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Soil Carbon Stocks Evolution in Organic Cotton-Based Cropping Systems in Southern and Northern Sudanese Agro-Ecological Zones of Burkina Faso

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Abstract: Variation of soil carbon stock in the cropping systems is an important indicator of their sustainability. The present study was conducted in 2015 and 2018 in seven organic cotton production areas distributed over the Southern and Northern Sudan agro-ecological zones in Burkina Faso. Soil samples were collected in 2015 as baseline and in 2018, after three years of cropping seasons, to determine the variations in carbon stocks in plots under organic farming systems. Surveys were also conducted to understand the fertilization practices implemented by producers during the same period. The results revealed that the recommended fertilization packages were not respected due to low production capacity and under using of organic manure. After three years of cropping in 2018, the deficit of organic restitution has led to a high decline of the soil carbon stocks. This decline was more severe in the 0-10 cm depth in some soils where the decrease in carbon stocks ranged from -4.6 t/ha to -5.5 t/ha. The correlation between soil types and their carbon stocks in the 0-10 cm soil layer was found to be significant (p < 0.05) in the Northern Sudan agro-ecological zone with adjusted R^2 = 74% and 54% in 2015 and 2018, respectively, and adjusted R^2 = 56% (2015) and 44% (2018) in the Southern Sudan agro-ecological zone. After three years of organic cotton-based farming, a decrease in the correlation between soil types and their carbon content was observed in the majority of cases. These results show that the process of carbon storage in soil is more influenced by agricultural practices and agro-ecological conditions than by the soil type.

Key words: Organic cotton, soil carbon stocks, cropping system, Burkina Faso.

1. Introduction

Carbon stocks in agricultural soils are an indicator of its fertility and the sustainability of farming systems. Globally, soil is the largest terrestrial carbon reservoir stored in the form of organic carbon [1-3]. This carbon plays an important role in maintaining soil productivity and contributing to the achievement of food security in the world [4]. Regarding this vital function, soil carbon represents a form of storage that various activity sectors and specially agriculture pursue to promote in order to reduce greenhouse gases emission [5, 6].

Several authors have reported that carbon storage capacity is strongly related to its intrinsic parameters and climatic conditions [7-9]. Therefore, most of the actions in favour of carbon sequestration in agricultural soils have been focused on the preservation of its integrity and creation of favourable environment through farming practices [10-12].

Among the farming practices that promote soil carbon storage capacity, organic farming systems are supposed to play a key role as projected by the initiative 4 per 1,000. Indeed, by promoting practices such as crop rotation integrating legumes into

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cropping systems, crop residue recycling at the plot scale, agro-forestry and agriculture-livestock integration [13], organic farming contributes to increasing the soil carbon stocks while reducing the emission of oxides nitrous. Therefore, organic farming appears as a form of agricultural production that is environmentally friendly [8, 14, 15]. In fact, the production and use of compost from crop residues reduces the use of nitrogen fertilizers and the burning of crop residues considered as sources of greenhouse gas emissions in agriculture [16, 17]. From economic point of view, organic farming is accessible to small-scale farmers with limited access to conventional inputs. In addition, the growing demand for organic products represents opportunities for small-scale farmers to integrate more profitable markets [18]. In view of the above, organic farming appears as an alternative to conventional agriculture with regard to the ecologic and economic aspects.

Despite the above-mentioned advantages, the implementation of organic farming requires consistent application of technological packages to achieve its objectives. In Burkina Faso farming activities rely on erratic rain conditions and inherently poor soils. In addition, farmers cannot produce organic fertilizer in sufficient quantity and quality to compensate nutrient outflow. This confers a certain fragility to the agro-systems in general and particularly organic farming systems and raises the question of sustainability of organic farming systems in such situation.

Organic farming covers several sectors including the fruits, vegetables and the cotton sectors in Burkina Faso. It has allowed organic crop producers to enter profitable markets and to make more profits from their production. Concerning the organic cotton-based farming systems, it is one of the most important sectors; the number of organic cotton producers was estimated to 6,589 producers in 2018 and areas under organic cotton-based farming systems were estimated 4,111 ha for 1,979 t of seed cotton produced. Despite its importance, low productivity problems resulting in steady yield decrease of seed cotton and rotation crops in organic cotton-based cropping systems are recorded in the sector.

To address this problem, there is a need to investigate in the soils' behaviour in organic cotton-based production systems to ensure their sustainability. The main objective of this study was to analyze changes of the carbon stocks in different soil types under organic cotton-based farming systems, and to propose levers for the sustainability of this production system in two agro-ecological zones of Burkina Faso.

2. Materials and Methods

2.1 Characterization of the Study Zones

The study was conducted in Southern and Northern Sudanese agro-ecological zones of Burkina Faso (Fig. 1). In the Southern Sudanese agro-ecological zone (Comoe, Ioba and Ziro), the annual rainfall varies from 900 mm to 1,200 mm and the sites of Boulgou, Koulpelgo, Gourma, Oubritenga and Nayala, in the Northern Sudanese agro-ecological zone, have annual rainfall between 700 mm and 900 mm. The rainy season goes from May to October and from June to October for the Southern Sudan and the Northern Sudan agro-ecological zones, respectively. The dry period runs from November to March in the Southern Sudan agro-ecological zone and from November to May in the Northern Sudan agro-ecological zone. These two zones are characterized by erratic rainfall in terms of quantity of rain and the number of rainy days.

2.2 Socio-Economic Context of the Study

The farmers selected for this study were involved in the project "Revenue through Cotton Livelihoods, Trade and Equity (RECOLTE)" implemented by the non-governmental organization (NGO) Catholic Relief Services of Burkina Faso. The selection processes were based on the soil types where they grow

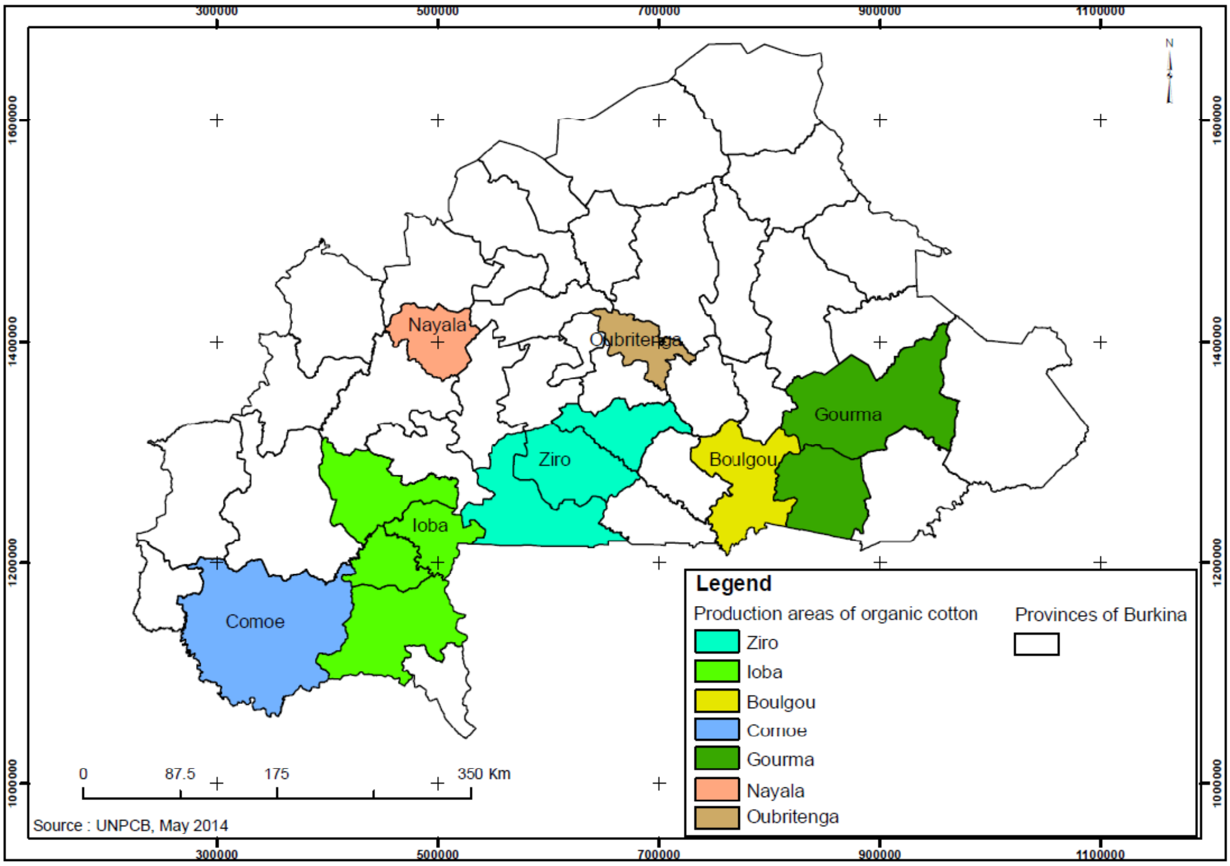

Fig. 1 Location of the organic cotton production zones of Burkina Faso.

the organic cotton and the rotation crops, their acceptance to implement the recommended technological packages in the organic cotton-based farming systems and the land tenor in order to make sure that producers will be able to use the same plot throughout the project duration (Table 1).

The organic manure consisted mainly of compost and park manure; they were applied at a triennial frequency (only when the plots are under cotton cultivation).

2.3 Sampling Fields

The organic cotton fields were selected by soil type per zone and according to the representative cotton field in these soil types. In total soil samples were collected in 168 plots; the number of plots per soil type varied from 3 to 18 in the Northern Sudan agro-ecological zone and from 6 to 15 in the Southern Sudan one (Table 2). For purpose of the sample collection, land survey and soil evaluations were conducted according to Food and Agriculture Organization of the United Nations (FAO) [19] and Bureau National des Sols (BUNASOLS) [20]. Pedological pits were studied according to Commission de Pédologie et de Cartographie des Sols (CPCS) [21] and World Reference Base for Soil Resources (WRB) [22]. From this information, the fields considered as suitable were codified by recording information of the GPS coordinates of the field, the background of the producer and crops in rotation with the organic cotton on the plots.

2.4 Soil Samples Collection

Two series of soil samples were collected during this study: the first set in 2015 for determining the baseline situation and the second one, in 2018 for

Table 1 Characterization of the farming systems and average application rates of organic fertilizer.

Organic cotton farming zones	Number of farmers	Average application rates of organic fertilizer	Systems of crops rotation
Comoé	8	4.5 t/ha (men) 0.7 t/ha (females)	Cotton//maize//peanut
Ziro	8	2.8 t/ha (men) 3.4 t/ha (females)	Cotton//maize//sesame
Ioba	8	2.1 t/ha (men) 1 t/ha (females)	Cotton//corn//local beans
Gourma	12	4.7 t/ha (men) 1.5 t/ha (females)	Cotton//corn//sesame
Boulgou	12	4 t/ha (men) 1 t/ha (females)	Cotton//corn//peanut
Oubritenga	16	3.6 t/ha (men) 1.5 t/ha (females)	Cotton//corn//soybeans

// = intra-annual crops rotation on the plot, sex ratio = 30% female.

Table 2 Codification of soil types and number of plots sampled by agro-ecological zone.

Agro-ecological zones	Codes of soil types [21]	Soil types [22]	Number of plots sampled per soil type
North Sudan (Boulgou, Koulpelgo, Gourma, Oubritenga, Nayala)	Bef/Beh	Gleyic Cambisol	9
	Bef/h	Endogleyic Eutric Cambisol	9
	Bef	Eutric Cambisol	15
	Bepe	Endoleptic Cambisol	6
	Bev, Bepe	Endoleptic Vertic Cambisol	9
	Flc	Ferric Lixisol	6
	Flimp, Flip	Chronic Endoplinthic Lixisol	12
	Flimp	Chromic Endopetric Lixisol	3
	Flip	Chromic Endoplinthic Lixisol	3
	Flipp	Petric Plinthosol	12
	Flis	Hyper Ferric Petric Plinthosol	18
	Fltc	Chromic Endogleyic Lixisol	3
South Sudan (Comoé, Ioba, Ziro)	Flimp/Flipp	Endocrinic Chromic Lixisol Hyper Ferric	9
	Flimp	Chromic Endopetric Lixisol	6
	Flip	Chromic Endoplinthic Lixisol	15
	Flipp	Petric Plinthosol	6
	Flis	Hyper Ferric Petric Plinthosol	6
	Fltc	Chromic Endogleyic Lixisol	9
	Peer/Lr	Epileptic Leptosol	12
Total number of fields sampled			168

determining the change in carbon stocks after three years under organic cotton-based farming systems. The samples for the determination of the carbon stocks were collected in the soil depths 0-10 cm and 10-20 cm. The choice of the top soil (0-20 cm) was sustained by the fact that seedbed preparation and the other soil management practices under organic cotton-based farming systems in Burkina Faso concern mainly soil top layers. In addition, the top layers are the most active part of soil because of the concentration of organic matter applied through fertilization process. At the plot level, sampling was done in three representative points.

2.5 Determination of Soil Carbon Stocks

Soil samples were collected using cylinders of known volume and oven dried for 24 h at 105 °C in order to determine the bulk density of soil (ρ) according to Eq. (1):

$$\text{Apparent bulk density } \rho = \frac{M}{V} \tag{1}$$

where ρ = apparent bulk density (g/cm^3), M = mass of an oven the soil sample dried (g) and V = soil volume (cm^3).

After this process, the carbon stocks were determined using Eq. (2) [23]. The calculation of the carbon stocks was done by multiplying the carbon content in soil micro-aggregates (diameter < 2 mm) by the apparent bulk density (ρ) and the soil depth (D) as follows:

$$\text{SOC (g/cm}^2) = \frac{C}{100} \times \rho \times D \times (1 - \text{frag}) \quad (2)$$

The carbon stocks were expressed in t/ha according to the following Eq. (3):

$$\text{SOC (t/ha)} = \frac{C}{100} \times \rho \times D \times (1 - \text{frag}) \times 100 \quad (3)$$

with SOC = soil organic carbon stock; C = soil carbon content; frag = the fraction of coarse particles.

3. Results

3.1 Variations of Carbon Stocks in Organic Cotton-Based Cropping Systems as Affected by Types of Soil

The carbon stock variations show a general decline trend in 0-10 cm and 10-20 cm of soil depths, respectively, in the North and Southern Sudanese agro-ecological zones from 2015 (baseline situation) to 2018 (Table 3).

General date trends in the Northern Sudan agro-ecological zone show that the balances of soil carbon stocks were positive in the Chromic Endoplinthic Lixisol (Flip) both in the surface soil layer 0-10 cm (+0.2 t/ha) and at the soil layer of 10-20 cm (+0.51 t/ha). However, in other soil types, three years of organic cotton-based farming systems led to negative balances of soil carbon stocks.

At the surface (0-10 cm), carbon losses ranging from -5.51 t/ha to -4.6 t/ha, were higher in soil with accumulation of iron and manganese sesquioxide (Chromic Endogleyic Lixisol (Fltc); Petric Plinthosol (Flipp) and Chromic Endopetric Lixisol (Flimp)). Concerning the Gleyic Cambisol (Bef/Beh), Endogleyic Eutric Cambisol (Bef/h), Eutric Cambisol (Bef), Endoleptic Cambisol (Bepe), and Endoleptic Vertic Cambisol (Bev, Bepe) the decline in soil carbon stocks was in the range of -3.88 t/ha to -0.22 t/ha. In the down layers 10-20 cm, the overall trend of carbon stock balance was similar to that of the 0-10 cm layer with a smaller amplitude (Table 3).

Table 3 Variations of soils carbon stocks from 2015 to 2018.

Soil types	Northern Sudan agro-ecological zone		Northern Sudan agro-ecological zone	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
	Carbon stocks (t/ha)			
Bef	-3.88 ± 1.65	-2.52 ± 1.95	-	-
Bef/Beh	-3.55 ± 1.43	-3.73 ± 1.76	-	-
Bef/h	-1.40 ± 0.21	-2.48 ± 1.46	-	-
Bepe	-0.22 ± 0.12	-0.28 ± 0.16	-	-
Bev, Bepe	-0.51 ± 0.18	-0.98 ± 0.68	-	-
Flc	-0.82 ± 0.95	-1.08 ± 1.16	-	-
Flimp	-4.51 ± 0.16	-3.43 ± 0.96	-3.36 ± 1.78	-2.54 ± 1.79
Flimp, Flip	-4.36 ± 1.47	-3.93 ± 1.79	-	-
Flimp/Flipp	-	-	-1.52 ± 0.30	-1.04 ± 0.39
Flip	+0.20 ± 0.09	+0.51 ± 0.17	-0.05 ± 0.30	-0.06 ± 0.26
Flipp	-4.54 ± 2.81	-3.76 ± 1.74	-4.14 ± 1.40	-2.10 ± 1.14
Flis	-1.20 ± 0.83	-2.06 ± 2.05	-1.86 ± 0.89	-1.75 ± 1.11
Fltc	-5.51 ± 0.59	-4.26 ± 0.44	-1.68 ± 0.60	-1.15 ± 0.68
Peer/Lr	-	-	-2.56 ± 2.56	-1.79 ± 1.46

Bef/Beh: Gleyic Cambisol; Bef/h: Endogleyic Eutric Cambisol; Bef: Eutric Cambisol; Bepe: Endoleptic Cambisol; Bev, Bepe: Endoleptic Vertic Cambisol; Flc: Ferric Lixisol; Flimp, Flip: Chromic Endoplinthic Lixisol; Flimp: Chromic Endopetric Lixisol; Flip: Chromic Endoplinthic Lixisol; Flipp: Petric Plinthosol; Flis: Hyper Ferric Petric Plinthosol; Fltc: Chromic Endogleyic Lixisol; Peer/Lr: Epileptic Leptosol; Flimp/Flipp: Endocrinic Chromic Lixisol Hyper Ferric.

In the Southern Sudan agro-ecological zone, indifferently to soil types organic cotton-based farming systems have led to negative balances of soil carbon stocks in the Southern Sudan agro-ecological zone. In the surface layers 0-10 cm, the Petric Plinthosol (Flipp) had the highest lost (-4.14 t/ha) followed by Chromic Endopetric Lixisol (Flimp) (-3.36 t/ha). The lowest carbon drop (-0.05 t/ha) was recorded in Chromic Endoplinthic Lixisol (Flip). In poorly developed soil Epileptic Leptosol (Peer/Lr) the loss in carbon stocks was -2.56 t/ha while in the developed soil (Chromic Endopetric Lixisol (Flimp) and Petric Plinthosol (Flipp)) it was ranged from -3.34 t/ha to -4.14 t/ha, respectively (Table 3). In the down soil layers 10-20 cm, although it was less severe, the diminution of carbon stocks followed the same trend as in the 0-10 cm.

3.2 Impacts of Different Soil Types on Soil Carbon Stocks in the Organic Cotton-Based Cropping Systems

In the Northern Sudan zone, 12 soil types have been inventoried under organic farming systems. Figs. 2a and 2b present respectively the correlation between soil carbon stocks and soil types at 0-10 cm depth in 2015 (baseline situation) and 2018. Fig. 2a shows that 74% of soil carbon storage capacity is explained by the type at the baseline situation (2015). The link between soil types and carbon storage capacity dropped after three years of soil cultivation under organic cotton-based farming systems from 74% to 56% (Fig. 2b).

In the Southern Sudan agro-ecological zone, the amount of carbon stored in 0-10 cm layer differed significantly with soil type ($p < 0.002$ in 2015 and $p < 0.034$ in 2018). However, a low correlation between soil type and soil carbon stocks was observed with an adjusted R^2 value = 22% (Fig. 3a). The same trend was observed in 2018 with $p = 0.034$ and adjusted $R^2 = 0.13$ (Fig. 3b).

Figs. 4a and 4b show that in the Northern Sudan agro-ecological zone, soil types had a significant effect on its carbon stocks ($p < 0.0001$) at the soil depth of 10-20 cm in 2015. Moderate correlation between carbon stocks and soil type was recorded (adjusted R^2 = 56%). After three years of organic cotton cropping in 2018, the correlation between soil type and carbon stocks dropped from moderate to low levels ($p = 0.034$ and adjusted R^2 = 44%).

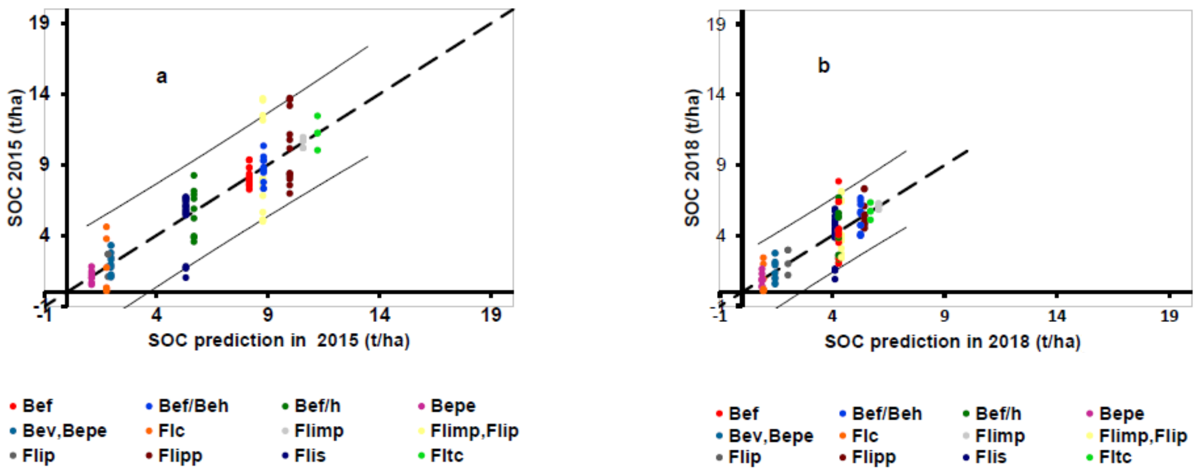

Fig. 2 Correlation between soil types and carbon stocks in 0-10 cm soil layer in the Northern Sudan agro-ecological zone in 2015 (a) and 2018 (b).

Bef: Eutric Cambisol; Bef/Beh: Gleyic Cambisol; Bef/h: Endogleyic Eutric Cambisol; Bepe: Endoleptic Cambisol; Bev, Bepe: Endoleptic Vertic Cambisol; Flc: Ferric Lixisol; Flimp, Flip: Chronic Endoplinthic Lixisol; Flimp: Chromic Endopetric Lixisol; Flip: Chromic Endoplinthic Lixisol; Flipp: Petric Plinthosol; Flis: Hyper Ferric Petric Plinthosol; Fltc: Chromic Endogleyic Lixisol.

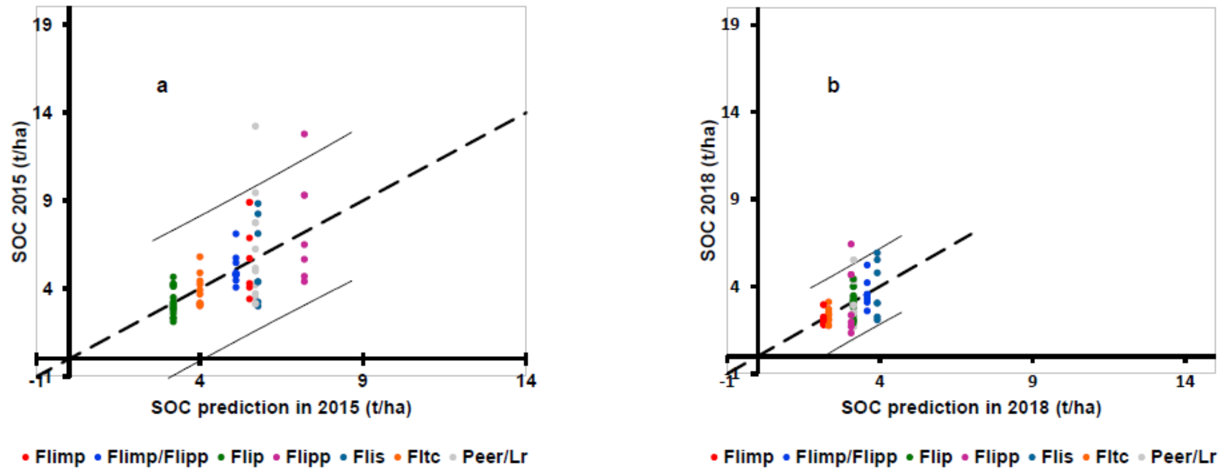

Fig. 3 Correlation between soil types and carbon stocks in 0-10 cm soil layer in the Southern Sudan agro-ecological in 2015 (a) and 2018 (b).

Flimp/Flipp: Endocrinic Chromic Lixisol/Hyper Ferric Petric Plinthosol; Flimp: Chromic Endopetric Lixisol; Flip: Chromic Endoplinthic Lixisol; Flipp: Petric Plinthosol; Flis: Hyper Ferric Petric Plinthosol; Fltc: Chromic Endogleyic Lixisol; Peer/Lr: Epileptic Leptosol.

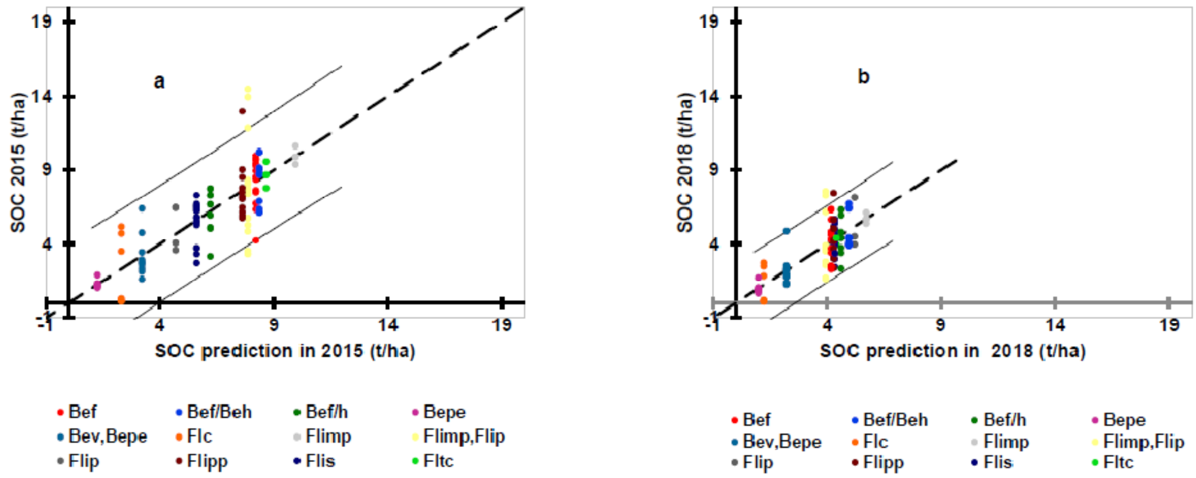

Fig. 4 Correlation between soil types and carbon stocks in 10-20 cm soil layer in the Northern Sudan agro-ecological zone in 2015 (a) and 2018 (b).

Bef: Eutric Cambisol; Bef/Beh: Gleyic Cambisol; Bef/h: Endogleyic Eutric Cambisol; Bepe: Endoleptic Cambisol; Bev, Bepe: Endoleptic Vertic Cambisol; Flc: Ferric Lixisol; Flimp, Flip: Chronic Endoplinthic Lixisol; Flimp: Chromic Endopetric Lixisol; Flip: Chromic Endoplinthic Lixisol; Flipp: Petric Plinthosol; Flis: Hyper Ferric Petric Plinthosol; Fltc: Chromic Endogleyic Lixisol.

In the Southern Sudan agro-ecological zone, the soil type also induced a significant variation in the amount of carbon stored in the soil depth of 10-20 cm (p = 0.04 in 2015 and p = 0.007 in 2018). However, weak correlation was recorded between soil types and its carbon stocks in 2015 and 2018 where the adjusted R^2 values were 18% in 2015 and 12% in 2018, respectively (Figs. 5a and 5b).

4. Discussion

4.1 Carbon Stocks Variation in Different Types of Soil

The organic cotton-based farming systems have led to an overall decrease in the carbon stocks in the soils with negative balances. This could be explained by an inappropriate fertilization practice: poor quality and low quantity of composts, low level of crop residues

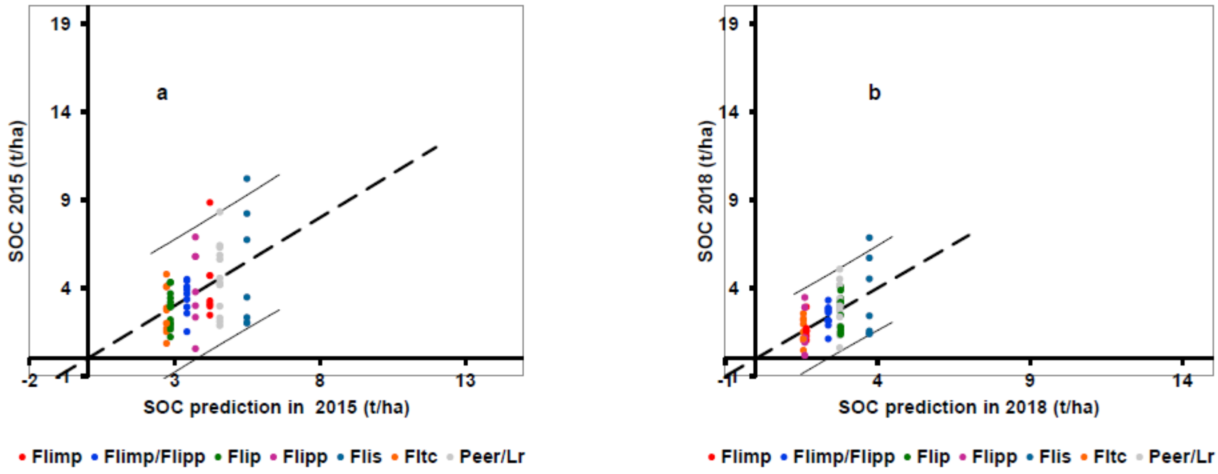

Fig. 5 Correlation between soil types and carbon stocks in 10-20 cm soil layer in the Southern Sudan agro-ecological in 2015 (a) and 2018 (b).

Flimp/Flipp: Endocrinic Chromic Lixisol Hyper Ferric; Flimp: Chromic Endopetric Lixisol; Flip: Chromic Endoplinthic Lixisol; Flipp: Petric Plinthosol; Flis: Hyper Ferric Petric Plinthosol; Fltc: Chromic Endogleyic Lixisol; Peer/Lr: Epileptic Leptosol.

recycling as well as crops rotation using legumes plants. Surveys have shown that application rates for these fertilizers ranged from 0.7 t/ha to 4.7 t/ha, and fertilizer applications were triennial. Indeed, the organic fertilizers were preferentially used on the cotton plants because rotation crops had low economic values. Under these conditions, the fertilizers applied in the first year were completely mineralized after three years. In the context of the present study, the average doses were below the minimum recommendation of 2-3 t/ha per year of compost [24]. This low application of compost is common in the farming systems in Burkina Faso and it is mainly related to various constraints as reported by Hema [25] and Dakuo *et al*. [26]. In addition, due to the non-utilization of substrates such as phosphate rock to enhance compost quality during the production process of the organic fertilizer, they have poor nutrients content [26, 27], while enrichment in P and N could improve the efficiency of compost even applied at low doses and favour in return, carbon storage in soils [28]. The low application rate and the intrinsic poor nutrients content of the organic fertilizers used on the plots would have led to a strong mineralization of the carbon due to the stimulation of soil microorganisms' activity. These results in the mineralization of the carbon provided by the organic fertilizers and also, the carbon contained in the soils and could be one of the causes of the negative balance of the soil carbon stocks.

Soils carbon storage monitoring showed a higher loss in the 0-10 cm layer, which would be bound to higher concentration of microorganisms at the surface compared to the layer 10-20 cm [29, 30]. This loss of carbon in the surface layers is also related to the various forms of erosion and others soil degradation factors exacerbated by the exposure to the surface soil layers to weather stripped during the dry season. Mrabet [31] through investigations conducted on the stratification of soil aggregation and organic matter under conservation tillage systems in Africa reported erosion as one of the causes of organic matter depletion. In depth, horizons (10-20 cm), these degradation factors are less expressive and predominance of root biomass represents a more stable carbon source in the investigated soils.

The results showed that for the same types of soils, the loss of carbon stock was higher in the Northern Sudan zone than in the Southern Sudan agro-ecological zone (Table 3). The influence of agro-ecological zone is due to the lower vegetation density and rainfall in the North Sudan area compared to the South Sudan zone [32]. Indeed, the duration of the dry season is five months in the Southern Sudan agro-ecological zone and six months in the Northern Sudan one. Consequently, in the organic cotton-based farming systems where there is no consistent conservation of crop residues on plots, the dry season corresponds to a period when the soil remains without vegetation cover exposing it to degradation factors with impacts on its capacity of carbon storage. In addition, the favorable conditions for vegetation growth in the Southern Sudan zone lead to better development of above and the root biomass that plays an important role in soil carbon storage and therefore contribute to improving the carbon stock balance in the soil.

4.2 Correlation between Carbon Storage by Soil Type

In the Northern Sudanese agro-ecological zone, after three years of organic farming, declines in correlation between soil types and their carbon stocks were observed in addition to soil carbon stock decline. Indeed, the adjusted R^2 values decreased from 74% (2015) to 56% (2018) in surface layers (0-10 cm) and from 56% (2015) to 44% (2018) in depth (10-20 cm). This shows that, although explained by soil type (Figs. 2a and 2b, Figs. 4a and 4b), carbon storage is influenced by farming practices. These results confirm previous studies outlining negative effects of mismanagement on soil carbon storage capacity in farming systems and other land use systems [2, 33-35]. In the present case, the influences of organic farming systems were more severe with a decrease with the adjusted R^2 value of 18% (in soil layer 0-10 cm) and 12% (in soil layer 10-20 cm) after three years. This high decline could be explained by the intrinsic fragility of soils characterized by low organic matter content and poor nutrient status as reported by Lompo *et al*. [27] and Bationo *et al.* [36].

In the Southern Sudan agro-ecological zone, a weak link has been recorded between soil carbon stocks and soil type (Figs. 3a and 3b, Figs. 5a and 5b). This low correlation between soil types and its carbon stocks could be explained by the predominance of other factors such as farming activities. Also, despite the suitability of the South Sudan zone for agricultural production, the soils are less resilient to the degradation agents. Indeed, the types of soil found in this zone are mainly Lixisols well known for their high carbon mineralization in the presence of high humidity [29].

Indifferently to the agro-ecological zone, the combination of the low application rates of organic fertilizers in the organic farming systems depicted above and the intrinsic poor organic matter content of soil has probably led to a rapid mineralization of the carbon stocks. This mineralization is exacerbated when fertilizer input does not meet the nutritional needs of plants as in the present case.

5. Conclusions

The results showed an overall decline of soil carbon stocks in organic cotton-based farming systems in the two agro-ecological zones; however, these decreases were severe in Northern Sudan zone. Out of the 14 soil types investigated, only the Flip in Northern Sudan agro-ecological zone had positive balance of carbon stocks. In general, the organic farming practices have also led to a stratification of soil carbon stocks in soil with higher concentration in 10-20 cm depth of soil compared to 0-10 cm surface layer.

Declines in correlation between soil carbon stocks and soil type were higher at the surface layers (0-10 cm) than at the soil depth of 10-20 cm both in Southern and Northern Sudanese zones with a smaller magnitude in soil depth of 10-20 cm. Results confirm that carbon storage in soils under organic cotton-based farming systems is more related to agricultural practices than the agro-ecological zones and soil types.

Even if soils fragility and harsh agro-climatic conditions partly explain the decline in soil carbon stocks, inconsistence of soil fertility practices by farmers highly contributed to the carbon depletion in organic cotton-based farming systems in Burkina Faso. Thus, the study recommends recycling of crop residues to compost and a better farming system for nutrients cycling in organic cotton-based cropping systems of Burkina Faso. These recommendations include the acquisition of industrial organic fertilizers to offset the current deficit on one hand and continue training of producers for technical skills to ensure sustainable production on the other hand.

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