https://dx.doi.org/10.22161/ijeab.46.40 ISSN: 2456-1878

Variation of carbon and major nutrients contents in two types of soil under stone bunds management in cotton-based cropping systems in the Sudanese zone of Burkina Faso

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Abstract— *In Burkina Faso, soil fertility decline is a major constraint in cotton-based farming systems. In this area, most of the soil fertility management are mainly focus on soil amendment with organic manure and the used of mineral fertilizers. In addition to these techniques, the present study on the use of stones bunds was conducted at Gombélédougou in order to limit erosion and improve availability of fertilizers provided to plants. Gombélédougou is in the district of Koumbia in Sudanese zone of Burkina Faso. About 605ha covering six (6) soil types were managed using stone bunds established along the contour lines. The spacing between the stone rows was 2.5 m. Concerning additional soil fertility management, it consisted in crops rotation (cotton//cereals); the application of mineral fertilizer at the dose of(110 ± 25 kg/ha for NPK (14-23-15) and 52.5 ± 15 kg / ha for urea (46%)) and organic manure (1787.50 ± 1390.96 kg / ha). The indicators for assessment of the effects of the stone bunds were evaluated using the variation of the carbon and of the major elements (nitrogen, phosphorus, potassium) contained in soil as well as the overall evolution of the fertility of these soils. The results showed that the stone bunds in combination with current fertilization techniques increased the soil carbon level by 0.04% and 0.15%, respectively in Lixisols (FLIP) and Cambisols(BEF) in one hand, and in the other hand, Nitrogen contents decreased from -0.01 to -0.02% and those in Phosphorus from -1.21 to -2.61 mg/kg in these soils. The stone bunds reduced significantly the transfer of sediments and nutrients from upper to the down slopes. As consequences soil fertility was improved in thelixisols located at the up slops at the detriment of Cambisolin the down slop. These results show that the stone bunds are more effective when producers combine an appropriate technique of organic (compost) and mineral fertilization.*

Keywords— ***cotton-based cropping systems, Gombélédougou-Burkina Faso, soil fertility, Stones bunds, Sudanian zone.***

I. INTRODUCTION

Soils degradation in cotton and cereals-based cropping systems area in Burkina Faso is a serious constraint and yield limiting factor. In these farming systems, cotton is a cash crop which is cultivated in rotation with steaple cereals (maize and sorghum) [1]. Therefore, this degradation treatment crops yields and consequently farmers´ incomes and food security. The cotton base-farming systems are located in the Sudanese zone with fairly good rainfall and less land pressure compared to the rest of the country. In addition, cotton producers have some facilities in getting mineral fertilizers. With regard of these advantages, soil fertility management have been focussed on mineral fertilization, crops rotation and fallow [2]. Currently, this area is experiencing internal population growth due to migration of populations coming from the other regions of the country for farmland. As consequences, the traditional soil fertility management systems are no longer able to address degradation issues. Alternative approaches in soil fertility management such as the development and the use of specifics fertilizers, conservation agriculture, crops residues recycling at the plot scale, have been developed to address the problem [3, 4, 5].

In the district of Koumbia as in most of the cotton production zones, Lixisols with sandy textural constitution and are the most dominant [6]. The topography is characterized by steep slopes (> 5%) with harsh and torrential rainfallexposing soil to heavy erosion risks. Despite of the situation depicted above, few actions such as establishing physical barriers on soil surface to mitigate runoff have been undertaken to address soil erosion as done in the Sahelian zones [7,8]. In Burkina Faso, soil erosion is a global constraint in agricultural lands and, in the Sahelian zones farmers have developed the settlement of stone bunds to address the issue since 1988. The use of stone bunds to control soil erosion and its adverse effects on soil nutrients (N, P and K) and carbon balance have been widely investigated [9, 10]. However, in the Sudanese zone (cotton production area), there are few integrations of stone bunds into soil fertility management packages despite the high risk of soil erosion. The few investigations focused on improving soil productivity using stone bunds were in forestry [11].

In the current context, with soil degradation and land pressure in the cotton production zones, it is consistent to move towards agricultural intensification while limiting the risk of erosion through the use of anti-erosion devices. Therefore, stone bunds appear as an alternative to experiment since this practice is unusual in the Sudanian zone as well as in the cotton-based cropping systems. The study reported here in was conducted at Gombélédougou in the district of Koumbia in Burkina Faso. It aimed to improve the organic and mineral status of soils by using stone bunds combined with organic and mineral fertilization. Carbon and nutrients (N, P, K) budget of different soil types were measured in order to assess the effectiveness of stone bunds on soil fertility management.

II. MATERIALS AND METHODS

2.1 Study site location

The study was conducted in the village of Gombélédougou, district of Koumbia(11°14’ 11’’ N Longitude, and 3°41’ 47’’ W Latitude) in Burkina Faso (Fig. 1) Gombélédougou has Sudanese climate with two distinct seasons. The rainy season lasts from juneto september and a dry season from october to may; In general,the rainfall distribution is irregular and the average rainfall ranged from 800 to 1100 mm.

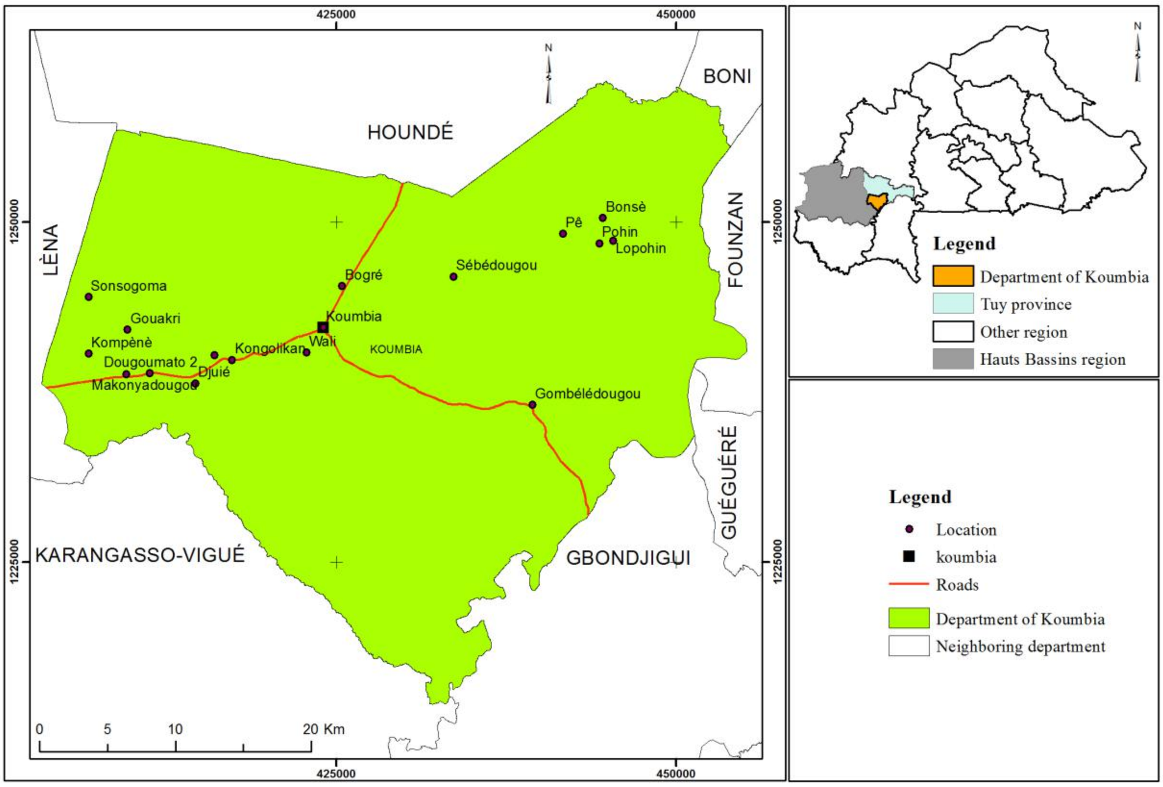

Fig.1: Land use map of the district of Koumbia

2.2 Treatments and background of the study site

The site presents a high level of soil degradation due to runoff and inconsistent soil fertility management practices. The stone bunds were hand constructed along the contour lines on 605.59 ha, using rock material from the surrounding mountains.The device includes main stones rows (40cm wide and 40 cm high) and stones minor rows (30 cm wide and 20 cm high) along the contour lines. Stone rows spacing were 5 meters between the consecutive main rows and 2.5 meters between the main row and the next minor row. The land use systems were mainly cotton based farming systems and fertility management techniques were mainly the application of organic manure in combination with NPK (14-23-15) and urea (46% N). The average application rates for these fertilizers were 1787.50 ± 1390.96 kg / ha for organic manure, 110 ± 25 kg / ha for NPK (14-23-15) and 52.5 ± 15 kg / ha for urea (46%).

2.3 Physical and chemical characteristics of the soil

At the baseline situation in 2016, physical and chemical characteristics of the soil were analysed after soil survey according to the standards [12, 13, 14]. In total, 40 soil samples (2 to 4 samples by soil type depending to the soil depths) were collected after the soil description in different soil types for the purpose of their characterization. Due to their unsuitability to farming activities, soil samples were not collected on the shallow soil (lithosolon rock or lateritic breastplate materials). In 2019, samples were collected at the same places as in 2016, using huger and at the soil 0-20 cm depth,for the purpose of the determination of soil fertility variation.

The soil parameters analysed were: total nitrogen (Nt), total phosphorus (Pt), assimilable phosphorus (Pass), total potassium (Kt) and available potassium (K dis), sulfur (S), and boron (B). The soil pH_{H2O}, organic carbon content (organic matter), the cation exchange capacity (CEC) and the sum of the exchangeable bases (S), These parameters were determined according BUNASOLS [15].

2.4 Determination of the average value of the chemical parameters and rating of the factors

For the determination of the average values of the chemical parameters and suitability classes of the different soil types, the following formula (I) and Table 1 were respectively used.

Average content of the parameter considered= $\frac{D1*C1+D2*C2+\cdots+Dn*Cn}{(D1+D2+\cdots Dn)}$ (I)

D (cm) = the thickness of the horizon

C = concentration of the chemical parameter considered

D1+D2+……. + Dn = depth the soil pit

Table1: Rating standards of parameters for the determation soil suitability

Parameters	Units	Very low/ unfavorable	Low	Medium	High	very high
Organicmatter (OM)	%	<0.5	0.5-1.0	1.0-2.0	2.0-3.0	> 3.0
Total Nitrogen (N)	%	<0.02	0.02-0.06	0.06-0.1	0.1-0.14	>0.14
Assimilable phosphorus (Pass)	mg/Kg	<5	5-10	10-20	20-30	>30
Availablepotassium (K)	mg/Kg	<25	25-50	50-100	100-200	>200

Source : BUNASOLS[13]

Table 2 gives the different soil fertility classes according to the standards of BUNSOLS [13]. Soil parameters considered for the rating were organic matter content, the sum of exchangeable bases and the pH_{water} [13].

Table 2 :Standard for evaluation of soil fertility

Classes	Very low	Low	Medium	High	Very high
Rating	< 4,4	4,5 – 7,5	7,6 – 10,5	10,6 – 13,5	> 13,6

III. RESULTS AND DISCUSSION

2.5 Soil resources of the study site

Details on soil types of the investigated site are summarized in Fig. 2. The most dominants soil in terms of proportion were the ferric epipetric plinthosols (53.17%) and endo/epipetric lixisols(30,83%).

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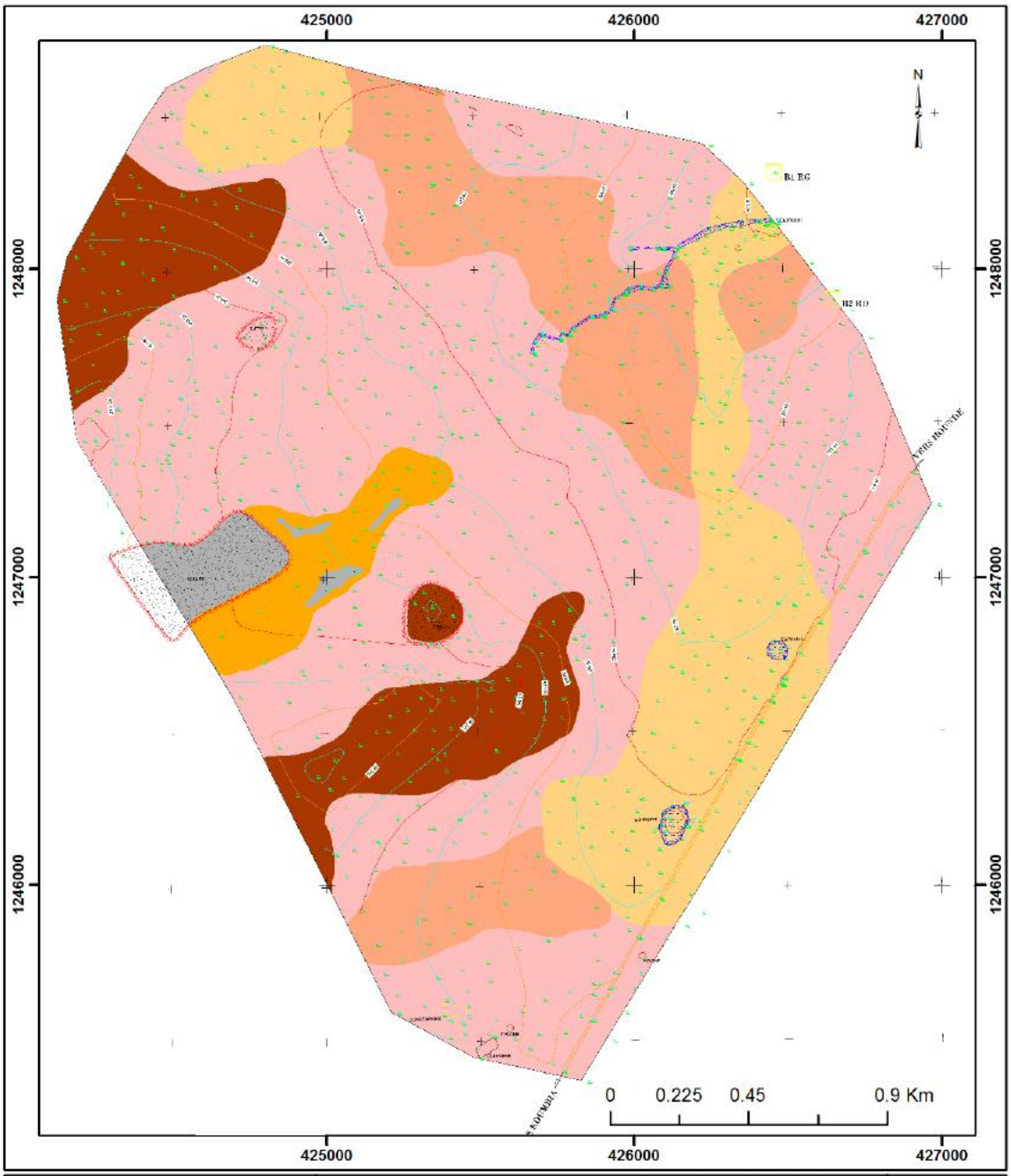

LEGEND

- ■ Sampled profiles
- Topographic boundaries
- Water level contours of 2.5 m
- Water level contours of 5 m
- Main water level contours
- National roads
- water flow
- Hill
- stamped area

Soils Units	Soil types FAO/WRB, 2014 classification	Area ha	Area %
Lithosol sur roche	Epipetric Plinthosol	10.57	1.75
Lithosol sur cuirasse	Epipetric Plinthosol	66.05	10.91
So brun eutrophe tropical ferruginisé	Cambisol eutrique ferrique	20.26	3.35
Sol ferrugineux tropical lessivé induré profond	Lixisol endopétroplinthique -ferrique	86.5	14.28
Sol ferrugineux tropical lessivé induré peu profond	Plinthosol épipétrique, ferrique	321.97	53.17
Sol ferrugineux tropical lessivé à taches et concrétions	Lixisol gleyique, ferrique	100.22	16.55

Fig.2: Soil map of the site of Gombélédougou

Note: Epipetric Plinthosol = L/r; or L/c; Cambisoleutriqueferrique = BEF; Lixisolendoplinthique-ferrique= FLIP ; Plinthosol epipetrique-ferrique = FLIPP ; Lixisolgleyique, ferrique = FLTC

https://dx.doi.org/10.22161/ijeab.46.40 ISSN: 2456-1878

2.6 Soil physical and chemical constitution

Soil physicochemical parameters were determined in 2016 as baseline situation. According to BUNASOLS [13], carbon, nitrogen and potassium in Eutric-ferric-cambisolwere "*medium*" and "*low*" in the other soil types (Table 3); indifferently to the soil type the available phosphorus was "*low*". Except the Eutric-ferric-cambisol with clay loamy textural constitution, the other soil had silty to clay-loam textural composition,

Table 3: Physicochemical characteristics of the different soil types in site of Gombélédougou at the baseline in 2016

		ferric epipetric plinthosols and endo/epipetric lixisols		
	BEF	**FLTC**	**FLIPP**	**FLIP**
Textural constitution	LA	LAF/LF	L	LA
Clay (%)	45.10	27.45 ± 11.09	25.49 ± 8.32	23.53 ± 2.77
Silt(%)	29.41	50.98 ± 8.32	39.22 ± 2.78	35.30 ± 2.78
sand(%)	25.49	21.57 ± 2.77	35.30 ± 11.09	41.18 ± 5.55
OM (%)	1.916	1.11 ± 0.30	1.21 ± 0.05	1.15 ± 0.11
C (%)	1.111	0.64 ± 0.17	0.70 ± 0.03	0.67 ± 0.07
N (%)	0.097	0.06 ± 0.02	0.06 ± 0.01	0.06 ± 0.01
C/N	11	11.00 ± 0.00	11.00 ± 1.41	11.50 ± 0.71
Pass(mg/kg)	4.24	4.27 ± 0.13	3.17 ± 1.01	3.16 ± 0.08
K_av(mg/kg)	51	41.50 ± 6.36	55.00 ± 43.84	47.50 ± 28.99
S total (S) %	0.4	0.68 ± 0.44	1.01 ± 0.18	0.72 ± 0.18
Total Br(B) %	0.04	0.05 ± 0.00	0.03 ± 0.01	0.04 ± 0.00
pH_{H2O}	5.7	5.28 ± 0.64	5.39 ± 0.18	4.93 ± 0.08

Note: BEF = Cambisoleutrique ferrique ; FLTC = Lixisolgleyique, ferrique ; FLIPP = Plinthosolepipetrique-ferrique ; FLIP= Lixisolendoplinthique-ferrique

2.7 Variation in soil organic carbon and major nutrients (N, P and K)content as affected by the stone bunds

2.7.1 Change in average organic carbon content

Regardless of the types of soil, stone bunds establishment and the application of organic manure contributed to accumulation of organic carbon soil (Fig. 3a). In fact, from 2016 to 2019, the increase in the soil carbon rate was ranged from 0.04% to 0.15%. Compared to CambisolEutric Ferric where the highest rate was recorded with 0.15% accumulation of organic carbon, this increase of soil carbon content in the ferric epipetric plinthosols and endo/epipetric lixisols was in the range of 0.04 and 0.08%. The accumulation of carbon recorded in the different soil types is linked to the mitigation of runoff by the stone bunds, and hence the lateral transfer of the sediments rich in organic matter from the upper to the down slops. These results are similar with those reported Zougmoré et *al*. [8] and Barry et *al*. [9] who found accumulation of soil organic carbon in soils under stone bunds management in the Sahelian zone of Burkina Faso.

Variation recorded in carbon accumulation between soil types could be explained by their textural constitution. Indeed, in addition to soil carbon loss through erosion, leaching is one of the main factors of soil carbon depletion in agriculturallands [16]. In the CambisolEutric Ferric leaching effects are lessened because of their high clay content 45.1%compared to the other soil types (Table 3).As consequence, carbon accumulation was found to be higher in the CambisolEutric Ferric compared to the other soil types.Also, by reducing runoff, the stone bunds promote water infiltration. In coarse textured soils (ferric epipetric plinthosols and endo/epipetric lixisols) this infiltration is favour the leaching of sediments from the upper soil layer to the down layers. In Cambisol Eutric Ferric, this process is reduced because the sediments are retained by the clay fraction at the soil upper layers.

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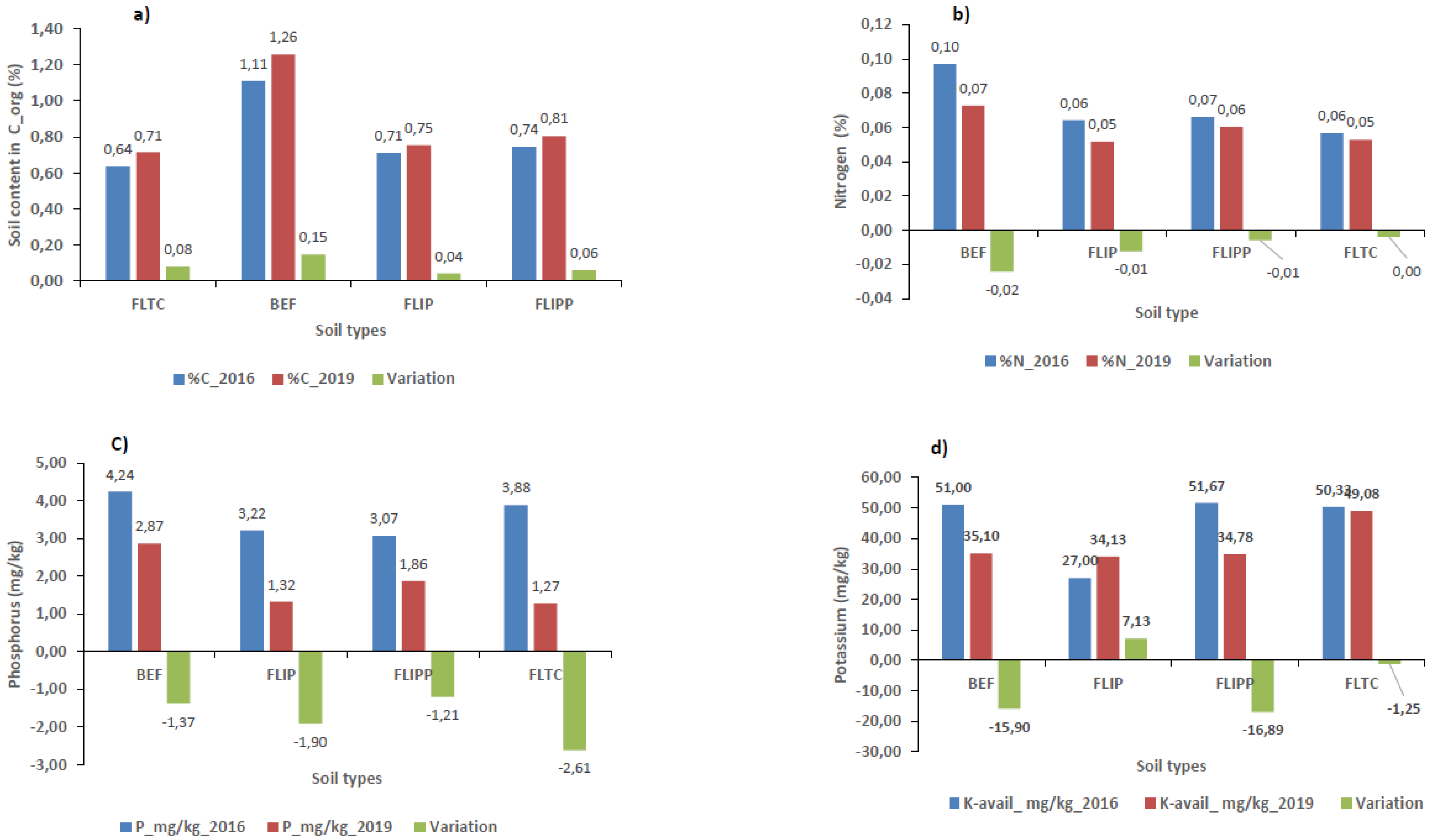

Fig.3: Variation in average carbon and major elements content (N, P and K) according to the soildifferent soil types from 2016 to 2019

Note: BEF = Cambisoleutrique ferrique ; FLTC = Lixisolgleyique, ferrique ; FLIPP = Plinthosolepipetrique-ferrique ; FLIP= Lixisolendoplinthique-ferrique

2.7.2 Variation of soil major nutrients (N, P and K) contents

Figures. 3b and 3c indicated decreases of the global trends of nitrogen and phosphorus after three cropping campaigns despite the construction of stone rows and the implementation of soil fertility management practices. The decline of nitrogen was more severe in Eutric-ferric-cambisol (BEF) compared to the Endopetric/Epipetric lixisols (FLIP and FLIPP) and in the Ferric-gleyic-lixisol(FLTC) where the highest nitrogen loss was recorded(Fig. 3c). As for the phosphorus, the average decreases were rangedfrom-1.21 to -2.61 mg/kg. Regarding variation in average potassium content (Fig. 3d), only epipetric-lixisol (FLIP) recorded positive balance (+7.13 mg/kg) while other soil types experienced decreases ranging from -1.25 to -16.89 mg/kg. These declines of soil major nutrients content are due to nutrient outflow through crop yields and heightened by poor soil fertility management practices indeed, organic manure and mineral fertilizers which are the main sources of compensation of nutrients outflow from the farms lands were applied at the rate of 1787.50 ± 1390.96 kg/ha for organic manure and 110 ± 25 kg/ha for NPK (14-23-15) and 52.5 ± 15 kg / ha for urea (46%). Theses application rates fertilizers are below the recommendations: 2500 kg/ha for organic manure and 1500kg and 100 kg for NPK and urea respectively [17, 18]. In addition to low rate of application of organic manure, 30.5% of producers did not regularly apply organic manure to their plots for various constraints. These results confirm the inaccessibility of organic manure to producers in the majority of cotton base cropping systems reported by Dakuo et *al*. [19].

The increase in carbon content observed in the different types of soil despite the shortcomings noted in organo-mineral fertilization could be explained by the positive effects of the stone bunds on soil´s water content. Indeed, previous studies have shown a positive contribution of the stone bunds on soil water status [20, 21]. Water scarcity and its irregular distribution is a limiting factor in rain-fed agriculture; the improvement of soil water status by the stone bunds induces a good development of crops and consequently, higher demand of nutrients from soil including N, P and K.

2.8 Evolution of soil fertility from 2016 to 2019

A decline of fertility trend in Eutric-ferric-cambisol (BEF) was noticed after three cropping seasons; however, it did not led decrease of their fertility class (Fig. 5). This could be explained by the fact that the BEF have a higher intrinsic potential for crop growing and this potential was improved with soil water status improvement due to the establishment of the stone bunds as outlined above. In a context of poor compensation of the nutrients exported by crops, this results in a sharp drop in nutrients, which has repercussions on the rating of factors determining soil fertility. These results are consistent with those found by Koulibaly et *al*., [22] Coulibaly et *al*., [23], reporting soil fertility decline in cotton-based cropping systems with low levels of organic and mineral fertilizer.

In FLIP and FLTC, a significant increase of the fertility level was recorded, resulting in the change from the fertility class "Low" to "High". Concerning the FLIPP the soil fertility remained the same after the three production campaigns. In the context of investigation area where soil fertility decline in cultivated soils is a common feature, these records in the trends of soil fertility for the FLIP, FLIPP and FLTC can be considered as an improvement of soil quality. Thus, this can be explained in one hand by the fact that farmers are aware of the fragility of these and preferentially use organic fertilisers on these soil in detrimental of BEF considered as fertile soils. In the other and the establishment of stone bunds have led to the reduction of runoff and consequently the transfer of sediments rich in organic matter from the FLIP et les FLIPP, FLTC located in the up slops to the down slops where the BEF are found. Gebrernichael et *al*., [24] and Zougmoré et *al*., [25] also reported a reduction in sediment losses from 21% to 61% from up to the down slops after establishment of stone bunds in the Sahelian zone of Burkina Faso. Therefore, the trend in soil fertility observed in the different soil classes can be explained by the dynamics of the sediments.

IV. CONCLUSION

This study showed that the establishment of the stone bunds induced an increase of soil organic matter content with higher accumulation in the Cambisol eutrique ferrique (BEF). However, the general trend for major nutrients (N, P, K) decreased after three year of cultivation. With regard to the overall trends soil fertility, the mismanagement of soil fertility and the mitigation of sediment transfer through runoff from the up to the down slopes contributed to a decline of the level of fertility in Cambisoleutriqueferrique (BEF). Also, sediments retained by the stone bunds and the applications of organo-mineral fertilizers on the Lixisolgleyiqueferrique (FLTC); Plinthosol epipetrique-ferrique (FLIPP); Lixisolendoplinthique-ferrique (FLIP) improved the fertility status of these soils.

The establishment of stone bunds allow physical restoration of the soil without compensating soils´ nutrients exported through crops. However, the stone bunds represent an initiation of alternative to soil fertility management on the site of Gombélédougou. To be effective, additional actions such us efficient recycling of nutrients on the agricultural plots scale through the appropriated use of organic manure and mineral fertilizers are recommended.

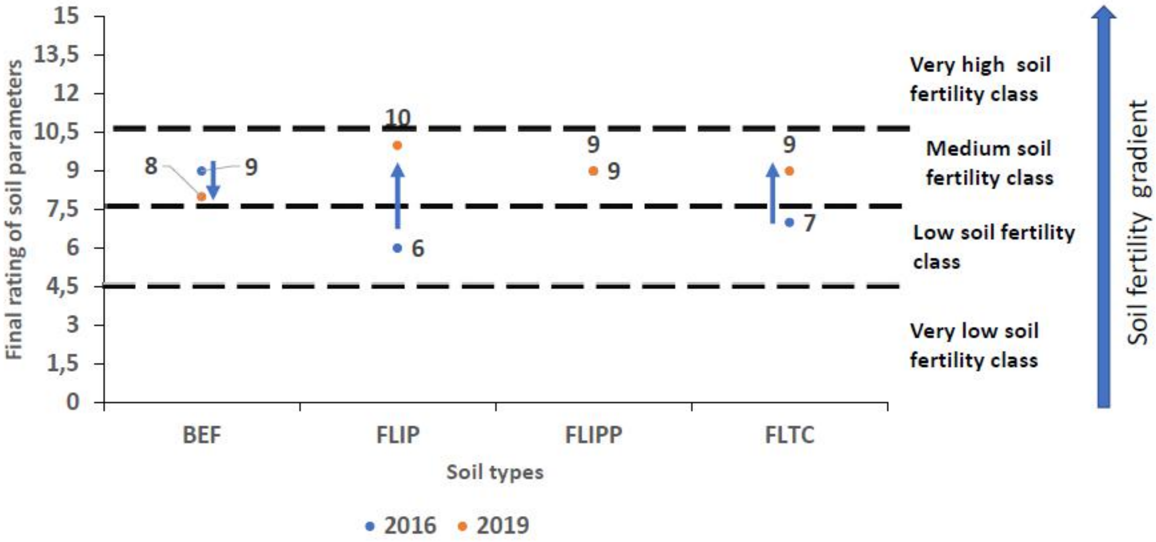

Fig.4: Evolution of fertility from 2016 to 2019 in the different types of soil

Note: BEF = Cambisoleutrique ferrique ; FLTC = Lixisolgleyique, ferrique ; FLIPP = Plinthosolepipetrique-ferrique ; FLIP= Lixisolendoplinthique-ferrique

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