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Transformation of savannahs into cocoa-based agroforests and carbon stock dynamics on the Mbam-sanaga confluence in central Cameroon

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Abstract
Cocoa farming contributes more than 60% of the local population's agricultural income. Farmers in central Cameroon, who have long grown cocoa under forest shade, have innovated by experimenting with growing cocoa in the savannah, combining it with multi-purpose trees that contribute to the formation of agroforests over the long term. The aim of this work is therefore to show how the creation of these cocoa-based agroforests contributes to increasing carbon stocks in the savannah. The study was based on botanical surveys of 1 hectare plots in the savannah and in the agroforests respectively, and the analysis of soil samples. The results show that forest scarcity is the main reason for the expansion of these agroforests in the savannah. The creation of agroforests is accompanied by an increase in the density of woody plants in the savannah and an increase in carbon stocks. These agroforests store 22 $tC.ha^{-1}$ compared with 18 $tC.ha^{-1}$ for natural savannas. In terms of soil organic carbon, 7-year-old agroforests store around 21.702 $g.kg^{-1}$ and 10-year-old agroforests around 28.641 $g.kg^{-1}$. These agroforests are an opportunity for forest conservation and REDD+ to combat global warming.

Keywords: Cocoa-based agroforest, dynamics, carbon stocks, forest-savanna mosaic, central Cameroon

Introduction

The fight against climate change caused by greenhouse gas emissions is at the heart of the international and scientific community's concerns. According to the WWF (2012), deforestation and forest degradation are responsible for 20% of global greenhouse gas emissions. Moreover, forests store 20 to 50 times more CO_2 than any other ecosystem, and absorb 50% more carbon than other wooded areas. Central Cameroon is a forest-savannah mosaic, with patches of dense semi-deciduous forest amidst expanses of shrubby and grassy peri-forest savannah (Letouzey, 1985). Cocoa farming is the main agricultural activity of the people living in the forest-savannah ecotone of central Cameroon. For a long time, cocoa has been grown under forest clearings since colonial times. However, over the last few decades, people have been extending cocoa-growing areas into the savannah by adding shade and fruit trees, which in the long term develop into agroforests. This extension of large areas of savannah agroforestry is linked to the lack of forest land reserves (Camara *et al*., 2012) [2]. This transformation of savannahs into cocoa-based agroforests reduces pressure on forests (Amougou *et al*., 2016) and increases carbon stocks. These savannah agroforests represent a real opportunity to step up the fight against global warming. This study is therefore modelled on the butterfly effect theory developed by Lorenz (1963), according to which the flapping of a butterfly's wing at one end of the earth could influence the climate at the other. In other words, the creation of savannah agroforests in Central Cameroon is helping to increase carbon stocks and combat climate change on a global scale. The study is based on the hypothesis that the expansion of cocoa-based agroforests in savannahs increases carbon stocks relative to the initial stand. The aim of the study is to compare biomass carbon stocks and soil organic carbon in natural savannahs and cocoa-based agroforests in order to prove the additionality of carbon stocks linked to the conversion of these savannahs into cocoa-based agroforests.

Materials and methods

Description of the study area

The Centre region of Cameroon covers an area of 68,953 km2 and comprises ten (10) divisions, three of which (Mbam-et-Inoubou, Lekié and Mbam-et-Kim), with a high proportion of savannah, were sampled. It is located on the southern Cameroonian plateau, at an average altitude of 700 m, and comprises a forest-savannah mosaic of vegetation, including secondary "domesticated" forests and forest islands in peri-forest savannahs cleared for cocoa plantations (Villers, 1995). The study area is located between 4° and 5° N, then 11° and 12° E (Figure 1). The soil and climate conditions are very favourable for agriculture. It has a transitional equatorial climate, with average annual rainfall varying between 1,400 and 1,600 mm (Suchel and Tsalefac, 1993), and is drained by two main rivers, the Sanaga and the Mbam. The soils are predominantly ferralitic and very deep, suitable for food crops and cocoa production.

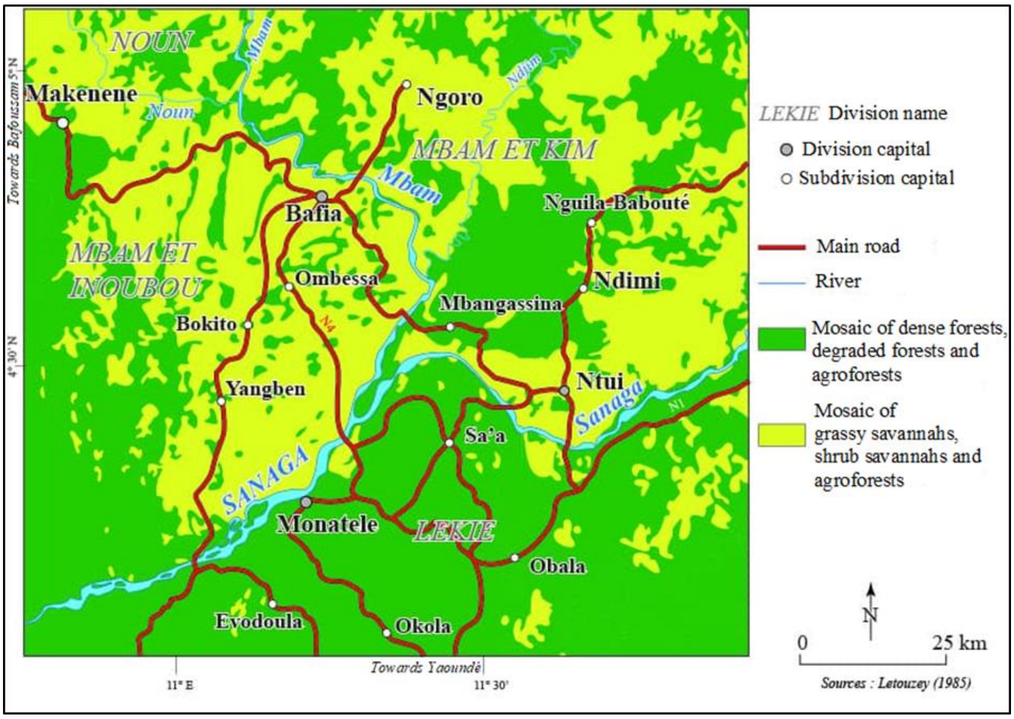


Fig 1: study area

Data collection

Data collection in this study consisted of botanical surveys and soil sampling in each type of land use, i.e. natural savannahs and cocoa-based agroforests aged between 7 and 10 years. Botanical surveys were carried out over areas of 1 hectare using plots of 2,500 m^2 in the natural savannahs and agroforests respectively. All the species were listed, and their Diameter at Breast Height (DBH) and height measured. Soil samples were then taken from each site, including 2 sites in the natural savannahs and 2 sites in the savannah agroforests, at a depth of 15 cm, with a view to assessing their organic carbon potential in the laboratory.

Data analysis

The above-ground biomass of associated trees and cocoa trees was estimated using the non-destructive method using the allometric equation of chave *et al*. (2014) [3], commonly used in carbon estimation in Cameroon. This equation takes into account tree diameter and height, as well as specific density according to the formula :

$$AGB = 0{,}0673 \times (\rho D^2 H)^{0{,}976} \quad (E1)$$

with AGB=Aerial biomass of the tree in kg; D=diameter at breast height of the tree (in cm); H=height of the tree (in m) and ρ=specific density of the tree (g.cm-3).

The species-specific densities used are those taken from the density database (htt://db.worldagroforestry.org/wd). In the absence of data on the specific densities of certain species, the mean value of the specific density of trees obtained by Brown (1997) for the FAO data on tropical African species was used (0.58g/cm3). The above-ground biomass data obtained for each plot were extrapolated. The root biomass of standing woody plants was estimated in accordance with the guidelines established by the IPCC in 2006. According to these guidelines, the root biomass equivalence of woody plants is found by multiplying the above-ground biomass value (AGB) by a coefficient R, the value of which is estimated at 0.24.

$$BGB = AGB \times R \quad (E2)$$

with BGB= below-ground biomass, AGB= above-ground biomass and R= root/stem ratio.

The carbon stock was obtained by multiplying the sum of the biomass (above and below ground) by the CF (carbon fraction) ratio, which is 0.47 (IPCC, 2006).

$$C = (AGB + BGB) \times 0.47 \quad ((E3)$$

Where C= total carbon stock; AGB= above-ground biomass and BGB= below-ground biomass.

The soil samples taken were analysed at the Plant, Soil, Fertiliser and Water Analysis Laboratory of the Agricultural Research Institute for Development in accordance with standard NF ISO14235 in order to determine the soil organic carbon content of each type of land use.

Results

Distribution of floristic surveys in the savannahs

The floristic surveys carried out in the shrub savannah, over an area of one hectare, revealed a total of 547 individuals divided into 25 species. In general, the number of small-diameter individuals was very high, in contrast to the small number of large-diameter individuals. Overall, the number of individuals decreases as their diameter increases. The species with the largest individuals include *Lannea Schweinfurthii* (Engl.) Engl; *Tectona grandis* L.F.; *Lophira lanceolata* Van Tiegh. ex Keay; *Terminalia glaucescens* Planch. ex Benth; *Bridelia ferruginea* Benth; and *Borassus aethiopuim* Mart (Table 1).

Table 1: Surveys of woody plants in the savannah

Species	Diameter classes (Cm)													Grand total
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	60-65	70-75	
Afzelia africana Smith ex Pers.		3	2		1									6
Annona senegalensis Pers.	5	7												12
Bersama engleriana Gürke	1													1
Borassus aethiopuim Mart.						2	1	2						5
Bridelia ferruginea Benth.	29	62	22	18	13	4		2						150
Combretum sp.					1	1								2
Crossopteryx febrifuga (Afz. ex G. Don) Benth.	4	2												6
Ficus sp.	1	1												2
Ficus sp. aff. *thonningii Blume*					1									1
Ficus sur Forssk.	12	2	1											15
Hymenocardia lyrata Tul.	1	6												7
Lannea Schweinfurthii (Engl.) Engl.	1	3	2							1			1	8
Lannea welwitschii (Hiern) Engl.	2													2
Lophira lanceolata Van Tiegh. ex Keay	48	30	18	10	6	5	1	2	1		2			123
Maytenus senegalensis (Lam.) Exell	1	7	4	3										15
Phyllanthus sp.		3	5	1										9
Piliostigma thonningii (Schumach.) Milne-Redh	2	4	5	4		1								16
Psorospermum aff. *glaucum* Engl.	2	2												4
Pterygota oblonga Mast.	1													1
Sarcocephalus latifolius (Smith) Bruce	20	25	4		1									50
Tectona grandis L.F.	6	2		1	1	3				1		1		15
Terminalia glaucescens Planch. ex Benth.	14	31	13	7	6	2			1					74
Terminalia superba Engl. & Diels	1													1
Vitex doniana Sweet	1	2	7	3	1	1								15
Zanthoxylon sp.			3	2	2									7
Grand total	152	192	86	49	33	19	2	6	2	2	2	1	1	547

Source : Field surveys, September 2020

Woody savannah stands only contain small-diameter individuals, which can be explained by the fact that these savannahs are mainly made up of shrubs; hence their name of shrub savannahs.

Distribution of floristic surveys in cocoa agroforests

Floristic surveys in cocoa-based SAFs revealed a total of 1093 individuals divided into 32 species. The dominant species, i.e. those with the largest diameters, were oil palm (*Elaeis guineensis* Jacq.); roast palm (*Borassus aethiopium* Mart.); cheese tree (*Ceiba pentandra* (L.) Gaertn.; *Markhamia cf. tomentosa* (Benth.) K. Schum. ex Engl.; mango (*Mangifera indica* L.) and *Trichilia cf. monadelpha* (Thonn.) J.J. de Wild. Overall, most of the trees are small in diameter. The 5 to 10 cm diameter class accounts for more than 50% of the trees in the stand (593), reflecting the young age of the stand (Table 2).

Table 2: Tree surveys in cocoa-based agroforests

Species	Diameter classes (Cm)																			Grand total
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	60-65	70-75	75-80	80-85	85-90	95-100	100-105	110-115	
Afzelia africana Smith ex Pers.				3	2		1	1												7
Annona Muricata L.	1				1															2
Anthocleista vogelii Planch.								1												1
Borassus aethiopium Mart.																	1			1
Bridelia ferruginea Benth.				1																1
Carica papaya L.	8	8	1		1															18
Ceiba pentandra (L.) Gaertn.	1				4	4	2	3					1							15
Citrus limon (L.) Burm.f.	3	6																		9
Citrus maxima (Burman) Merrill	1																			1
Citrus reticulata Blanco	2	5		8																15
Citrus sinensis (L.) Osbeck		4	4	8																16
Cola aff. digitata Mast.							1													1
Dacryodes edulis (G. Don) H.J.Lam	4	3	3	4			1													15
Elaeis guineensis Jacq.		6	9	7	2	7		1		4	1	1	1		1	1	2	1	2	46
Erythrophleum suaveolens (Guill. & Perr.) Brenan					1	2														3
Ficus exasperata Vahl		1																		1
Mangifera indica L.	1	2		2	3	2	1		1											12
Markhamia cf. tomentosa (Benth.) K. Schum. ex Engl.														1						1
Musanga cecropioides R.Br.						1	1													2
Persea americana Mill.	3	2	6	6	3	3	1	1												25
Psidium guajava L.		1	1																	2
Rauvolfia cf. macrophilla Stapf						1														1
Rauvolfia vomitoria Afzel.					1															1
Ricinodendron heudelotii (Baill.) Pierre ex Heckel						1	1													2
Sanseviera sp.			1																	1

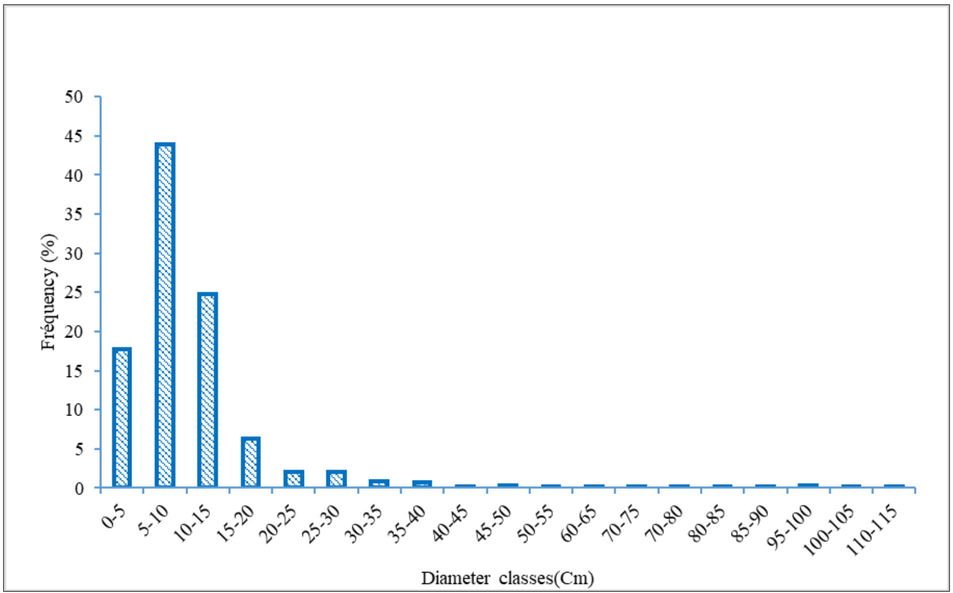
Spondias dulcis FORST.		1			1			1												3
Terminalia glaucescens Planch. ex Benth.						1														1
Terminalia superba Engl. et Diels	1			2	1	1														5
Tetrapleura tetraptera (Schum.&Thonn.) Taub.	1																			1
Theobroma cacao L.	165	440	245	28	2															880
Trichilia cf. monadelpha (Thonn.) J.J. de Wild									1											1
Voacanga africana Stapf	2				1															3
Grand total	193	479	270	69	23	23	9	8	2	4	1	1	2	1	1	1	3	1	2	1093

Source : Field surveys, September 2020

The survey reveals that the number of individuals decreases overall as the diameter increases. These are therefore young agroforests (7 to 10 years old) which, over time, may evolve into a stand similar to that of the forest.

Distribution of individuals in height classes in the savannah

The representation of the structure of woody stands in terms of diameter classes, based on the histogram of cumulative frequencies, shows a relatively young stand structure dominated mainly by small-diameter individuals. Individuals in the [5-10[cm] diameter class are the most numerous, representing 43.91% of the woody stand, followed by those in the [10-15[cm] diameter class (24.75%), [0-5[cm] (17.71%), [15-20[cm] (6.32%), [20-25[cm] and [25-30[cm] (2.02%) respectively; [30-35[cm (0.82%); [35-40[cm (0.73%); [45-50[cm (0.37%); [95-100[cm (0.27%); [40-45[cm, [70-75[cm and [110-115[cm (0.18%) respectively; [50-55[cm, [60-65[cm, [75-80[cm, [80-85[cm, [85-90[cm and [100-105[cm (0.09%) respectively (Figure 2).



Source : Field surveys

Fig 2: Distribution of diameter classes in cocoa-based agroforestry systems

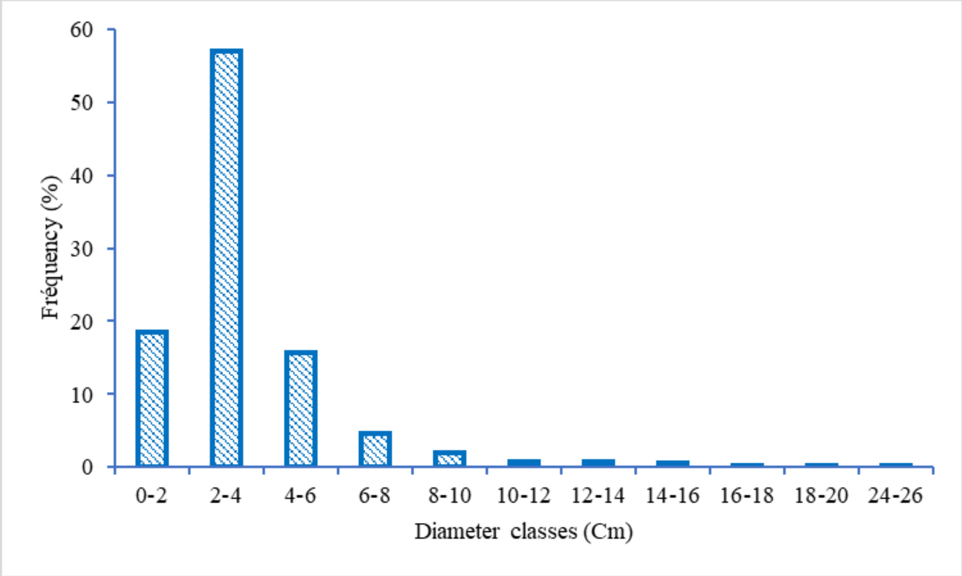
Savannah cocoa agroforests are dominated by small-diameter trees. This result is consistent with the work of Pindi *et al*. (2019) [11], which showed a distribution of tree species by diameter class dominated by a large number of small-diameter stems [10-20] cm.

This predominance of small diameters can be explained, on the one hand, by the fact that cocoa is primarily a shrub crop and, on the other hand, by the young or recent nature of cocoa production practices in the savannahs, which only date from the 2000s.

As a result, the associated trees have not yet had enough time to develop and take on significant volume.

Distribution of individuals in height classes in cocoa agroforests

The histogram representing the height structure of the woody stand in cocoa-based agroforests distinguishes 11 height classes, each with a 2 m amplitude. The most represented individuals are those belonging to the [2-4[m height class with a percentage of 56.92%, followed by those belonging to the [0-2[m class (18.48%) ; [4-6[m (15.65%) ; [6-8[m (4.57%) ; [8-10[m (2.01%) ; [10-12[m (0.82%) ; [12-14[m (0.73%) ; [14-16[m (0.55%) ; [16-18[m ; [18-20[m and [24-26[m (0.09%) (Figure 3).



Source : Field surveys, September 2020

Fig 3: Distribution of height classes in cocoa-based agroforestry systems

The analysis that can be made of this distribution in height classes is that there is a correlation between the diameter and the size of the individuals, due to the fact that the woody plants present in the savannah cocoa tree agroforests are mainly part of the small diameter and low height class, due to the predominance of cocoa trees, which are basic shrub crops.

Comparative analysis of carbon stocks between savannahs and cocoa agroforests

Cocoa-based agroforests play an important role in carbon storage. They are sustainable and therefore eligible for the mechanism for reducing emissions from deforestation and forest degradation (Jagorêt, 2011; Atangana *et al*., 2014). Studies carried out in two types of land use on the Mbam Sanaga confluence, namely unharvested savannahs and savannah cocoa tree-based agroforests, found a clear increase in carbon stocks in cocoa tree-based SAFs compared to savannahs.

The results obtained indicate a value of 21.94 $tC.ha^{-1}$ in young cocoa tree-based FAS aged 7-10 years compared with 17.94 $tC.ha^{-1}$ in unharvested savannahs, i.e. a significant difference of 4 $tC.ha^{-1}$ (Table 3).

Table 3: Carbon storage potential between the two types of land use

Type of land use	Above Ground Biomass (Kg)	Below Ground Biomass (Kg)	Carbon stocks (t $C.ha^{-1}$)
Cocoa-based agroforest (7-10 years old)	37652,32	9036,56	21,94
Shrubby savannah	30787,41	7388,98	17,94

Source : Field data, November 2020

It can therefore be concluded from the results that cocoa production in savannahs leads to an increase in biomass carbon stocks. The quantities of carbon stock obtained in the savannas are close to the values obtained by Amougou *et al*. (2016) [1], whose recorded carbon stocks were 15.47 and 16.40 $tC.ha^{-1}$; and differ significantly from those of Durot (2013) [4], whose quantities of carbon stock were 9 $tC.ha^{-1}$ in the Bokito region. Furthermore, the carbon stocks obtained in cocoa-based FAS (21.94 $tC.ha^{-1}$) differ significantly from those found by Amougou *et al*. (2016) [1], who found values of 68.12 $tC.ha^{-1}$ - 76.99 $tC.ha^{-1}$, Durot (2013) [4], who found values of 58 $tC.ha^{-1}$, and Etchike *et al*. (2020) [5], who found values of 146.63 $tC.ha^{-1}$.

These differences could be explained by the use of the allometric equations of Chave *et al*. (2005) by these authors, whose validity in tropical Africa has been strongly debated; unlike the equation of Chave *et al*. (2014) [3], which is more robust and performs better with an accuracy of 90% (Loubouta Panzou *et al*., 2016), used in this study, and also by the high mortality of cocoa plants in the plots sampled or, better still, the differences in the density of the associated stand in the plots sampled.

In fact, 880 cocoa trees were counted in one hectare compared with 1200 trees according to standards, i.e. a deficit of 320 cocoa trees. The floristic surveys carried out during this study show that a cocoa tree stores an average of 0.0038 $tC.ha^{-1}$. By multiplying this value by the number of cocoa trees lost, we can see that this deficit resulted in a shortfall of 1.22 $tC.ha^{-1}$.

In cocoa-based agroforestry systems, associated species contribute most to carbon storage, with 18.59 $tC.ha^{-1}$ compared with 3.35 $tC.ha^{-1}$ for the cocoa tree (*Theobroma cacao* L.). The associated species with a high storage potential are : *Elaeis guineensis* Jacq. (5.76 $tC.ha^{-1}$); *Borassus aethiopium* Mart. (3.43 $tC.ha^{-1}$); *Ceiba pentandra* (L.) Gaertn. (1, 38 $tC.ha^{-1}$); *Mangifera indica* L. (1, 30 $tC.ha^{-1}$); *Markhamia* cf. *tomentosa* (Benth.) K., Schum. ex Engl. Schum. (1.10 $tC.ha^{-1}$) and *Persea americana* Mill. (1.06 $tC.ha^{-1}$).

The remaining species each have a storage capacity of less than 1 $tC.ha^{-1}$. These results differ from those presented by Etchike *et al* (2020) [5], who reported *Mangifera indica* L. (64.80 $tC.ha^{-1}$), *Dacryodes edulis* (G. Don) H. J.Lam (41.23 $tC.ha^{-1}$), *Spondias cythera* Sonn (37.41 $tC.ha^{-1}$) and *Ricinodendron heudelotii* (Baill.) Pierre ex Heckel (24.81 $tC.ha^{-1}$), *Alibizia zygia* (D.C) J F. Macbr. (14.86 $tC.ha^{-1}$) and *Ficus exasperata* (13.65 $tC.ha^{-1}$) as the species storing the most carbon. However, in line with the results found, these authors noted that *Elaeis guineensis* Jacq. (0.72 $tC.ha^{-1}$) is the species that stores the most carbon in the Arecaceae family.

In addition, the 4 by 1000 initiative was launched at COP21 in Paris in 2015, with the aim of increasing the carbon stock in the top 30-40 cm of soil by 0.4%/year, based on the observation that agricultural and forest soils contain twice as much carbon as the atmosphere. The aim of this initiative is therefore to significantly reduce the concentration of CO2 linked to human activities and to combat climate change by taking concrete action to increase carbon storage in soils, through practices such as agroforestry and landscape management.

With this in mind, soil samples were taken at four sites (A, B, C, D), including A and B in cocoa-based agroforestry systems and C and D in unharvested savannahs, in order to assess variations in soil organic carbon content. Soil organic carbon content was found to be higher in the savannahs, at 21.702 $g.kg^{-1}$ and 28.641 $g.kg^{-1}$ in sites C and D respectively. On the other hand, in cocoa-based agroforestry systems, this content is lower and varies from 16.368$g.kg^{-1}$ in site A (7-year-old agroforestry system) to 20.705$g.kg^{-1}$ (10-year-old agroforestry system) (Table 4).

Table 4: Soil organic matter and carbon content

Types of land use	Organic matter ($g.kg^{-1}$)	Organic carbon ($g.kg^{-1}$)
Cocoa-based agroforestry system (7 years old ; site A)	28,218	16,368
Cocoa-based agroforestry system (10 years old ; site B)	35,696	20,705
Shrubby savannah (site C)	37,415	21,702
Shrubby savannah (site D)	49,377	28,641

Source : Field data, November 2020

It can therefore be seen that cocoa production in savannahs leads to a drop in soil organic carbon content due to the destruction of biomass during land preparation. Once the cocoa plantation has been established, the growth of the cocoa tree and associated trees enables organic carbon stocks to be reconstituted as a function of the age of the plantation. This observation leads to the conclusion that the creation of cocoa tree-based agroforests in savannahs helps to strengthen carbon sequestration and combat global warming. These cocoa-based agroforestry systems are therefore of particular interest as part of the implementation of the REDD+ mechanism.

Discussion

Tropical forests play a fairly important role in the fight against climate change through the quantities of carbon they store. Despite being carbon sinks, these forests are increasingly threatened by deforestation and degradation caused by human activities, including agriculture. In the forest-savannah transition zone, as in central Cameroon, the farming population has for a long time made its living mainly from cocoa farming, to the detriment of the forest. This is also the point made by Michel *et al*., (2019) [8], who show that cocoa agroforestry is the product of an ancient history that originated with native farmers in Central and Southern Cameroon more than a century ago. With the increasing scarcity of forests, these farmers have innovated by experimenting with savannah agroforests in which various trees are associated with cocoa trees. This is what Durot (2013) [4], Messie (2007) [7] and Mopi Touoyem (2022) [9] point out when they show that cocoa tree-based agroforests in central Cameroon are made up of cocoa trees and associated trees, preserved or introduced for reasons of shade, self-consumption and marketing. This association of trees with cocoa trees led Nomo Bidzanga *et al* (2009) [10] to emphasise that cocoa agroforests are less damaging to the environment than other forms of soil management.

In addition, the conversion or transformation of savannahs into agroforests increases carbon storage capacity and is an advantage in the fight against climate change. This is also the view of Durot (2013) [4], who shows in his studies in central Cameroon that an unexploited savannah stores an average of 9 tC. ha^{-1}, compared with 58 $tC.ha^{-1}$ in cocoa-based agroforests established on savannah. It is for this reason that the creation of cocoa tree-based agroforests in savannahs deserves to be encouraged with a view to moving towards a low-carbon agriculture, because the transformation of natural forests into agroforests rather reduces the potential for carbon storage, as Durot (2013) [4] also notes, noting that a natural forest stores an average of 121 $tC.ha^{-1}$, compared with 85 $tC.ha^{-1}$ in cocoa tree-based agroforests established in forests.

Conclusion

The aim of this study, conducted in the forest-savannah mosaic zone of central Cameroon, was to show how the expansion of cocoa-based agroforestry systems into savannah contributes to an increase in carbon storage potential. The result is that, although the creation of cocoa-based agroforests in forests is accompanied by a reversible reduction in carbon stocks, their expansion into savannahs contributes to a densification of ligneous species and a continuous increase in carbon stocks, and therefore a positive balance in terms of climate change mitigation. Natural savannas store an average of 17.94 $tC.ha^{-1}$, while savannah agroforests store 21.94 $tC.ha^{-1}$. This leads to the conclusion that the conversion of savannahs into cocoa-based agroforests leads to an increase in carbon stocks of 4 tC. ha^{-1} on average at the young stage. The transformation of savannah into agroforest initially leads to a loss of soil organic carbon, which is replenished over time as the cocoa plantation ages. Measurement of soil organic carbon showed values of 16.368 $g.kg^{-1}$ in agroforests based on 7-year-old cocoa trees, compared with 20.705 $g.kg^{-1}$ in agroforests based on 10-year-old cocoa trees. These results show that these initiatives to transform savannahs into agroforests should be encouraged if we want to move towards low-carbon agriculture, intensify climate change mitigation and promote the production of certified cocoa that does not result from deforestation.

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