

# Variation Of $\delta^{13}\text{C}$ And Soil Organic Carbon Dynamics In The Savannah Of Plateau Bateke, Congo Bassin

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**ABSTRACT:** In Republic of Congo, forests occupy 64.6 % of the territory. They spread from north to south over nearly 22,106 ha distributed in three major zones: the forest of the Northern Congo (68%), the forest of Chaillu (16%) and the forest of Mayombe (7%). The remaining 9% are mosaic forests and savannah, mostly gallery and forest clump (HF) forests like in the Iboubikro site ( $3^{\circ}11'S$ ,  $15^{\circ}28'E$ ). Currently characterized by a positive dynamics for at least five or six centuries, these natural forests could play an important role in the mitigation of  $\text{CO}_2$  in the atmosphere. The objective of this work: (i)-quantifying carbon stock in forests and savannah; (ii) following deep inputs of organic matter originated from savannah and forest. The results obtained showed that the total carbon up to one meter is more important in the gallery and secondary forest than under the savannah. We obtained up to one meter  $6.4 \text{ kg.m}^{-2}$  in the GF,  $6.2 \text{ kg.m}^{-2}$  in SF and  $4.6 \text{ kg.m}^{-2}$  in the savannah. The three means of total C are differ from one site to another ( $p=0.0001$ ). A Study of the variation of  $\delta^{13}\text{C}$  with profile depth showed that in the forest, the  $\delta^{13}\text{C}$  values were close to those of  $\text{C}_3$  (-26‰),  $\delta^{13}\text{C}$  decrease in depth until -19‰ in the deepest at -100 cm. Under savannah, the  $\delta^{13}\text{C}$  values are close to those of  $\text{C}_4$  vegetation (-13.6‰). In all the profile under savannah, we observed that the  $\delta^{13}\text{C}$  values are constant. We concluded that there is a clear mixture between old organic matter from savannah and the new organic matter from trees. The result suggests a net effect of the growing of forest on the old savannah vegetation due to climate change in this area.

**Keywords:** Carbon, savannah, forest, Plateaux Bateke,, Congo Bassin

## 1 INTRODUCTION

Tropical and sub-tropical forest soil contributes for about 30% to the overall total organic matter [3], and inputs of organic carbon in the soil are essentially by two ways: aboveground litter fall (leaves, twigs, seeds, woody debris) and belowground litter (dead roots). Quantification of the amount of organic carbon as well as processes which increase or decrease these stocks is one of the current concerns of the international scientific community. In Congo Brazzaville in the Bateke, plateaux, this study is conducted to monitor the impact of forest progression on Savannah on soil carbon stocks. The study of the dynamics of organic matter is made through the determination of carbon 13 the signal of which provides information on the evolution of the vegetation type at a specific time. Indeed the Bateke plateaux have been characterized by the coexistence of Savannas and forests. For centuries previous studies in this area have highlighted a positive dynamics in the Bateke plateaux [11, 3]. The main objectives of this study are: (i) quantification of total carbon stocks in soil under the two forests; (ii) monitoring the dynamics of organic matter under these three sites.

## 2 MATERIEL AND METHODS

### 2.1 Study sites

The study sites are located at Iboubikro ( $3^{\circ}11'S$ ,  $15^{\circ}28'E$ ), 140 km north east of Brazzaville on the Bateke, Plateaux. The average annual rainfall is 2100 mm (2006-2008) with a marked dry season from June to September (figure 1a), and an annual average air temperature of  $26^{\circ}\text{C}$ .

The soil is deep, acidic, sandy arenosol type with clay content varying from 0.3% to 7.6% [14]. The two studied forest groves were a gallery forest (GF) with many individuals of *Colletocema dewevrei* (De Wild.) Petit. [Rubiaceae] and *Eriocoelum microspermum* (De Wild.) Radlk. [Sapindaceae], and a hill-slope forest clump (HF) dominated by *Musanga cecropioides* R. Br. [Cecropiaceae], and *Macaranga barteri* Müll.Arg. [Euphorbiaceae]. Three plots of 40m x 40m were delimited in each forest types. All plots were within a range 300 m of each other. The height of the canopy was approximately 20-26 m in GF and 15-21 m in HF. Tree density was  $640 \text{ stems ha}^{-1}$  in GF and  $119 \text{ stems ha}^{-1}$  in HF (diameter at breast height above 0.1 m), and the basal area was respectively  $17$  and  $7 \text{ m}^2 \text{ ha}^{-1}$ .

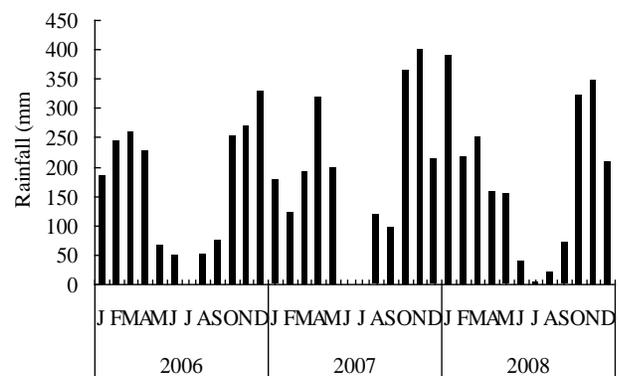


Figure 1: rainfall trends in Iboubikro site

### 2.2 Data collection methodology

With an Auger, samples of soil cores were made in SF (SF), Gallery forest (GF) and Savannah following the plan presented. As a whole, eight soil profiles (3 in the SF, 3 in GF and 2 in the savannah) were collected systematically in increments of 20 cm to 1 meter in depth to characterize the vertical gradient of the soils of the Iboubikro site. After treatment of the soil samples, they were analyzed in France at the Nancy-Champenoux INRA facilities at the analytical

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pole of the UMR INRA - PUH Ecology and Forest Ecophysiology. Determinations focused on carbon and organic total nitrogen rate and  $\delta^{13}C$  isotopic composition. The respective part of forest carbon and Savannah are determined from Equation 1

$$C_{for} = \left( \frac{(\delta^{13}C_t - \delta^{13}C_s)}{(\delta^{13}C_f - \delta^{13}C_s)} \right) \times C_t$$

$\delta^{13}C_t$  = isotopic composition of the sample of soil under forest;  
 $\delta^{13}C_s$  = isotopic composition of homologous profile of Savannah reference levels;  
 $\delta^{13}C_f$  = carbon 13 of forest litter  
 $C_t$  = the quantity of total organic carbon of soil of the forest reporting level.

The stock of soil carbon  $Q_i$  (g .cm<sup>-2</sup>, equation 2) is expressed in the layer  $i$ , layer  $E_i$  (cm), contents of carbon  $C_i$  (gC.g<sup>-1</sup>), volume density  $D_i$  (g.cm<sup>-3</sup>) and the fraction of the volume of the element considered [6,2].

$$Q_i = C_i \times D_i \times E_i \quad \text{Equation 2}$$

To determine the total stock of carbon on a soil profile with k horizon, the following 3 equations were used:

$$Q_t = \sum_{i=1}^k Q_i = \sum_{i=1}^k C_i D_i E_i (1 - G_i) \quad \text{Equation 3}$$

It is the sum total of the  $Q_i$  of k horizons. The results from the elemental analyzer are expressed in %. The C% is reported by 100 to convert the data to g.C.g<sup>-1</sup>. The volume density of the soil was determined by the following equation 4:

$$D = \frac{m}{\pi \left( \frac{d^2}{4} \right) h} \quad \text{Equation 4}$$

### 3 RESULTS

#### 3.1 Cumulative total carbon stock

The results showed that the amount of total organic carbon cumulated in each site increases with depth. In the topsoil (20 cm) we obtained 2873 gC.m<sup>-2</sup> in GF, 1890 gC.m<sup>-2</sup> in the SF and 1328 gC.m<sup>-2</sup> in the Savannah. In all of the profile (0-100 cm), the total stock of carbon in the Savannah is the lowest with 4592 gC.m<sup>-2</sup>. The most important stock is noted in GF with 6400 gC.m<sup>-2</sup> while in SF, we obtained a stock of 6190 g.m<sup>-2</sup>. The ANOVA indicates that carbon stock averages differ from one site to another (P = 0.0001), but also that these stocks are different in the depths (P = 0.0001). Organic carbon stock averages between two forests GF and SF revealed the existence of a significant difference between the two sites (P = 0.021) (figure 2), but also at each depth (P = 0.0002).

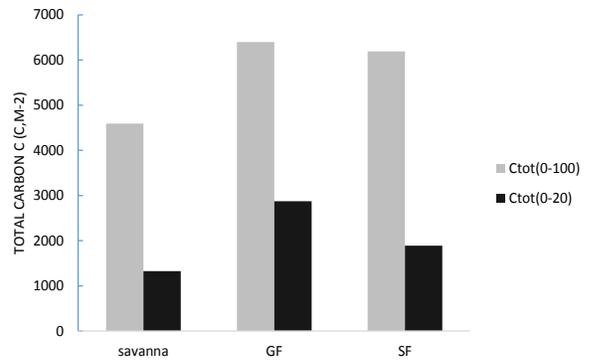


Figure 2: comparison of stocks of total carbon in SF, GF, and savannah

#### 3.2 Distribution of organic carbon on the 0-100 cm profile

Profiles of soil under forests and savannas showed organic carbon quantify evolution from surface horizons to depth. Along the profile in the three sites, organic carbon stocks are decreasing from the topsoil to depth (figure 3). Between the three sites, we noted in the horizon 0-20 cm respectively the values of 11.4 mg mg.g<sup>-1</sup>, 7.5 mg.g<sup>-1</sup> and 5.3 mg.g<sup>-1</sup> in GF, SF and Savannah. In deep horizon (100 cm), we obtained the lowest levels of organic carbon of the profile with 2.6 mg mg.g<sup>-1</sup> in Savannah and 2.3 mg.g<sup>-1</sup> and 1.3 mg mg.g<sup>-1</sup> in SF and GF respectively..

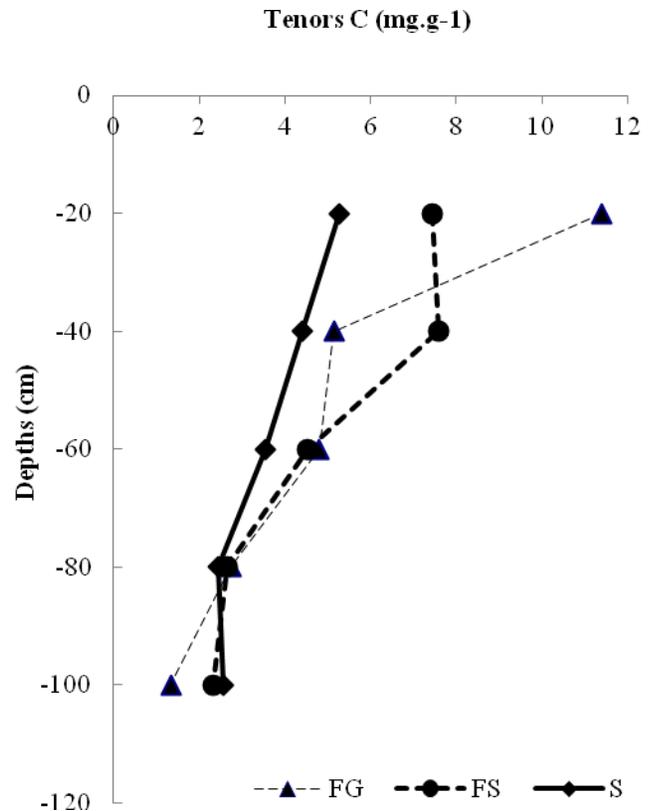
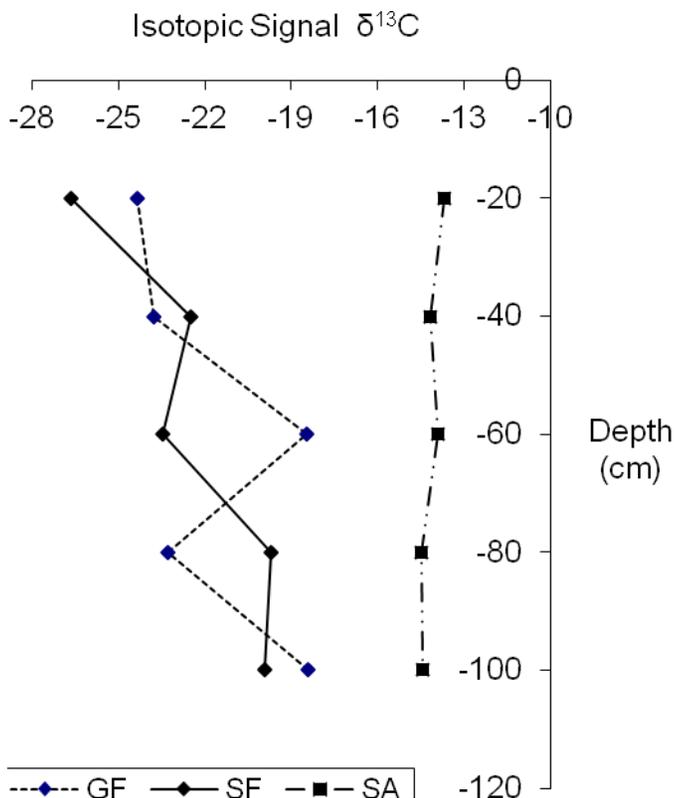


Figure 3: Distribution of tenors of organic carbon along the profile

### 3.3 Distribution of $\delta^{13}\text{C}$ in the profil of 0-100 cm within 3 sites (GF, SF and SA)

In Savannah, the distribution of isotopic signal ( $\delta^{13}\text{C}$ ) on the profile showed that the values of  $\delta^{13}\text{C}$  were almost constant. We obtained the value of  $\delta^{13}\text{C} = -13.7\text{‰}$  in the topsoil horizon, and in the depth the value of  $-14.4\text{‰}$ . In forests another trend is observed, an increase in of values of  $\delta^{13}\text{C}$  with depth (figure 4). The values of  $\delta^{13}\text{C}$  in the top surface (0-20 cm) ranged from  $-24.3$  to  $-26.6\text{‰}$  in forest to the value of  $-18.4$  and  $-19.9\text{‰}$  in depth (80-100 cm). Nevertheless, we noted a tenor enrichment of  $\delta^{13}\text{C}$  with depth was not regular in GF since it is observed in the horizon 60-80 cm an isotopic signal ( $-23.3\text{‰}$ ) lower than the one noted in horizons 40-60 cm ( $\delta^{13}\text{C} = -18.5\text{‰}$ ) and 80-100 cm ( $\delta^{13}\text{C} = -18.4\text{‰}$ ).

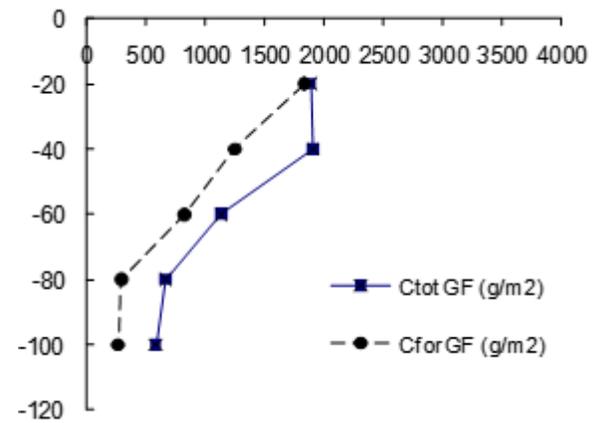


**Figure 4:** Vertical distribution of isotopic signal  $\delta^{13}\text{C}$  within 3 sites

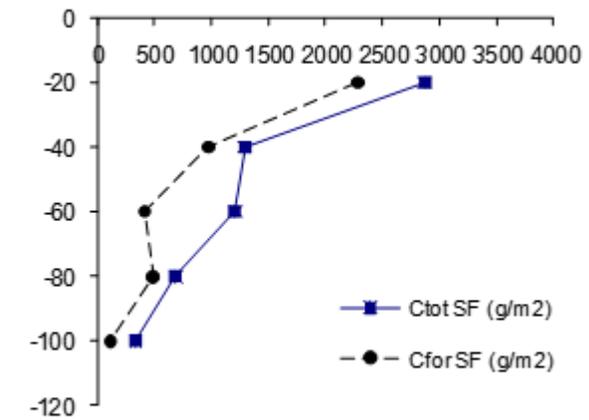
### 3.4 Evolution of carbon stocks resulting from forest from the total carbon

In the two forests GF and SF, we observed a decline in organic carbon amount originated from forest (Cfor) with depth. The proportions of the forest carbon in comparison with the total carbon vary in the SF from 97% by 0-20 cm to 46% in depth along the profile 0-100 cm. corresponding to a stock of  $1838\text{ g.m}^{-2}$  of CforSF as against  $1980\text{ g.m}^{-2}$  of total carbon, and  $266\text{ g CforSF g.m}^{-2}$  as against  $585\text{ g.m}^{-2}$  respectively along the profile. In GF, the proportions of CforGF range from 79% in topsoil (0-20 cm) to 34% in depth (80-100 cm). These percentages correspond respectively to amounts of total carbon of  $1838\text{ g.m}^{-2}$  of CforGF as against  $2873\text{ g.m}^{-2}$  of total carbon (0-20 cm), and

$266\text{ g.m}^{-2}$  of CforGF as against  $336\text{ g.m}^{-2}$  of total carbon for the 0-100 cm horizon (figure 5a and 5b).



(a)



(b)

**Figure 5 a and b:** Evolution of organic carbon stock originated from forest in comparison with total GF (a) and SF (b) carbon.

## 4 DISCUSSION AND CONCLUSION

The decline in tenors of total organic carbon with depth in our study are close to those observed by other authors in their studies on the dynamics of soil organic matter [15, 5]. As shown in the results, GF has more important tenors of carbon in the surface horizon than SF. Density per hectare of the biomass of fine roots could explain the differences noted. Indeed, inventories conducted in the two forests showed that. There is an average density per hectare of about 640 trees per hectare as against 119 trees per hectare [7]. Given the important role played by fine root turnover in the allocation of carbon to the soil, we can explain these results by the difference of fine roots between two forests in the considered horizon. Compared with the tenors achieved by other authors, the results in our site appear lower than those obtained by Desjardins *et al.* [5] in an Amazonian forest where they had obtained on the surface of the organic carbon contents ranging from  $14$  to  $20\text{ mg.g}^{-1}$ . However, the values obtained in our study are higher than those obtained by Trouve, [15] under Eucalyptus plantations in Pointe Noire in the Republic of

Congo, about 2 mg.g<sup>-1</sup>. In Savannah Trouve, [15] got means of organic carbon higher (6.5 mg.g<sup>-1</sup>) than those obtained in our study site. The low values of organic carbon of the soil beneath our study savannah study compared to those observed in forests could be explained by lower inputs of litter in savannah in comparison to the input of litter on the ground in forest, but also by their low clay content. In this research we could not conduct soil tests to determine the tenors of clay in soil. Through Makany, [8] conducted this study; it is difficult for us to discuss our results based on soil analyses results that he obtained. Just because forests types under which these analyses were made different from ours, taking into account the concept of the evolution of soils according to the stage of development of the forest. The Physical and chemical parameters such as texture, pH, soil clay content, porosity may also explain the differences in the observed soil organic carbon. Total carbon stocks accumulated throughout the profile (0-100 cm) in our sites increase with depth. Total forest carbon stocks are more important under forests in the adjacent savanna. The total differences between savanna and forest carbon stocks tell us the positive impact of the development of forests on savannas in the *Bateke* plateaux. The distribution of the isotopic signal along the 0-100 cm profile, the amount of organic carbon originated from forest and total organic carbon help verify the hypothesis of the significant impact of positive forest dynamics observed in the *Bateke*, plateau on soil organic carbon stocks. The constant isotopic signal of the  $\delta^{13}\text{C}$  along the savannah profile reveals that it was established in these places from a few decades to several centuries ago. We could not perform  $\delta^{14}\text{C}$  measures to date horizons and estimate more or less the exact beginning establishment dates of this forest vegetation. Under (GF and SF) forest, in surface horizons, we have a characteristic signal of forest vegetation with 24.3 and -26.6 ‰. However, this signal is enriched significantly with depth. Thus, we noted from 100 cm of depth isotopic signal  $\delta^{13}\text{C}$  values of -18.4 ‰ in the GF and -19.9 ‰ in the SF. The enrichment of isotope  $\delta^{13}\text{C}$  with depth is not specific to our study site. It was also observed in other sites by other authors where there had been replacement of vegetation [1, 9, 12] Desjardins *et al.* [5] noted an enrichment of 2.1 to 3.2 ‰ with depth in forest soils of Amazonia. Our study reveals important gaps at different horizons of the soil between the signal under forest and the signal in savannah. It has 4 ‰ in GF and 5.5 ‰ under SF enrichment. This profile is characteristic of all areas where there is replacement of vegetation by forest (forest) C<sub>3</sub>, C<sub>4</sub> (characteristics of plants of the *Poaceae* family). Total organic carbon stocks increase with depth below the three sites (GF, SF and savannah). In these three sites, the most important carbon stocks are noted under both forests under savannah vegetation. In savannah isotope registration up to -100 cm deep reveals some constancy of the typical isotopic signal of savanna vegetation (-13 per 1.000). Under the two forests isotopic signal is typically characteristic of vegetation C<sub>3</sub>. There is some enrichment with depth. Total organic carbon stocks are more important under forest vegetation than in savannah. These results indicate significant positive impact of forest vegetation in contrast to the savannah vegetation.

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## References

- [1] Balesdent, J., Mariotti A., Guillet, B. (1987). Natural <sup>13</sup>C abundance as a tracer for soil organic matter dynamics studies. *Soil Biology Biochemistry* 19:25-30.
- [2] Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. *European Journal Soil Science* 47 (2): 151–163.
- [3] Dalal, R.C., Carter, J.O. (2000). Soil organic matter dynamics, carbon sequestration in Australian tropical soils. In: Lal, R., Kimble, J.M., Stewart, B.A. (Eds.), *Global Climate Change and Tropical Ecosystems*. CRC Press, Boca Raton, FL, pp. 283–314.
- [4] Desjardins, T. Volkoff, B., Andreux, F., Ceni, C.C. (1991). Distribution du carbone total et de l'isotope <sup>13</sup>C dans des sols ferrallitiques du Bresil. *Science du Sol* 29:175-187
- [5] Desjardins, T., Filho A. C., Mariotti A., Chauvel A., Girardin, C. (1996). Changes of the forest-savanna boundary in Brazilian Amazonia during the Holocene revealed by stable isotope ratios of soil organic carbon. *Oecologia*. 108:749-756.
- [6] Feller, C. (1995). La matière organique dans les sols tropicaux à argile 1:1. Recherche des Compartiments Fonctionnels. Une approche granulométrique. Tome 1, Texte. ORSTOM éditions, Paris, TDM no. 144, pp. 393
- [7] Ifo S. A. (2010). Apports de Carbone au sol et stocks dans deux types forestiers (forêts galerie et forêts secondaire) des plateaux teke, Thèse de doctorat Université Marien N'GOUABI.
- [8] Makany, J. (1976). Vegetation des plateaux teke. *Travaux Universitaires Brazzaville*, pp 301.
- [9] Martin, A., Mariotti, A., Balesdent, J., Lavelle, P., Vuattoux, R. (1990). Estimate of organic matter turnover rate in a savanna soil by <sup>13</sup>C natural abundance measurements. *Soil Biol Biochem* 22: 517-523.
- [10] Martin, A., Mariotti, A., Balesdent, J., Lavelle, P., Vuattoux, R. (1990). Estimate of organic matter turnover rate in a savanna soil by <sup>13</sup>C natural abundance measurements. *Soil Biol Biochem* 22: 517-523.

- [11] Schwartz, D., Mariotti, A., Lanfranchi, R., Guillet, B. (1986)  $^{13}\text{C}/^{17}\text{C}$  ratios of soil organic matter as indicators of ecosystem changes in tropical regions. *Geoderma* 39: 97-103.
- [12] Schwartz, D. (1992). Interêt de la mesure du Carbone  $^{13}\text{C}$  des sols en milieu naturel equatorial our la connaissance des aspects pedologiques et ecologiques des relations savane-forêt. *Cah ORSTOM Ser Pedol* 26:327-341.
- [13] Scharzt, D., Elenga, H., Vincens, A., Bertaux, J., Mariotti, A., Achoundong, G., Alexandre, A., Belingard, C., Girardin, C., Guillet, B., Maley, J., De Namur, C., Reynaud-Farrera, I., Youta Happi, J. (1996). Dans : M.
- [14] Schwartz D., Namri M. (2002). Mapping the total organic Carbon in the soils of the Congo. *Global and Planetary Change*. 33: 77-93
- [15] Trouve, C. (1992). Apport de la geochemie isotopique ( $^{13}\text{C}$ ) à l'etude du renouvellement des matières organiques et des sucres neutres dans les sols tropicaux soumis à des changements d'écosystèmes. Thèse. Université P. et M. Curie. 112p.