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EVALUATION OF THE EFFECT OF PLOUGHING (ANIMAL TRACTION) AND DIRECT SEEDING ON THE SUSCEPTIBILITY TO EROSION OF VERTISOLS IN LERE BY THE ANALYTICAL METHOD, SOUTHWESTERN CHAD

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ABSTRACT

A study on the erodibility of Lere soils is conducted on plots subjected to different cultivation practices in the Bipare –Foulmbare village sector (located to the west of Lere/Chad). The objective of the present work is to evaluate the effect of animal-drawn ploughing and direct seeding on the susceptibility of Vertisols to erosion using the indirect analytical method. More specifically, it was a question of comparing the two types of cultivation practices based on their erodibility indices, to see their influence on some chemical parameters and in order to highlight the interaction existing between the cultivation practices and/or erodibility indices and the organic matter rate. From the results obtained, the erodibility indices reveal that soils subjected to no-tillage (HS1 and HS2) are less sensitive to erosion than soils subjected to ploughing with animal traction (HL1 and HL2). Total clay (TC), clay aggregation (CA) and clay flocculation index (CFI) are positively correlated with each other and with OM and Ca^{2+}, while clay dispersion degree (CDD) and water dispersible clay (WDC) are positively correlated with each other. This would indicate that organic matter and calcium would play the roles of the main stabilizers of soils with a lower sensitivity to erosion. Soils under no-till have higher levels of organic matter, cation exchange capacity (CEC) and available phosphorus, while those under ploughing and animal traction have lower levels. Thus, cultivation practices influence soil fertility and in this case, ploughing with animal traction has a more negative impact than direct seeding on the chemical fertility of the soils studied.

Keywords : *cropping practices, erodibility, soil, Chad.*

RÉSUMÉ

Évaluation de l'effet du labour (traction animale) et du semis direct sur la susceptibilité à l'érosion des vertisols de Léré par la méthode analytique, Sud-ouest du Tchad

Une étude sur l'érodibilité des sols de Léré est conduite sur des parcelles soumises aux différentes pratiques culturales dans le secteur Biparé-Foulmbaré (situé à l'ouest de Léré/Tchad). L'objectif du travail est d'évaluer l'effet du labour et du semis direct sur la sensibilité à l'érosion des vertisols par la méthode analytique. Plus spécifiquement, il s'agissait de comparer les deux pratiques culturales sur la bases des leurs indices d'érodibilité, de voir leur influence sur quelques paramètres chimiques et afin de mettre en évidence l'interaction existant entre les pratiques culturales et/ou indices d'érodibilité et le taux de la matière organique. Les indices d'érodibilité utilisés des horizons de surface de ces sols révèlent que les horizons sous semis direct (HS1 et HS2) sont moins sensibles à l'érosion que les sols labourés à la traction animale (HL1 et HL2). L'argile totale (AT), l'agrégation d'argile (AgA) et l'indice de floculation (IFA) sont positivement corrélés entre eux et à la MO et au Ca^{2+}, alors que le degré de dispersion d'argile (DDA) et l'argile dispersable dans l'eau (ADE) sont positivement corrélés entre eux. Les sols sous semis direct présentent des taux plus élevés en matière organique, une teneur plus élevée en CEC et en phosphore assimilable que ceux soumis au labour à la traction animale.

Mots-clés : *pratiques culturales, érodibilité, sol, Tchad.*

I - INTRODUCTION

The rapid demographic growth of Third World countries poses multiple problems, including that of soil degradation. Soil is an essential resource for the proper agronomic functioning of ecosystems [1], and is increasingly threatened by major degradation processes such as erosion, which compromises the ecological integrity and productivity of land on a global scale, with around two-thirds of agricultural land having suffered from varying degrees of degradation [2]. This is because population growth and agricultural practices are not evolving at the same pace. Indeed, land management practices such as fallowing are not practiced under optimal conditions due to the very difficult access to new cultivable land, which is a direct cause of soil exposure to erosive phenomena [3]. In dry tropical zones, particularly in Chad, cultivation with inappropriate practices degrades the land and leads to a rapid decrease in soil organic carbon (SOC) content and the appearance of deficiencies in various mineral elements. Crop yields decrease and the land is sometimes abandoned [4]. Water erosion is one of the most active processes in the current dynamics of soil covers and is a major threat to agricultural soils worldwide. According to [5, 6], this phenomenon is responsible for land and nutrient losses and contributes in part to the reduction of the production potential of cultivated soils, following the export by runoff and eroded particles of essential elements and nutrients of soil fertility such as organic matter, calcium, potassium, nitrogen and phosphorus. This is therefore a major challenge for sustainable development. One of the factors influencing erosion is the adoption of inappropriate management methods [7, 8], in this case ploughing. Ploughing, for example, disorganizes the soil structure and makes it vulnerable to erosion. Indeed, it favours the pulverization of the surface soil during subsequent rainfall. The surface soil thus "pulverized" loses its cohesion and quickly becomes saturated: muddy flows, capping and surface sealing are the consequences. In addition, cultivation practices affect the stability of aggregation and the carbon content of the surface layer of the soil [9, 10]. Thus, water erosion is enhanced by tillage operations, including the depth and direction of tillage, the timing of ploughing, the type of implements used and the number of passes.

It is therefore urgent to develop a method that is both rapid and precise in order to predict the sensitivity of soils to different types of erosion, their evolution under cultivation and the conservation measures to be implemented as soon as land is cleared [11]. In the Biparé-Foulmbaré sector (located to the west of Léré), there are soils that are highly prized for their fertility, commonly known as 'damé', which are vertisols. This sector is an area where agricultural activity is almost intense [12] and constitutes a grazing corridor par excellence [13]. Moreover, these soils have been described as sensitive to erosion by [14]. Knowing and understanding the sensitivity of soils to erosion is a crucial step in proposing the best techniques for rational and sustainable management of the soil resource. It is in a sense that several authors have evaluated the sensitivity of soils to erosion in the field under simulated rainfall [15], under natural rainfall and in the laboratory [16 - 19]. The main objective of the present work is to evaluate the effect of ploughing and no-till on the erosion susceptibility of Vertisols in Lere. More specifically, it aims to compare the two cropping practices based on their erodibility indices, to see the influence of cultivation practices on some chemical parameters, to highlight the interaction between cultivation practices and/or erodibility indices and the organic matter content.

II - MATERIAL AND METHODS

II-1. MATERIAL

II-1-1. Presentation of the study area

The ***Figure 1*** shows the location of the study area in the Mayo-Kebbi West region of southwestern Chad. The area extends between latitude 9.62° to 9.66° North and longitude 14.00° to 14.06° East. Its climate is of the Sahelo-Sudanese type [13] with two seasons, a seven-month dry season from October to April and a rainy season from May to September. The geological bedrock of the region is a Precambrian basement consisting of various granites and metamorphosed volcano-sedimentary rocks from the Pan-African Orogeny (~600 million years ago), detrital sedimentary rocks and Cretaceous basalt seams [13]. The vegetation is characterized by a wooded savannah up to 8-10 m high [12]. The hydrographic network consists of Lake Lere, Lake Trene, Mayo-Kebbi, Mayo-Binder and Mayo-El Ouaya and several other small mayo. The population of the Bipare-Foulmbare sector is agro-pastoral and practices flood recession agriculture in the winter season (end of November-beginning of February) and in the rainy season (from the end of April). The main crops are food crops and cash crops. Food crops are mainly sorghum, rice, maize, penicillium, sesame, flood recession sorghum, cassava, cowpeas and groundnuts. The main cash crop is cotton, to which are added groundnuts and rice.

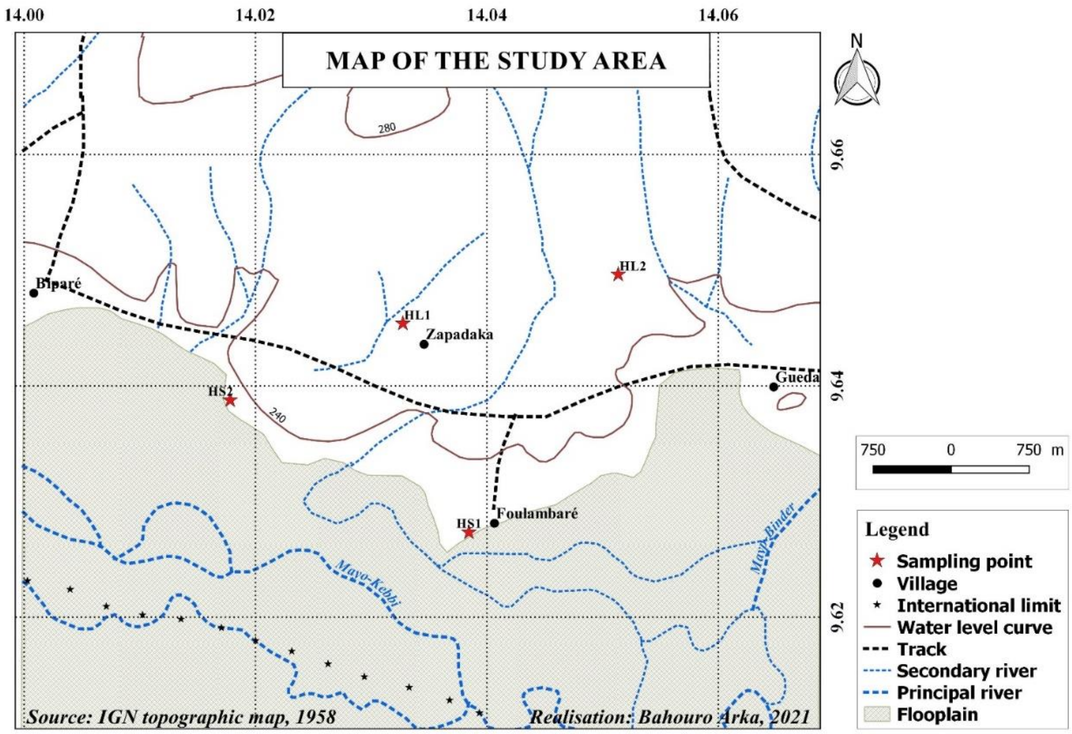

Figure 1 : *Location map of the study area (extract from map NC-33-IX, E = 1/200000)*

II-2. METHODS

II-2-1. Analytical method of laboratory

To carry out our work, the method adopted is the so-called indirect or analytical laboratory method, which consists of evaluating the erodibility of the soils based on erodibility indices, calculated based on the physics and chemical data of the soils. In the framework of this study, these indices are: the water-dispersible clay rate (WDC), the degree of clay dispersion (CDD), the clay flocculation index (CFI) and the clay aggregation (CA). In addition to these indices, OM and Ca2+ contents were used to see the impact of tillage on soil stability.

II-2-1-1. Calculation of erodibility indices

The indices used are obtained by the following ***Equations*** :
The degree of clay dispersion is obtained by the ***Equation*** :

$$DCD = WDC/TC \quad (1)$$

The aggregation of the clay is determined by the ***Equation***

$$CA = TC-WDC \quad (2)$$

The clay flocculation index is calculated as

$$CFI = (TC-WDC)/TC \quad (3)$$

NB : TC = total clay

II-2-2. Fieldwork

Prior to soil sampling, plots well identified based on cultivation practices were selected at the end of the rainy season after the harvest (December-January). Four plots of one hectare each under cultivation were chosen. Two of which were ploughed by animal traction and two others under direct seeding. The ***Figure 2*** shows soil-sampling scheme for surface horizons in a given field. Thus, on each plot, thirteen (13) samples were systematically taken ***(Figure 2)*** at depths of 0-25 cm. All these samples were put together, mixed well and then by quartering, the two diametrically opposed parts were put back together and mixed again to finally obtain a final composite sample for physics and chemical analysis in the laboratory. Four final composite samples from two cropping practices were subjected to physics and chemical analyses. The samples from no-tillage are designated HS1 and HS2, while those from plots ploughed with animal traction are coded HL1 and HL2.

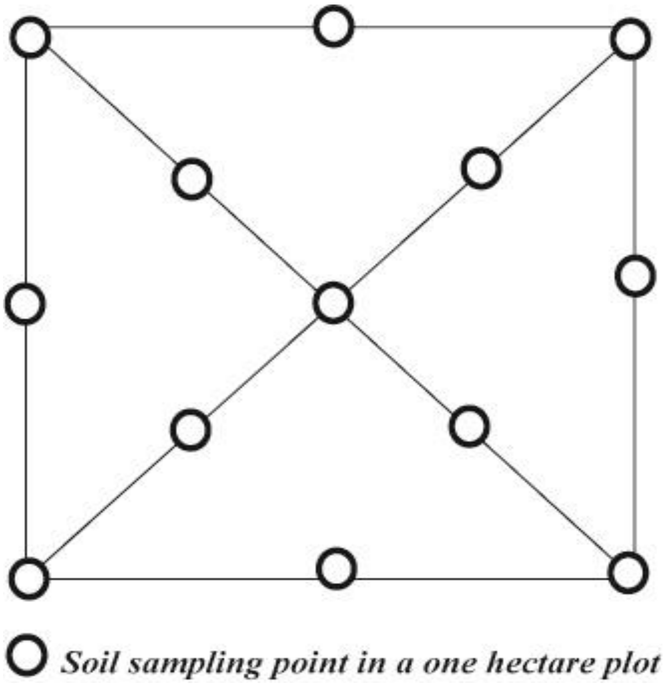

Figure 2 : *Sampling scheme for surface horizons in a given field*

II-2-3. In the laboratory

In the laboratory, the physics and chemical analyses were carried out on the fine soil (< 2 mm) of the surface samples taken from the plots. The particle size analysis was done mainly with distilled water for particle size analysis without dispersant. For the determination of total clay and total silt, the particle size analysis was done by the dispersant method. The method used for the determination of OM is that of Walkley and Black. The determination is based on the determination of one of the constituents of OM : organic carbon (OC). OM contains on average 58 % CO or % CO × 1.724 = % OM. Total nitrogen was determined by mineralization of the sample using the Khjedahl method. Assimilable phosphorus was measured by the OLSEN method. For the determination of the CEC, the method used was that described such as [20] : the exchangeable bases were determined by complexometry with EDTA (Ethylene Diamine Tetra-acetic acid).

III - RESULTS

III-1. Presentation of the results

The ***Table 1*** presents the results of the physico-chemical analyses of the soil samples studied.

Table 1 : *Physico-chemical analysis results of soil samples*

Horizons	Particle size with dispersant in %				Particle size without dispersant in %			Exchangeable bases in meq/100g				CEC in meq/ 100g	Nt in %	OM in %	av. P in ppm	pH
	S	Lf	Lg	A	S	Lt	A	Ca^{2+}	Mg^{2+}	K^+	Na^+					
HS1	46	6	22	26	47	50	3	4.4	1.6	0.03	0.4	13 .2	0,86	4.00	8	8.8
HS2	26	16	24	34	29	68	3	3.76	1.76	0.03	0.3	15.2	0.65	6.51	7	6
HL1	38	35	1	26	40	53	7	4	2.4	0.03	0.4	10.4	0.66	2.93	1	7.7
HL2	18	32	27	22	20	74	6	0.64	1.2	0.03	0.4	12.4	0,60	3. 04	0.5	7.9

S : sand, A : clay, Lf : fine silt, Lg : coarse silt, Lt : total silt ; CEC : cation exchange capacity ; Nt: total nitrogen ; av. P: available phosphorus. The Ca^{2+} and Mg^{2+} contents are highest in the HS1, HS2 and HL1 horizons (4.4, 3.76 and 4 meq/100g respectively; 1.6, 1.76, 2.4 meq/100g); the HL2 horizon has the lowest values (0.64 and 1.2 meq/100g). The other exchangeable bases such as K+ and Na+ have very low to medium levels in the soils. The CEC is average in the HS1 and HS2 horizons and low in the HL1 and HL2 horizons. The HS1, HL1 and HL2 horizons have an average OM content (4.00 %, 2.93 and 3.04 respectively); the HS2 horizon has a very high content (6.51 %). The total nitrogen content is generally high in all horizons. Assimilable phosphorus is generally low in all horizons.

The ***Table 2*** presents summary of the soil erodibility indices obtained from particle size analyses with and without dispersant.

Table 2 : *Summary of erodibility indices*

Horizons	TC (%)	TS (%)	WDC (%)	CA (%)	CFI (%)	DCD
HS1	26	28	3	23	0.89	0.11
HS2	34	40	3	31	0.91	0.09
HL1	26	36	7	19	0.73	0.27
HL2	22	60	6	16	0.73	0.27

III-2. Comparative analysis of results

The variation of erodibility indices according to cultivation practices is shown in ***Figure 3***.

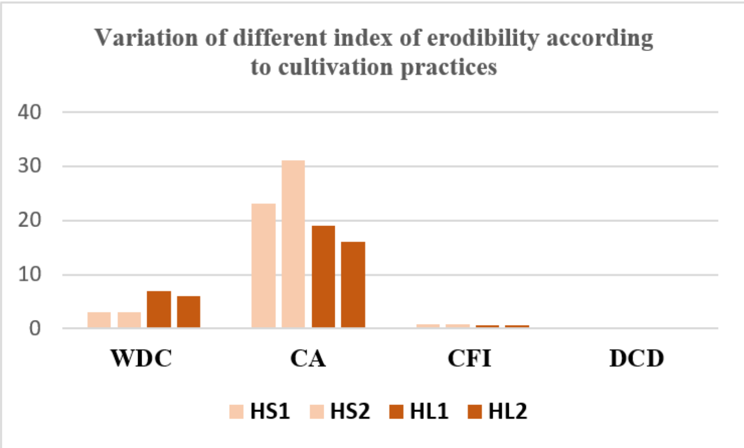

Figure 3 : *Diagram of Variation of different index of erodibility in the different soils studied*

III-2-1. Water Dispersible Clay

The ***Figure 4*** presents the variation of water dispersible clay according to cultivation practices. Water dispersible clay is generally relatively low in all surface horizons (3-7 %) ***(Table 2)***. HL1 and HL2 have the highest WDC values (7 % and 6 % respectively), while HS1 and HS2 have the lowest values (same contents : 3 %).

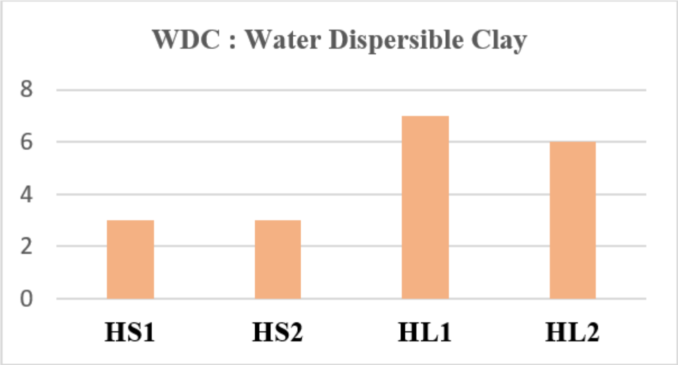

Figure 4 : *Diagram of variation of water dispersible clay in the different soils studied*

III-2-2. Degree of Clay Dispersion

The ***Figure 5*** shows the variation in the degree of clay dispersion according to cultivation practices. The DDA of the studied soils varies between 0.09 % and 0.27 %. The HL1 and HL2 horizons have the highest levels of clay dispersion (0.27 % each); while the HS1 and HS2 horizons have lower levels (0.11 % and 0.09 % respectively).

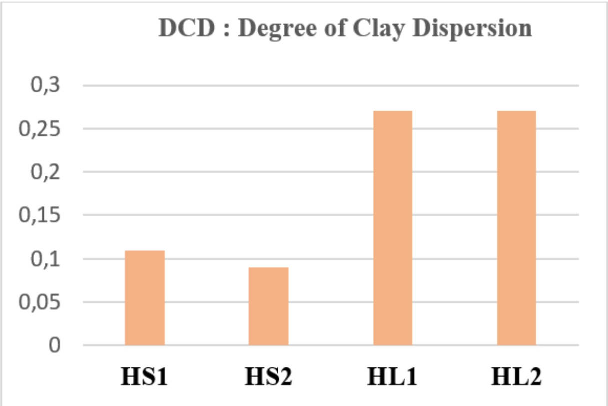

Figure 5 : *Diagram of Variation of degree of clay dispersion in the soils studied*

III-2-3. Clay Aggregation

The relationship between farming practices and clay aggregation is shown in ***Figure 6*** below. CA varies from 16 to 31 % in the studied surface horizons. It is highest in the HS1 and HS2 horizons (23 % and 31 % respectively); while the HL1 and HL2 horizons have lower values (19 % and 16 % respectively).

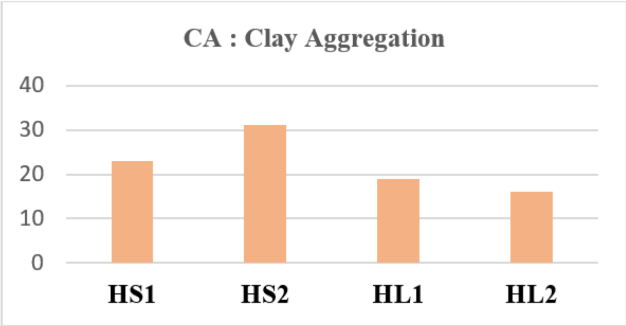

Figure 6 : *Diagram of Variation of clay aggregation according to cultivation practices*

III-2-4. Clay Flocculation Index

The ***Figure 7*** shows the variation of the clay flocculation index in soils according to cultivation practices. It can be seen that the HS1 and HS2 horizons have higher clay flocculation indices (0.89 % and 0.91 % respectively) than the HL1 and HL2 horizons, which have the same values (0.73 %).

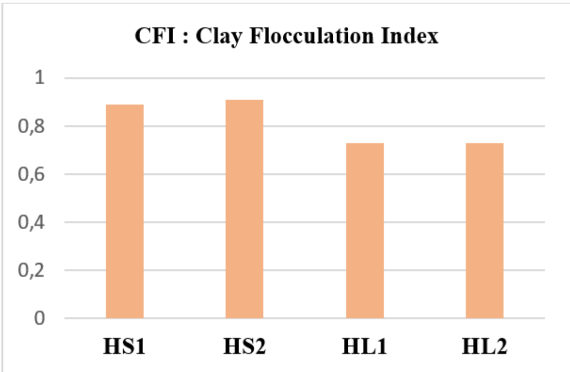

Figure 7 : *Diagram of Variation of clay flocculation in the studied soils*

Relationship between some chemical parameters of studied soils and cultivation practices. The ***Figure 8*** shows the relationship between some chemical parameters of soils and cultivation practices.

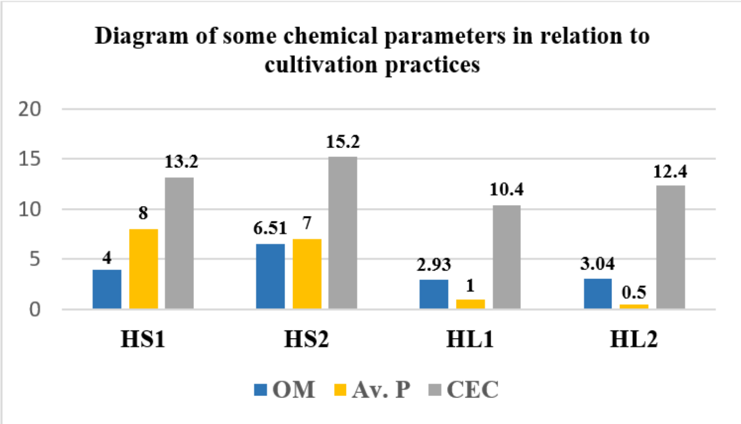

Figure 8 : *Diagram showing the relationship between some chemical parameters of studied soils and cultivation practices*

III-3. Statistical analysis

The ***Table 3*** gives the correlation matrix between the different erodibility indices and the organic matter content and calcium. In this table, organic matter is positively correlated to CFI and TC, and significantly positive to CA. Exchangeable Ca^{2+} content is very low in HL2 (0.64 meq/100g) and low in HS1, HS2 and HL1 horizons respectively (4 meq/100g, 3.76 meq/100g and 4.4 meq/100g. However, it is positively correlated with TC, CA and CFI.

Table 3 : *Correlation matrix between erodibility indices and some physics and chemical properties*

Variables	TC (%)	TS (%)	WDC (%)	CA (%)	CFI (%)	DCD	OM (%)	Ca (meq/100g)
TC (%)	1							
TS (%)	-0,409	1						
WDC (%)	-0.610	0,439	1					
CA (%)	0,968	-0,456	-0,790	1				
CFI (%)	0,740	-0,562	-0,977	0,883	1			
DCD	-0,740	0,562	0,977	-0,883	-1,000	1		
OM (%)	0,932	-0,225	-0,778	0,968	0,836	-0,836	1	
Ca meq%	0,564	-0,975	-0,419	0,570	0,574	-0,574	0,347	1

NB : The correlation is established at $P \leq 0.05$. All values in bold show a significant correlation.

IV - DISCUSSION

This work, which aims to evaluate the effect of ploughing with animal traction and no-till on soil erodibility by the analytical method, highlights the impact of tillage on their sensitivity to erosive phenomena on the one hand and on their chemical quality on the other. The results obtained are as clear as that under no-till conditions, the organic matter, CEC and assimilable phosphorus rates are higher than under animal-drawn tillage conditions. OM contents are higher in the no-till horizons (4.00 % and 6.51 % for HS1 and HS2 respectively) and lower in the ploughed horizons with animal traction (2.93 % and 3.04 % for HL1 and HL2 respectively). The very strong correlations between the erodibility indices of clay aggregation (r = 0.968) and clay flocculation index (r = 0.836) and OM indicate that the latter controls soil stabilization. This stability is itself due to the cultivation practice used, which is direct seeding. Organic matter is known for its role as a binder between soil aggregates. It is the source of the maintenance of clay particles between them subjected to the osmotic pressure induced by the sodium adsorbed on their surface. To this end, organic matter plays an indirect role in soil stability by reducing evaporation induced by direct seeding. These results are confirmed by the work of [21], which states that reducing tillage (i.e. no-till) increases the stock of soil organic matter. Other authors have also shown that soils with greater resistance to erosion are those that are rich in organic matter [8].

In Brazil, research has shown that cropping practices have a strong impact on soil carbon storage and that no-till cropping systems are the method to increase yields and soil carbon storage [22, 23]. Calcium is a key element of soil fertility and at the same time a flocculant of clay particles [24] and allows soil structuring. Although calcium levels in these soils hardly vary according to the cultivation practices, the positive correlation with AgA and IFA indicates that it would play the role of flocculant and would thus direct the erodibility of the studied soils. Total clay is relatively high (22 % to 34 %) in all surface horizons studied. However, water dispersible clay (WDC) is higher in the horizons under traction tillage than in those under no-till. Some authors have shown that soils with higher values of WDC are more vulnerable to erosion than those with lower values [16, 18, 19]. From the results obtained, it can be deduced that the horizons under animal traction cultivation are more sensitive to erosion than those under no-till. This can be explained by a high degree of clay mobility due to the tillage of these soils. This is confirmed in the work of [8, 25] who concluded that cultivation practices, in particular tillage, have an influence on the erosion of cultivated soils. Thus, tillage destabilizes soil aggregates and makes them vulnerable to erosive phenomena such as rainwater and runoff. It is concluded that the erodibility of these soils is linked to the dispersability of the clays, which in turn is linked to the cultivation practice, which in this case is ploughing. CA and CFI indicate aggregate stability and clay mobility [17]. Both indices have higher values in no-till horizons than in ploughed horizons. Thus, HS1 and HS2 horizons are more stable than HL1 and HL2. The higher percentage of AgA in HS1 and HS2 would be related to the fact that the aggregates in these soils are not disturbed by tillage. Furthermore, the positive correlation between these indices (CA and CFI), Ca (respectively r = 0.570 and r = 0.574) and OM (respectively r = 0.968 and r = 0.836) indicates that flocculation and aggregation would be linked to the role that calcium and OM would play in the stability of soil structures. Thus, calcium and OM would play the respective roles of flocculant and soil stabilizer, which are themselves linked to tillage and therefore to cultivation practices. Clay dispersion degree (CDD) values are lower in no-till soils than in animal-drawn soils. High CDD values imply a high susceptibility to erosion as in the work of [18, 26]. Thus, no-till soils are more stable and therefore less susceptible to erosion; whereas horizons under traction tillage are less stable and more susceptible to erosion. This high degree of dispersion in HL1 and HL2 soils would be linked to ploughing, which destabilizes the aggregates and makes them easily dispersible in water. In short, in the horizons under animal traction cultivation, ploughing would be the cause of this greater sensitivity to erosion. On the other hand, the low sensitivity to erosion of soils under no-tillage is explained by the fact that the soils are not disturbed, are richer in organic matter and are therefore less sensitive and less exposed to erosive phenomena.

- ***Influence of cultivation practices on some soil chemical parameters***

The parameters chosen and observed are CEC, assimilable phosphorus and organic matter. It is observed that all these parameters, except calcium, under animal traction cultivation (ploughing) present lower rates than those under no-tillage (15.2 and 13.2 meq/100g of CEC under no-tillage against 12.4 and 104 under ploughing; 8 and 7 ppm of assimilable phosphorus under no-tillage against 1 and 0.5 under ploughing; 6.51 and 4 % of OM under no-tillage against 3.04 and 2.93 under ploughing) It is clear from the results obtained that these chemical parameters are influenced by the cultivation practice. Thus, no-till conserves organic matter [23] and consequently increases CEC, which is dependent on the soil's clay-humus complex ***(Figure 8)***. From this discussion on erodibility, the present study has shown that the soils of Léré are relatively sensitive to erosion, which in turn is a function of cropping practices. These cultural practices in turn have a clear influence on certain chemical parameters and consequently on soil fertility.

V - CONCLUSION

It is clear that the erodibility of the soils in the study area depends on the cultivation practices. Indices indicating aggregate stability such as clay flocculation index and clay aggregation are higher in the no-till horizons than in the ploughed horizons. Both the water-dispersible clay and the degree of clay dispersion show the dispersability and mobility of clays and consequently the instability of aggregates are higher in the horizons under traction tillage than in the horizons under no-tillage. Calcium and organic matter, which act as flocculants and aggregators, are positively correlated with clay aggregation and clay flocculation index, indicating their important role in soil stabilization processes. In addition, based on the contents of some chemical parameters obtained, the cultivation practices clearly influence the chemical and physical fertility of the soils of the studied plots. Reduced tillage and direct seeding are effective means of limiting this type of erosion

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