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Amount of Soil Carbon Stock within Primary and Secondary Forest in the North of the Republic of Congo

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Abstract
The amount of carbon stock under different land type's cover was studied in the north east of Republic of Congo. Samples of soil from the surface 0-15 cm horizon were collected under 12 land types classes. Results showed that the lowest soil C was noted in flooded primary forests of Lophira alata Banks ex Gaertu. With an amount of 17.21 t C ha^{-1}, and the highest values were noted in the savanna of Jardinea congoensis with an amount of 117.6 t C ha^{-1} and the primary forest of Guibourtia demeusei (Harms) Léon. With 116.16 t C ha^{-1} ($p < 0.05$).
Our study revealed the importance of carbon stock in different type of land in tropical area to reduce the emission of CO_2 from the conversion of forestland to another type of land.
Keywords
soil carbon stock, forest, tropical, Likouala, Congo

1. Introduction

The construction of predictive models of the impact of climate change due to the effects of greenhouse gases first requires a comprehensive knowledge of stocks but also of carbon fluxes or transfers between different pools of carbon. So far the stock of carbon in the atmosphere, oceans and terrestrial vegetation are relatively well known. This is not the case for stocks of soil carbon (Schawrtz & Nagaraju, 2002) where many works are trying to refine their estimate in different type of ecosystems (Sundarapandian et al., 2016; Shaohui et al., 2016). Soil Organic Carbon (SOC) is an important component of the global carbon cycle, as it is one of the largest carbon sink that exchanges actively with atmospheric carbon dioxide at timescales of human concern (Schimel, 1995; Baldock, 2007). Global estimates of SOC were advanced by several authors. In terrestrial ecosystems, the organic carbon pool in the soils is about twice greater than in living vegetation (Post et al., 1990). Thus, the Earth's crust contain stocks of carbon ranging from 1500 to 3000 Gt C according to the authors Batjes (1996), Bolin and Sukumar (2000); Eswaran et al. (1993); Schwartz and Nagaraju (2002); nearly 80% of the total terrestrial carbon stock (Schlesinger, 1995).

Soils of the tropics may contain one third of the global SOC pool, with about 128, 151, 136 and 56 Pg C stored in tropical wet, moist, dry and montane regions, respectively (Hiederer & Kochy, 2011). At the scale of ecosystems, some studies have shown that in tropical forests and subtropical soils accounted for nearly 30 percent to the overall total organic matter (Daisy & Carter, 2000). Studies of the carbon storage in secondary tropical forests are more and more reported (Hughes et al., 2002; Feldpausch et al., 2004). Moreover, Silver et al. (2000) and Guo et al. (2002) reported that natural regeneration on land abandoned after intense use is often characterized by an increase in soil carbon storage, suggesting as well as secondary forests and fast-growing young forests can significantly increase carbon sequestration in the abandoned fallow.

Firsts estimations of C stock in Congo basin were made very recently (Zhang et al., 2002; Schwartz & Namri, 2002; Batjes, 2008), and these soils are very deep up to ten meters. In Republic of Congo, the average stock of carbon for the first two meters has been estimated at 160.5.ha^{-1} (Schwartz & Namri, 2002). These carbon stocks vary depending on the type of soil. In podzols of the plateau Batéké Schwartz (1988) found that the soil carbon stock was 1250 t.ha^{-1}.

This study are taking place in a context where there are few available data on carbon stock of the soils in different types of forest land in the whole of congo bassin in general and in the Republic of Congo particularly (Namri, 1996; Namri & Schwartz, 1998; Ifo, 2016). Several studies have presented on the aboveground biomass in various pools of carbon (Bocko et al., 2017), deadwood debris (Ifo et al., 2015), biodiversity of flora (Ifo et al., 2016) but to date we do not have a lot of data available on C soils under different type of forest but also under savanna soils in Republic of Congo Except for the swamp forests-peat is a type of soil (Greta et al., 2017), and mainly in the forest of Likouala which have per department of the Republic of Congo the greatest superficial of forest with 85% of the size area of Likouala.

The mains aims of this study were: (i) to quantify carbon stock among land type cover of our study area, (ii) Find the cause of spatial variation of C stock.

2. Material and Methods

2.1 Study Area

The study was carried out within the tropical rainforest of the North of the Republic of Congo in the Likouala Department (Figure 1). The study region lies between 1°27' 52,85" N and 2°6' 55,76" N of and between 17°52' 35,04" E and 18°04' 32,65" E and covers an area of 155,000 ha. The climate of the study area is of equatorial type. Mean annual rainfall is 1760 mm, with a dry season from December to January, and a long wet season from February to November The annual mean of temperature is 25-26

°C with amplitude of 1 to 2 °C (Figure 2). The soil cover is of tertiary clay sandy formation and a quaternary alluvial formation to the east. The forests of the Likouala Department contains a high diversity of trees and plants The principal vegetation types are: partially deciduous dense rainforests of *Ulmaceae* and *Sterculiaceae*, swampy flooded forest of *Uapacaheudelotii Baill*, forest of *Guibourtia demeusei* (Harms) Léon (Ifo et al., 2016).

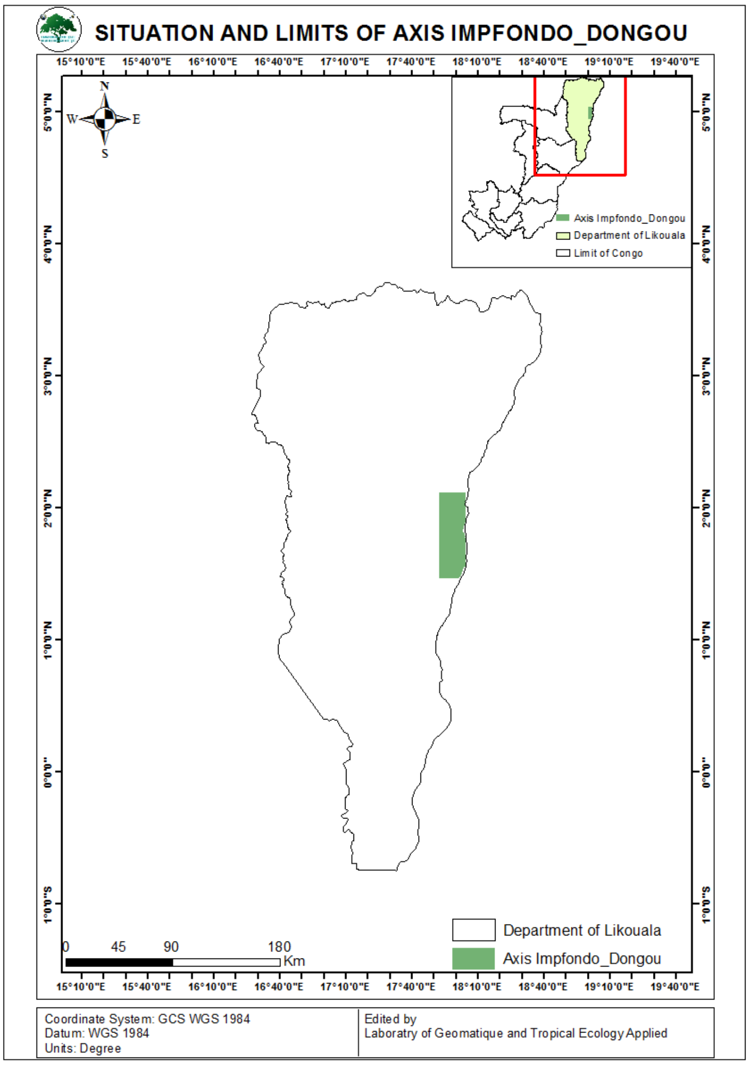

Figure 1. Map of the Study Area within the Likouala Department, Republic of Congo

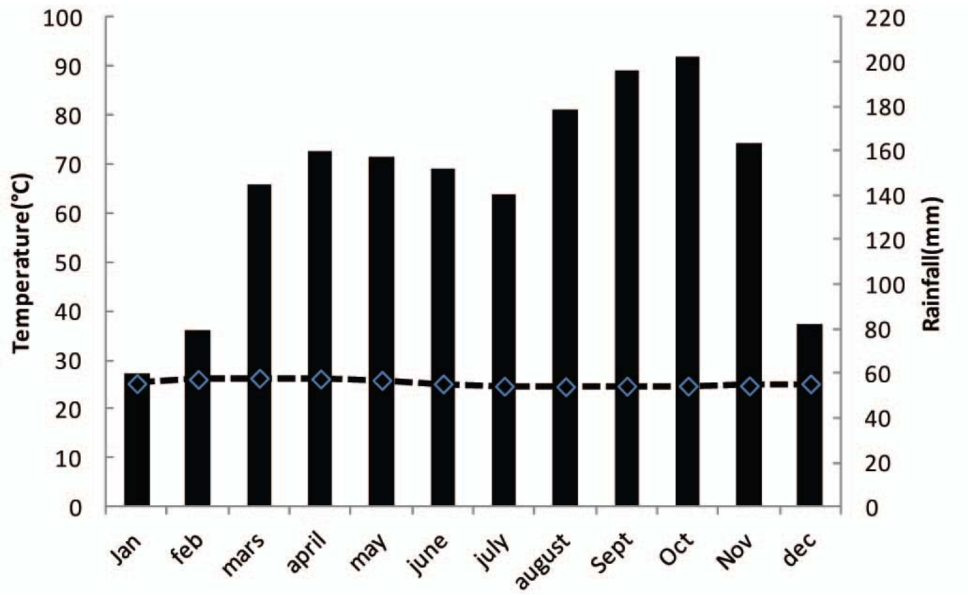

Figure 2. Mean Annual Temperature (Left Axis) and Rainfall (Right Axis) for the Likouala Department, Republic of Congo (Years 1932 to 2015; ANAC, 2016)

2.2 Methodology

The samples of soil used to do analyses of C content were collected in the following various classes of land cover type: secondary forest of *Musanga ceprodioides* (FSM), savanna of *Jadinea congoensis* (SI), Fallow (RF), burned crop (CB), primary forest of *Lophira alata* (FPLa), primary forest of *Guibourtia demeusei* (FPGb), field crop of *Zea maîs* (CM), primary forest of *Celtis adolphi-friderici* (FPCa), Agro forest field (AGF), secondary forest with *Macaranga sp* (FSMa), field of manioc with *Manihot sculenta* (CdM), young secondary forest (JFS).

Soils samples were collected with a minimum distance of 100 m, soils samples were sampled randomly inside each land cover type but not closed to the limit of classes. Soil samples were collected at the top soil horizon (0-15 cm). Finally, 36 soils samples were taken throughout the whole study area with three samples within each class of land type to determine stocks of organic carbon. Samples were air-dried for four days, then sieved at 2 mm to remove plant debris. Soil total carbon (C) concentrations were determined using the Walkley Black method (Walkley, 1934). Soil total nitrogen was determined using the Kjedahl method (Baize, 2000). The soil Bulk Density (BD), also known as dry bulk density, is the weight of dry soil (M_{solids}) divided by the total soil volume (V_{soil}).

The soil surface C content ($C_{Content}$; tC ha^{-1}) was calculated by:

$$C_{content} = BD*C*e$$

Where BD is the soil bulk density (g cm^{-3}) and C is the soil C concentration (%), e = height of soil sample.

2.4 Statistical Analysis

One-Way Analysis of Variance (ANOVA) was used to examine the effects of land type cover on soil C contents and stocks and multiple comparisons were conducted with a post hoc Tukey's-HSD test for soil C contents and stocks at different land type cover.

3. Results

3.1 Trends of C (%) and N (%) in the Different Land Type

Total organic nitrogen stock showed a high variability between different land cover and land use type, in contrast to organic carbon where the highest stock was recorded in the savannah land Furthermore we noted that the apparent density of the soil varies from one soil to another type, as well as the results of the percentage of C and N varies from one type of vegetation to another or from one type of land to another use (Figure 3).

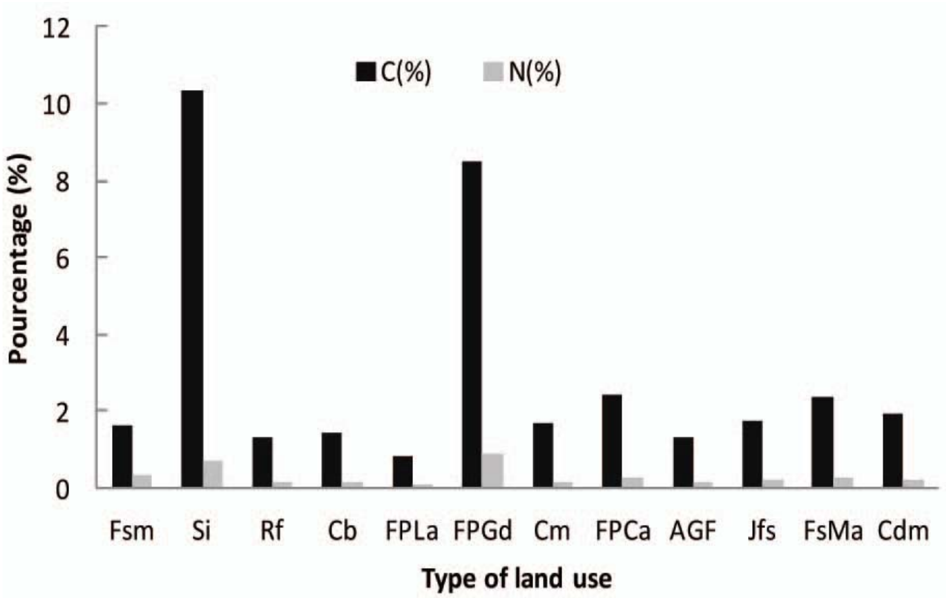

Figure 3. Trends of C (%) and N (%) in the Different Land Type

3.1 Spatial Variation of C

Spatial variability of C stock in the different land type showed that C stock varies among different types of land cover ($p < 0.05$). The lowest C stock was noted in flooded primary forests of *Lophira alata* Banks ex Gaertu. with a quantity of 17.21 t C ha^{-1} and the highest value was noted in the savanna of *Jardinea congoensis* with an amount of 117.65 t C ha^{-1}. The primary forest of *Guibourtia demeusei* (Harms) Léon contains also important stocks of carbon 116.16 t C ha^{-1} (Table 1), but there are no difference in terms of stock between FPGd and Si ($p = 0.05$).

According to our results stock of C soil was different with the stock of carbon into the following land type FPCa, FsMa, FPGd and Si ($p < 0.05$). Error bar represent significant or not between class of land type cover.

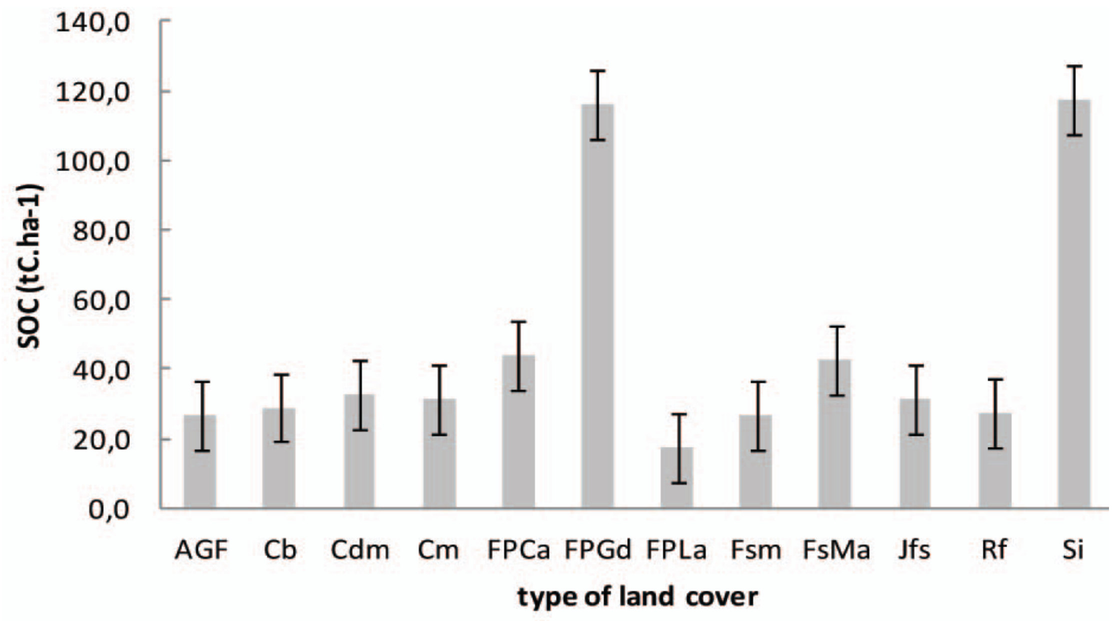

Figure 4. Spatial Vatial of Stock of Carbon in the Different Land Type

Table 1. Variation of Soil Bulk Density; Stock of C and C/N in Different Type of Land Cover

soil samples	code	number of samples	Type of strata	bulk density (g.cm^{-3})	stocks of C (tC.ha^{-1})	C/N
sf of *Musanga* spp	FSM	3	non	1.11	26.97	5.06
Savanna	SI	3	Sfl*	0.76	117.65	14.96
Fallow	RF	3	non	1.37	27.13	8.25
Burnt crop	CB	3		1.36	28.97	8.88
pf of *Lophira alata* Banks ex Gaertu.	FPLa	3	sfl	1.35	17.21	9.44
pf of *Guibourtia demeusei* (Harms) Léon.	FPGb	3	sfl	0.91	116.16	9.46
Crop of Maiz	CM	3	non	1.23	31.55	10.06
pf of *Celtis adolphi-friderici* Engl.	FPCa	3	non	1.21	43.92	9.68
Agroforestry	AGF	3	non	1.33	26.33	9.43
Young secondary forest	JFS	3	non	1.21	31.58	9.16
sf of Macaranga sp	FSMa	3	non	1.2	42.3	9.4
Crop of *Manihot sculenta*	CdM	3	non	1.11	32.47	9.48

Sfl* seasonnaly flooded land.

Our results show us that a high value of bulk density does not means a high carbon stock for this soil samples. The highest values of bulk density were recorded in the fallow and burnt crop whereas the lowest values were recorded in the savanna. Also these results showed us a spatial variation of C/N into the different types study area. The high value of C/N was recorded in savanna with 14.96. Nine out of twelve classes of occupation of the soil have C/N values which vary between 9 and 10, whereas the low value of C/N was recorded in the secondary forest with *Musanga cecropioides*.

4. Discussion

4.1 Stock of Soil Organic Carbon

The results obtained in our study revealed a high variability of soil C stock between land cover type of Likouala. A very high soil C stock was noted in savanna and in the primary forest of *Guibourtia demeusei* in comparison with the soil C stock obtained in the others types of land cover type. Factors explaining the decline of soil C are many and not very easy to determine. But following factors could explain the variation of C stock: The conversion from the primary forest to secondary forest or to agricultural activities, the decomposition of soil organic C by breaking down the physical protection of soil C (Guo et al., 2002; Wang et al., 2011), and increasing the frequency of erosion after rainfall, especially within the first few years (Chen et al., 2007), could explain the decline of C stock in the study area. Indeed,

But Yu et al. (2006) some others reasons to explain the spatial variability of soil stock C: local climate, specific conditions of site, mother stone, vegetation on the site.

We noted on the ground continue to assist to deforestation for several reasons, but the main is traditional agricultural done by locals peoples. To date the agricultural activities constitute the first cause of deforestation in the Republic of Congo but also in Congo Basin (Tchatchou et al., 2014). The factors mentioned above surely could explain the fact of the decline of soil C stock during the conversion of the land.

Our study revealed very high significant variation in carbon stocks under natural forest land of *Guibourtia demeusei* (Harms) Léon in comparison with to the stock of carbon into others types of natural forest land in the study area like forests of *Musanga cecropioides*, *Macaranga spp*, *Lophira alata* Banks ex Gaertu. Why the soil stock of C is more important in the savanna of *Jardinea congoensis* and in the forest of *Guibourtia demeusei* than in the others soil land cover? For the soil of the forest of *Guibourtia demeusei*, we suppose that the high rate of nitrogen and carbon could be explain by the fact that *Guibourtia demeusei* is a species belong to the leguminous family which is characterized by a high content of nitrogen, in ecophysiology we know that high rate of nitrogen increase the capacity of the plant to more assimilate CO_2 by phosynthesis and then of C in the plant. Another principal reason to which could explain the high soil stock of C could be also the type of soil.

The stock of C was low but not zero in the fallow, young secondary forest of *Musanga cecropioides*, and of *Macaranga sp*. This suggests that accumulation of soil C stock. Silver et al. (2000); and Guo et al. (2002) have reported that natural regeneration on the grounds given up following an intense use is often characterized by the increase of the storage of the carbon of the soil, suggesting as well as that the secondary forests and the young forests in full growth can to a significant degree increase the accumulation of carbon in the abandoned fallow. Fallow was mainly characterized by the plant species called *Chromolenana odaratum* and trees. Comparison of soil properties under the canopy of individual trees with those in the surrounds without a tree cover allowed to note that under the canopy authors observed increase of orgnic matter with increased water-holding capacity (Felker, 1978). Trees improve soils by: increasing inputs (organic matter; nitrogen fixation, nutrient uptake), reducing losses (organic matter, nutrients) by promoting recycling and checking erosion, improving soil physical properties, including water-holding capacity, beneficial effects on soil biological processes (Young, 1989).

The low carbon stock in the different land type cover in our study area could be explained by the leaching of soil during the rainfall season.

4.2 C/N Ratios

In soils, the C/N ratio reveals the kinetic of mineralization of the humic amendments to the soil (Boulaine, 1982). More C/N is low, the faster is the decomposition of matter organic fresh. However, the C/N also directs the decomposition of organic matter mineralization, either to the humification. If the C/N is less than 10: mineralization is favored, there is a strong production of mineral nitrogen usable by plants. If the C/N ratio is way (approximately equal to 20): mineralization and the humification balance; if the C/N ratio is greater than 50: mineralization is practically zero. In our study most of the value of C/N is around 10. This is means that the mineralization taking place in this biotope is normal. The decay of organic matter is slow and drives to the accumulation of organic matter in the soils.

Table 2. Estimates of Soil Organic Carbon Stocks from across the Tropics

Authors	**Localities**	**Types of soils**	**Horizon (cm)**	**Organic carbon stocks (kg/m2)**
Grinand, 2010	Madagascar	ferruginous and ferralitic	0 - 30	5.6
Ifo, 2016	Congo (Plateaux tékés)	Ferralitique, podzols and hydromorphic	0 -20	1.3 (savanna); 1.9 (secondary forest)
Antoni and Arrouays, 2007	Martinique	Grounds martiniquais	0 - 30	6.2
Antoni and Arrouays, 2007	In moderate zone	Grounds of the moderate zones	0 - 30	6.5 (meadow). 7 (the forest)
Bernoux *et al.,* 2005	Brazil	Grounds of Brazil	0 -30	1.5 to 41.8
Hien *et al.,* 2003	Burkina South-west	Ferruginous	0 - 30	6.15 (savanna)
Volkoff *et al.,* 1999	Benin	ferruginous and ferralitic	0 -20	2.2
Volkoff *et al.,* 1999	Benin	ferruginous and ferralitic	0 -50	3.5
Bernoux *et al.,* 1998	Brazilian Amazonia	Ferralitiques and ferruginous tropical	0 -30	6.67

Namri and Schwartz, 1998	Congo	Ferralitiques, podzols, not very advanced and hydromorphic	0 -10	3.45
Namri, 1996	Congo	Ferralitiques, podzols, peu évolués et hydromorphes	0 - 10	2.63

5. Conclusion

This study revealed the high spatial variability of soil C stock in the study area. Soil C stocks were highest within the *Jardinea congoensis* savanna and the forest of *Guibourtia demeusei* (Harms) Léon. The result obtained during our study could help for the best management of soil and forest in the tropical region in general and in Republic of Congo mainly. Seeing the large distribution of *Lophira alata*, *Guibourtia demeusei* but also of the savanna of *Jardinea congoensis* in African tropical region, our results must to be confirm by others studies According to the importance of C stock in the different land type, the non well management of these lands could release in the atmosphere important quantity of CO_2-GHG.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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