	Sacko	Takapti	Béro	Bélekara	Kaba	Bémou	Bépara	Bébara	Bodo	Bédouada	Békodo II	Béyama	Gouri
MO (%)	Unlimited	Unlimited	Severe Limitation	Unlimited	Unlimited	Average Limitation	Low Limitation	Severe Limitation	Very severe limitation	Average Limitation	Low Limitation	Average Limitation	Average Limitation
N (%)	Unlimited	Unlimited	Low Limitation	Very severe limitation	Low Limitation	Average Limitation	Very severe limitation	Low Limitation	Average Limitation	Very severe limitation	Severe Limitation	Severe Limitation	Severe Limitation
P_{ass} ($cmol^+/kg$)	Severe Limitation	Unlimited	Severe Limitation	Unlimited	Severe Limitation	Unlimited	Unlimited	Severe Limitation	Severe Limitation	Severe Limitation	Severe Limitation	Unlimited	Severe Limitation
K^+ ($cmol^+/kg$)	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Very severe limitation	Unlimited	Severe Limitation	Average Limitation	Very severe limitation	Very severe limitation	Severe Limitation
S ($cmol^+/kg$)	Unlimited	Average Limitation	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Severe Limitation	Severe Limitation	Very severe limitation	Very severe limitation	Very severe limitation
CEC ($cmol^+/kg$)	Low Limitation	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Average Limitation	Average Limitation	Low Limitation	Average Limitation	Low Limitation
V (%)	Low Limitation	Severe Limitation	Average Limitation	Unlimited	Average Limitation	Average Limitation	Average Limitation	Low Limitation	Severe Limitation	Severe Limitation	Very severe limitation	Severe Limitation	Very severe limitation
pH	Unlimited	Unlimited	Unlimited	Low Limitation	Very severe limitation	Unlimited	Low Limitation	Low Limitation	Low Limitation	Low Limitation	Low Limitation	Unlimited	Low Limitation
Limiting factors	**CEC, V**	**SBE, V**	**MO, N, P, V**	**N, pH**	**N, P, V, pH**	**MO, N, V**	**MO, N, K, V, pH**	**MO, N, P, V, pH**	**MO, N, P, K V, SBE, CEC**	**MO, N, P, K V, SBE, CEC, pH**	**MO, N, P, K V, SBE, CEC**	**MO, N, K, SBE, CEC, V**	**MO, N, P, K, SBE, CEC, V, pH**
Soil Class	III	III	IV	III	IV	III	IV	IV	IV	IV	IV	IV	IV
Fertility level	Low fertility	Low fertility	Very low fertility	Low fertility	Very low fertility	Low fertility	Very low fertility	Very low fertility	Very low fertility	Very low fertility	Very low fertility	Very low fertility	Very low fertility

V. CONCLUSION

At the end of the study, the main objective of which was to assess the fertility of the soils by physico-chemical characteristics, it is apparent from the measurement of the physical parameters that the soils studied have a predominantly clay-sand to clay-sand texture overall. This gives them an acceptable retention capacity of mineral elements brought by fertilization.

Measurements of soil chemical parameters have shown that soils have low to neutral pH values (5.10<pH<7.60), very low organic matter contents, and average cation exchange capacity values. The contents of alkali and alkaline-earth elements are mainly low, a deficiency of total nitrogen and assimilable phosphorus has been observed. Fertility level assessment revealed four fertility classes with low to very low fertility overall, with the exception of Békorobe Class I soils with good fertility and Sandana and Djoli Class II soils with medium fertility. In view of the low organic matter content of organic and chemical soil improvers, it is essential to increase soil fertility.

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