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Carbon stock estimates for plant formations in Manda National Park (MNP) in the Moyen-Chari Province of Chad

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Abstract

The study was conducted in the Manda National Park (MNP), Moyen-Chari Province, Chad. The aim of this work was to estimate the quantities of carbon sequestered by the various plant formations in the MNP. The survey area is a 1m x 1m square plot and a 10m x 10m semi-plot for grassy savannah (20 plots) and shrub savannah (28 sub-plots) respectively, and a 50m x 20m rectangular plot for woodland (54 plots) and tree savannah (46 plots). The diameter at breast height of all woody individuals was measured, followed by floristic inventories (woody and herbaceous species). Analysis of variance between grass savannah, shrubs savannah and trees savannah and woodland and between trees, shrubs and grasses clearly shows that there is a significant difference ($P<0.001$) between the amount of phytomass, carbon and atmospheric carbon dioxide stock. Woodland contributed 118.32 t C/ha, tree savannah 57.96 t C/ha, shrub savannah 4.42 t C/ha and grass savannah an estimated 0.23 t C/ha. The woodland has a higher carbon credit value (3894590.7 FCFA) than the other plant formations, whose credit values range from 7886.2 FCFA to 1957100.9 FCFA. This research enables protected area managers to monitor vegetation for their conservation and sustainable management.

Keywords: Carbon, Chad, Estimation, MNP, Moyen-Chari, Plant formation

Introduction

Around the world, forests are the most important terrestrial carbon sinks (Kurz *et al*., 2016). Tropical forests contain 40-50% of terrestrial carbon and play a major role in the global carbon cycle (Pan *et al*., 2011; Panzou *et al*., 2016; Mertens *et al*., 2019). The loss of forest cover resulting from deforestation and degradation of these forests contributes around 10-15% of annual global greenhouse gas emissions (Van der Werf *et al*., 2009; Mertens *et al*., 2019). Carbon stock is a key component of the global carbon cycle (FAO, 2017; Mertens *et al*., 2019). The Intergovernmental Panel on Climate Change (IPCC) and other scientific committees estimate this loss at up to 20% (ILWAC, 2013). The degradation of these forests represents a serious environmental, social and economic problem, particularly in developing countries (FAO, 2011). Vegetation annually and globally subtracts around 120 Gt of carbon from the atmosphere via photosynthesis (Bernoux and Chevallier, 2013). Protected areas are zones set aside for the protection and conservation of biodiversity.

National parks belonging to the protected areas domain are managed according to a management plan (Adjonou *et al*., 2009; Sandjong *et al*., 2013). The trees and shrubs found there play a multiple role in production systems through the quantity of biomass produced (Bognounou *et al*., 2008). Quantifying the biomass and carbon stocks contained in tropical forests has become an international priority as part of the implementation of the REDD+ mechanism (Bali Action Plan, 2007; Gorin, 2011). This REDD+ mechanism aims to encourage developing countries to preserve forest massifs in return for financial compensation from carbon credits (Angelsen *et al*., 2013; Panzou *et al*., 2016). According to Sedjo (1992) and Dixon *et al*. (1994) cited by Jessica, 2009, forests worldwide contain between 360-480Gt C in vegetation and 790-930 Gt C in soils. However, CO2 fluxes vary spatially and temporally (Goodale *et al*., 2002). Depending on the forest stand type, various autogenous and allogenous factors will influence these changes (Jessica, 2009).

As part of the sustainable development approach we have initiated, this research is part of the process of assessing carbon sequestration in the Manda National Park (MNP), with a view to identifying guidelines for reconciling conservation and the rational use of natural resources. The aim of this work is to estimate the phytomass of the stands of different plant formations in the MNP. As such, this research has proved essential, to contribute to the knowledge of the quantities of carbon sequestered in the MNP. It is important to know the phytomass of this protected area in order to monitor its rehabilitation and development process.

Materials and Methods

Study sites

The study sites are located in the Manda National Park (MNP) in southern Chad, in the Moyen Chari region (Bahr Kôh department), (Figure 1). It lies between latitudes 9°20 - 9°50 North and longitudes 17°45 - 18°20 East, at an altitude ranging from 344 to 691 m. It officially covers an area of 114,000 ha. It is bounded to the west by the Sarh - N'Djamena road, to the south by the Bahr Sara, to the east by the Chari river and to the north by the Niellim rocks. The MNP was created on March 19, 1965, and is located as the crow flies 25 km northwest of the town of Sarh, some 450 km southeast of N’Djaména, and 80 km from the Central African border. The area is characterized by a tropical-type climate, with an average annual rainfall of 1.000 mm, an average annual temperature of 24.5°C and a relative humidity depending on the month of 32 to 85% (ASECNA, 2018). Soil types are: erosion soils on acidic rocks dominant on Mont Niellim; sesquioxides with ferruginous stains and concretions and cuirasses; and hydromorphic soils characteristic of soils in the south of the park (Pias, 1964). Vegetation formations include gallery forests, shrub and tree savannahs. Overall, the vegetation is of the Sudanian type, whose density and distribution are a function of topography and soil type (PAPNM, 2010).The MNP area had been known for its rich fauna since the 1950s, leading to its classification as a wildlife reserve. In the early 1980s, politico-military events in Chad led to a drop in the number of species present, and even more so in their numbers (PAPNM, 2010). Before and after their creation, the reserve and then the park received technical and financial support from the Fondation of home, of hunting and of nature, thanks to its founder François Sommer, who died in 1973. Following his death and the socio-political events in Chad in the late 70s and 80s, much of the fauna was decimated (including the Elands Derby, the park's flagship).

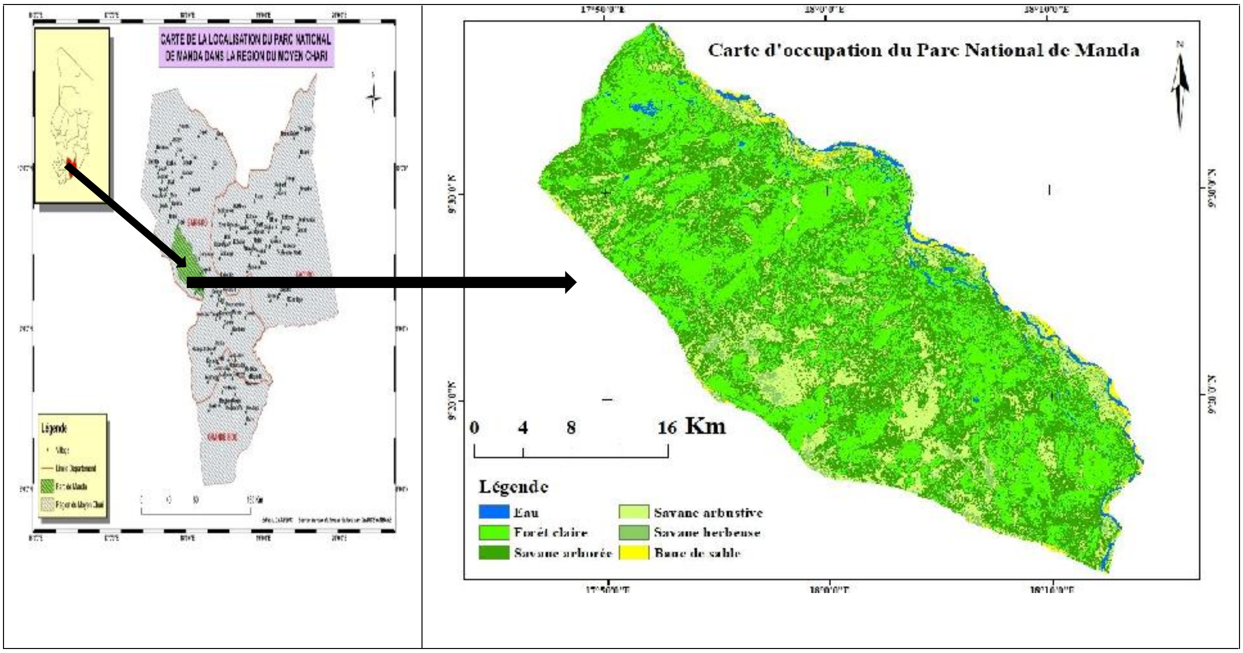

Figure 1: Location of the MNP in the Moyen-Chari region of Chad (Source: EsaieWaya, 2019)

Data collection system

The study was conducted during the dry season. However, due to the exceptional meteorological phenomenon this year, the park was flooded for more than three months until November. This led to the disappearance of ground litter. Four types of plant formations, distinguished by remote sensing and homogeneous, were the subject of this study: woodland (FC), tree savannah (SA), shrub savannah (SU) and grassy savannah (SH). The data collection plan is semi-random and stratified. Based on the remote sensing location of the plant formations, the inventory plots were located randomly in the field. In FC (54 plots) and SA (46 plots), phytomass was eventually estimated in 1000 m²(50 m x 20 m) rectangular plots. In SU (28 plots), phytomass was estimated in 100 m² (10 m x 10 m) square plots and finally in SH (15 plots),phytomass was estimated in 1 m² (1 m x 1 m) square sub-plots of the first three plant formations. To minimize spatial heterogeneity, the plots are spaced close together, at around fifty meters or more. The sampling rate is certainly not optimal, but suitable within the framework of an inventory aimed at the management of a natural forest in a dry zone (Bellefontaine *et al*., 1997; Sandjong, 2018).

Carbon data collection

To assess the amount of carbon stored in an ecosystem, we evaluated the biomass present in the sample plots, since plants accumulate atmospheric carbon dioxide (CO_2) in their cellular constituents (Tufekcioglu *et al*., 2003; Sharrow and Ismail, 2004; Mertens *et al*., 2019). It involves assessing the biomass present in several components (above-ground and below-ground). Biomass can be estimated using two approaches:

direct or so-called destructive methods and indirect, so-called non-destructive methods (Segura and Kanninen, 2001; Mertens *et al*., 2019). The first methods generally involve the field collection of samples and sometimes even complete plants. The second methods involve, among other things, applying regression models, volume tables or geometric formulas to field measurements. In the present study, carbon data were collected by the non-destructive method for standing trees (dhp ≥ 5cm and height ≥ 3m)) and shrubs (dbh ≤ 5cm and height ≤ 3m) and by the destructive method for herbaceous plants. These methods were used by Ibrahima and Fanta, 2008 and Ibrahima *et al*., 2019.

Field data and materials

For the collection of carbon inventory data, we measured the heights, circumferences at 1.30m from the ground of all trees and the scientific and/or dialect (Sara) names in plots of different plant formations in the park, using a 7 m graduated pole, a Blume-leiss and a tape measure respectively. The Global Position System (GPS) was used to locate and survey the points of the plots inventoried. Machetes were used to mark the boundaries of the sample plots. Adhesive tape was used to delimit and identify plot boundaries.

Estimation of above-ground biomass for woody and herbaceous plants

Calculation of the total dry mass of herbaceous plants: The method used is that of integral harvesting (photo 1), known as the destructive method, employed by many authors (Zoungrana, 1991; Ibrahima and Abib Fanta, 2008; Santi, 2011; Saidou *et al*., 2010; Yé *et al*., 2016; Ibrahima *et al*., 2019). Herbaceous phytomass is estimated by the direct method, in five 1 m² subplots delimited at each apex and in the center of the 1000 m² and 100 m² plot, used for sampling trees and shrubs, in an area presenting a fairly dense herbaceous physiognomy, free from grazing or straw collection by the populations. All herbaceous plants included in the sample were inventoried, then cut to ground level. The total mass of cut grasses was determined by weighing them using a balance (photo1). To determine carbon concentration, all herbaceous plants were brought back to the laboratory in paper bags to be dried at 60°C in an oven for 72 hours, i.e. until a constant dry mass was reached (Photo 2). The dry masses were then calculated and expressed in tonnes per hectare (t/ha). The water content (Te in % of dry mass) of all sub-samples was calculated using the following formula:

$$\mathbf{Te = ((MH - MS)/ MS) \times 100}$$

Where MH (g) is the wet mass and MS (g) is the dry mass.

Based on the water content of the sub-samples (vegetation and soil), the total dry mass was calculated as follows:

$$\mathbf{MST = 100 \times MHT / (100 + Te)}$$

where MST is the total dry mass and MHT is the total wet mass.

Photo 1: Complete harvesting of 1m² of herbaceous vegetation

Photo 2: Weighing fresh grass biomass in the field

Photo 3: Drying and weighing herbaceous vegetation in the laboratory

For woody plants: For this study, we opted for the non-destructive method, given the limited means and time available, and the fact that felling a tree in the MNP requires authorization from the forestry administration. The phytomass of trees and shrubs is estimated using a mathematical model, taking into account the parameter diameter at breast height at 1.30m (DBH at 1.30m) of the tree. The most important predictors of biomass are, in descending order: trunk diameter, wood density and total height (Chave *et al*., 2005; Panzou *et al*., 2016). Any plant with DBH ≥ 5.01cm and height ≥ 3m is considered a tree, but one with DBH between 4cm and 5cm and height between 2.99m and 1.5m is considered a shrub (Ibrahima *et al*., 2019). Among the equations found in the literature, those used by Saidou *et al*. (2012); Djono *et al*. (2016); Baudain *et al*. (2018) and Ibrahima *et al*. (2019) were applied. For individuals whose dbh ≥ 5cm in savannahs (tree and shrub), we applied equation 2 (R^2=0.912).Those where dbh≤ 5cm, equation 3 (R^2=0.987) is used and individuals whose dbh between 1cm and 212cm in any forest type, for example, in the woodland of our study area, equation 1 (R^2= 0.970) is used, as their coefficient of determination (R^2) is highly significant in these equations.

$$\mathbf{Ba\ (Kg) = exp\ (a + b*ln(D) + C*(lnD)^2)} \qquad \text{Equation 1}$$

a=-1,975 b=2,266 c=0,046 D= diameter in cm R^2=0,970 (Djono *et al*. (2016)
ln= neperian logarithm, exp= exponential

$$\mathbf{Ba\ (Kg) = 0{,}011*DBH^3 + 0{,}234*DBH^2 - 5{,}283DBH + 37{,}501} \qquad \text{Equation 2}$$

DBH= diameter in cm R^2=0,912 Baudain *et al.* (2018)

$$\mathbf{Ba\ (Kg) = exp\ (-1{,}996 + 2{,}32*lnD)} \qquad \text{Equation 3}$$

ln= neperian logarithm, exp= exponential, D= diameter in cm, R^2=0,987 Ibrahima *et al*.(2019)

In the case of the palms present, it is their height that is taken into account, as their biomass is closer to height than to diameter (Maguette *et al*., 2013). Palm biomass was calculated using the formula below (Winrock, 2005; Etchike *et al*., 2020):

$$Y = 23{,}487 + 41{,}851 * \ln(H)^2 \qquad \text{Equation 4}$$

with Y: biomass, H: vegetation height and ln: neperian logarithm

Estimation of below-ground biomass

For the assessment of carbon sequestration in the hypogeous part, the equation established by Cairns *et al*. (1997) was used. The calculation of below-ground biomass is based on our knowledge of above-ground biomass. This equation has been used successfully by Saïdou *et al*. (2012) and Ouédraogo *et al*. (2019). Moreover, this regression model is widely used in tropical zones point out McGhee *et al*. (2016). It is written:

$$Bs\ (t/ha) = \exp(-1{,}0587 + 0{,}8836 * \mathrm{Ln}(Ba))$$

Where Bs = below-ground biomass in tonnes per hectare (t/ha) and Ba = above-ground biomass (t/ha).

Using this equation provides an estimate of underground biomass. It is the most practical and least expensive method for determining root biomass (Maguette *et al*., 2013).

Carbon quantity estimation

Estimation of carbon content in above-ground phytomass

For herbaceous plants: From the total dry mass (MST) of the vegetation (fraction, component or category) and their carbon concentrations, carbon quantities were calculated as follows:

$$QCh = (MST \times C)/100$$

Where QCh is the amount of carbon in grasses, expressed in tC/ha, MST: total dry mass in t/ha and C= 0, 47 according to GIEC (2006).

For woody plants: The quantity of carbon in standing woody plants was estimated using the following formulae:

$$QCv = Ba \times Cv$$

With :QCv or QC aerial = vegetation carbon quantity (tC/ha), Ba = aerial biomass (t/ha), Cv = vegetation carbon concentration (0.47).

Estimation of carbon in root phytomass

This estimate of the amount of carbon in standing vegetation (woody and herbaceous) was calculated using the following formula:

$$QCr = Br \times Cv$$

With :QCr = amount of root carbon (tC/ha), Br = root biomass (t/ha), Cv = vegetation carbon concentration (0.47).

Estimating total carbon quantity

The total carbon quantity (QCt) for biomass is calculated using the following formula:

$$QC_t = 0{,}47 \times (Bt + Bh)$$

Where QCt is total carbon (woody and herbaceous), Bt is total woody biomass and Bh is total herbaceous biomass.

Estimating the equivalent atmospheric carbon dioxide (CO_2) stock and estimating the economic value.

With regard to the stock of sequestered atmospheric carbon dioxide (CO_2), it is recognized that the atomic mass of Carbon (MaC) is equal to 12 and that of Oxygen is 16. The molecular mass of CO_2 is 44. Thus, the combination ratio of Carbon (C) to Oxygen (O_2) is 3.67 (Tsoumou *et al.*, 2016). The equivalent atmospheric CO_2 stock is estimated by multiplying the biomass carbon stock by 3.67 (44/12=3.67). Furthermore, to estimate the carbon credit of vegetation, the quantity of carbon dioxide emitted into the atmosphere by vegetation

(QCO_2) was first calculated using the formula adapted from the method used by the World Resources Institute (2005), cited by Sandjong (2018):

$$\mathbf{QCO_2 = QCt * PMCO_2/PMC}$$

where QCO_2, the amount of carbon dioxide emitted into the atmosphere by vegetation, QCt is the total amount of carbon in the sample plot, $PMCO_2$ is the molecular weight of carbon dioxide (44) and PMC is the molecular weight of carbon (12). This value is then transformed into a monetary unit using the rate of 14 Euro/t of CO_2 recommended by the REDD+ carbon market (Gueulou *et al*., 2020). One Euro (£) = 655 FCFA.

Data processing and analysis

The dendrometric parameters (diameter and height) of the species sampled in the field were entered and compiled using Microsoft Excel 2010 to process and calculate biomass and sequestered carbon. Analyses of variance (ANOVA) at a probability threshold of 5% followed by comparison of means using Duncan's test were used to compare biomass, vegetation sequestered carbon and atmospheric carbon (CO_2) of herbaceous and woody plants between the four types of plant formations (FC, SA, SU and SH) and between vegetative types (Trees, Shrubs and Herbs). We also used this analysis of variance to compare tree, shrub and herb biomass between plant formations. The tools used for these analyses included Office Excel (Windows 10) spreadsheets and XLSTAT 16 software.

Results and Discussion

Above-ground biomass production as a function of vegetation type and plant formations

The amount of total above-ground phytomass varies significantly ($P=0.0001< 0.001$) on average between vegetation type (herbaceous, shrub and tree) and between plant formation type ($P=0.0001< 0.001$) (woodland, tree savannah, shrub savannah and grassy savannah) (Table 1). For woodland, the contribution of trees is highest (209.85 T/ha), i.e. 99.17%; that of herbaceous plants is intermediate (1.68 T/ha), i.e. 0.79%, and that of shrubs is low (0.07 T/ha), i.e. 0.03%. In the tree savannah, the contribution of trees is the highest at 102.21 T/ha, i.e. 92.61%, that of herbaceous plants is intermediate at 7.54 T/ha, i.e. 6.83%, and that of shrubs at 0.61 T/ha, i.e. 0.55%. In the shrub savannah, the contribution of herbaceous plants is highest (6.27 T/ha), i.e. 50.24%, followed by trees (5.39 T/ha), i.e. 43.18% and 0.82 T/ha, i.e. 6.57% for shrubs. Finally, in the grassy savannah, only grasses are present, contributing 1.47 T/ha, or 100%.

Phytomass quantities ranged from 1.4 T/ha to 211.60 T/ha (Table 1). The highest total amount of phytomass was recorded in the woodland (221.60 T/ha) and the lowest in the grassy savannah (1.47 T/ha). The abundance of large-diameter trees in this part of the forest would justify this. Similarly, Dorvil (2010), Monssou *et al*. (2016) and Ilboudo (2018) emphasized that large-diameter woody individuals are inevitably the dominant component of above-ground phytomass. However, our results are globally superior to those found by Chanceyambaye *et al*. (2016), who found phytomass values ranging from 37.21 t/ha to 15.3 t/ha in the same study area (MNP). Specifically, the phytomass values in shrub (15.3 t/ha) and grass (19 t/ha) savannas estimated by Chanceyambaye *et al*. (2016) are higher than the values I found in the same savannas, respectively 12.48 t/ha and 1.47 t/ha. The decrease in phytomass from 2016 to 2023 would be due to grazing and anthropogenic activities in these savannahs. However, our results are much lower than those found by Gomgnimbou *et al*. (2019) in the urban landscaped areas of the city of Bobo-Dioulasso in Burkina Faso, where phytomass values ranged from 6.44 t/ha to 713.97 t/ha. These differences may be linked to the methodological approach to data collection. While our study took into account subjects with small diameters (DBH ≤ 3 cm), the other authors previously mentioned, only considered individuals with a diameter greater than or equal to 3 cm. Human activities, including logging, inevitably affect phytomass (Lindsell *et al*., 2013; Willcock *et al*., 2014; Panzou *et al*., 2016).

Table 1: Above-ground phytomass

TB	**Above-ground phytomass**				
TF	**Trees**	**Shrubs**	**Grass**	**Total**	**F**
FC	209,85±81,83 α a	0,07±0,58 β b	1,68±0,13 β c	**211,6±82,54 a**	**191,99*****
SA	102,21±45,11 α b	0,61±0,96 β a	7,54±0,38 β a	**110,36±46,45 b**	**126,46*****
SU	5,39±4,85 α c	0,82±0,50 β a	6,27±0,20 α b	**12,48±5,55 c**	**15,24*****
SH	-	-	1,47±0,25 α c	**1,47±0,25 c**	**161,29*****
Total	**317,45±131,79 a**	**1,5±2,04 b**	**16,96±0,96 b**	**335,91±134,79**	
F	**77,23*****	**8,68*****	**711,61*****		

Numbers followed by different Arabic letters (a, b, c) in columns, different Greek letters (α and β) and capital Arabic letters (A, B, C) in row and column averages are significantly different at *** P< 0.001. Numbers with the same letter in the same row or column are not statistically different at the 5% level. According to Duncan's test. TV= Vegetation type; TF= Formation type; FC = woodland; SA = Tree savannah; SU = Shrub savannah; SH = Grassland savannah; F = Fisher test.

Underground phytomass production as a function of plant formations

Examination of Table 2 shows a clear variation in phytomass from one plant formation to another. Indeed, Table 2 shows that grassy savannah has the lowest value (0.48 T/ha) for overall underground phytomass.

Underground phytomass (Bs) varies very significantly between plant formations (P=0.0001<0.001). The underground phytomass production of the species thus highlighted is closely linked to above-ground phytomass, as shown by Cairns *et al*. (1997). To this end, the same species reputed for high above-ground phytomass production are also reputed for high below-ground phytomass production. Our results are far superior to those obtained by Ouédraogo *et al*. (2019) in the forest massif of the National School of Waters and Forests of Dindéresso, Province du Houet in Burkina Faso, varying from one vegetation type to another from 0.70 to 14.19 T/ha.

Table 2: Underground phytomass

TB	**Underground phytomass**				
TF	**Trees**	**Shrubs**	**Grass**	**Total**	**F**
FC	28,76±13,48 α a	0,01±0,09 β b	0,54±0,03 β c	**29,31±13,6 a**	**132,60*****
SA	18,14±6,74 α b	0,15±0,23 β a	2,06±0,09 β a	**20,35±7,06 b**	**188,33*****
SU	1,18±0,91 α c	0,20±0,12 β a	1,75±0,05 α b	**3,13±1,08 c**	**22,67*****
SH	-	-	0,48±0,07 α c	**0,48±0,07 c**	**372,68*****
Total	**48,08±21,13 a**	**0,36±0,44 b**	**4,83±0,24 b**	**53,27±21,81**	
F	**58,00*****	**14,73******	**673,15*****		

Numbers followed by different Arabic letters (a, b, c) in columns, different Greek letters (α and β) and capital Arabic letters (A, B, C) in row and column averages are significantly different at *** P< 0.001. Numbers with the same letter in the same row or column are not statistically different at the 5% level. According to Duncan's test. TV= Vegetation type; TF= Formation type; FC = woodland; SA = Tree savannah; SU = Shrub savannah; SH = Grass savannah; F = Fisher test.

Total phytomass production by type of plant formation

Table 3 shows the averages for total phytomass production (above and below ground). Analysis of this table reveals that total phytomass varies significantly from one type of plant formation to another (P < 0.001). The highest total phytomassis obtained in woodland. It decreases significantly in tree, shrub and grass savannahs (Table 3), as shown in the following diagram: FC.> SA > SU > SH.

Woodland has a higher total phytomass production (248.08 T/ha) than other plant formations (Table 3). This high total phytomass production in woodland is linked to the quality and quantity of woody phytodiversity, where their diameter is large. Total phytomass in Manda National Park is estimated at 396.48 T/ha. Overall, it is important to note that the woodland contains 62.57% of the overall phytomass, i.e. 248.08 T/ha, the tree savannah provides 32.99%, i.e. 130.81 T/ha, the shrub savannah contributes 3.94%, i.e. 15.6 T/ha, and finally the grassy savannah has only 1.96 T/ha, with a percentage of 0.49%. This could be due, in part, to differences in soil quality, the specific composition of the vegetation, the intensity of exploitation of these plant formations and the distribution of large and tall trees. Our results are significantly lower than those of Moumouni *et al.* (2017), who estimated 7394.63 tMs/ha in the Wari-maro classified forest in Centre-Benin, but higher than those obtained by Ouédraogo *et al*. (2019), who estimated 122.96 tMs/ha in the forest massif of the National School of Waters and Forests of Dindéresso, Houet Province in Burkina Faso. These differences in phytomass could be explained by the abundance and quantity of large-diameter plant species.

Table 3: Total phytomass (t/ha)

TB	**Total phytomass**				
TF	**Trees**	**Shrubs**	**Grass**	**Total**	**F**
FC	245,77±93,32 α a	0,09±0,07 β b	2,22±0,17 β c	**248,08±93,56 a**	**202,45*****
SA	120,44±51,71 α b	0,77±0,12 β a	9,61±5,47 β a	**130,82±57,3b**	**133,38*****
SU	6,57±5,76 α c	1,03±0,62 β a	8,03±3,26 α b	**15,63±9,64c**	**16,33*****
SH	-	-	1,96±0,33 α c	**1,96±0,33 c**	**171,04*****
Total	**372,78±150,79 a**	**1,89±0,81b**	**21,82±9,23b**	**396,49±160,83**	
F	**89,79*****	**9,25*****	**714,54*****		

Numbers followed by different Arabic letters (a, b, c) in columns, different Greek letters (α and β) and capital Arabic letters (A, B, C) in row and column averages are significantly different at *** P< 0.001. Numbers with the same letter in the same row or column are not statistically different at the 5% level. According to Duncan's test. TV= Vegetation type; TF= Formation type; FC = woodland; SA = Tree savannah; SU = Shrub savannah; SH = Grass savannah; F = Fisher test.

Estimation of total carbon stock as a function of vegetation type

The total quantity of carbon stored in all plant formations is estimated at an average of 180.93 tC/ha (Table 4). According to analyses of variance, the amount of carbon varies significantly (P < 0.05) between plant formations and between vegetation types. Woodland had a higher carbon content (118.32 tC/ha) than the other vegetation types (tree, shrub and grass savannahs). In woodland, the carbon content of trees (115.51 tC/ha) is significantly higher than that of other vegetation types (shrubs and grasses). Comparison of means by Duncan's test shows that carbon stocks do not differ significantly at 5% between the shrub vegetation component in tree and shrub savannahs. Shrubs and grasses do not differ significantly in woodland, tree and shrub savannahs. The amount of carbon in herbaceous plants is significantly different between plant formations. These differences between the four plant formations would be due not only to differences in their structure, such as vegetation type and density (trees, shrubs and herbaceous plants), diameter distribution, but also to the intensity of anthropogenic pressure (especially grazing and exploitation of vegetation for food, medicinal purposes etc.) exerted on the plant formation types. In this study, biomass and carbon values vary considerably from one diameter to another. This reflects the influence of diameter at breast height (dbh) on the quantity of biomass and therefore on the carbon sequestration rate. Indeed, the larger the diameter of the tree, the higher the rate of carbon sequestered by it (Moumouni *et al*., 2017; Gueulou *et al*., 2020). Other parameters such as tree quality and quantity mentioned by Amougou *et al*. (2016) cited by Gomgnimbou *et al*. (2019) would justify this result. The carbon value of tree and shrub savannahs is relatively low due to the predominance of small-diameter woody species, while that of grassy savannahs is due to grazing and the harvesting of straws for weaving "séko" for the construction of houses, sheds and so on. This shows that the mechanisms of carbon sequestration in different plant formations are different, and consequently the sustainable management strategy for maintaining the carbon balance must vary according to the type and facies of plant formation.

Our results on the carbon stocks of plant formations in the MNP are significantly higher than the 35.47 tC/ha contained in the woodland formations of the Akposso Plateau in Togo's sub-humid zone, according to the results of work by Kombate *et al*. (2019). The quantities of carbon found, nevertheless corroborate with the carbon values (117.74 tC/ha) obtained by Tankoano (2014) in the Tiogo classified forest in Burkina-Faso and those of Tsoumou *et al*. (2016) who obtained an estimated carbon stock of 129 tC/ha in the Dimonika model forest in the Republic of Congo. Ago (2016) studied the dynamics of carbon fluxes between the atmosphere and West African ecosystems: the case of forests and savannahs in the Sudanian climate of Benin, and showed that carbon fluxes exhibit significant spatial variability, mainly linked to the variability of pedo-climatic conditions, management methods, vegetation types and forms of ecosystem use. As for Kombate *et al*. (2019), the environmental factors likely to influence carbon sequestration in the Akposso Plateau, would be the effect of topography, plant distribution, soils, disturbance and forest management history, ecological zone, climate, insect and disease tolerance, age, structure and land use type. While Folega *et al*. (2017) focus on certain factors that are tree-specific and likely to affect carbon storage and even growth strategy. Herintsitohaina (2009) talks more about the taxonomic side, i.e. the amount of carbon stored varies with species. In our study, these factors could explain the difference in carbon stock between plant formations.

Table 4: Total carbon stock (tC/ha)

TB	**Total carbon**				
TF	**Trees**	**Shrubs**	**Grass**	**Total**	**F**
FC	115,51±43,86 α a	0,04±0,32 β b	2,77±0,21 β a	**118,32±44,39 a**	**201,92*****
SA	56,60±24,30 α b	0,36±0,56 β a	1,00±0,04 β b	**57,96±24,9 b**	**134,88*****
SU	3,09±2,70 α c	0,48±0,29 β a	0,85±0,02 β c	**4,42±3,01 c**	**14,33*****
SH	-	-	0,23±0,03 α d	**0,23±0,03 c**	**204,79*****
Total	**175,2±70,86 a**	**0,88±1,17 b**	**4,85±0,3 b**	**180,93±72,33**	
F	**89,78*****	**9,18*****	**481,44*****		

Numbers followed by different Arabic letters (a, b, c) in columns, different Greek letters (α and β) and capital Arabic letters (A, B, C) in row and column averages are significantly different at *** P< 0.001. Numbers with the same letter in the same row or column are not statistically different at the 5% level. According to Duncan's test. TV= Vegetation type; TF= Formation type; FC = woodland; SA = Tree savannah; SU = Shrub savannah; SH = Grass savannah; F = Fisher test.

Estimation of atmospheric carbon dioxide (CO_2) stock and its monetary value according to species and plant formations

Manda National Park sequestered a total of 654.52tonnes of atmospheric carbon (CO_2) in the plant formations sampled on 12.82 ha plots. Woodland contributed 424.71 t CO2, tree savannah 212.77 t CO_2, shrub savannah 16.18 t CO_2 and grass savannah an estimated 0.86 t CO_2. The greatest atmospheric carbon sequestration potential per hectare is found in woodland, and is significantly different from savannas ($p=0.0001< 0.001$). The wooded savannah also accumulates more atmospheric carbon than the shrub and grass savannahs, and this difference is statistically significant ($p=0.0001< 0.001$). There is a significant difference in the quantities of atmospheric carbon sequestered according to forest formations. These results confirm that the carbon equivalent stock (per hectare) of the four forest formations studied follows the ranking below: FC > SA > SU > SH.

The average carbon credit value for all the plant formations sampled was 9,163.28 Euro (€), or 6,007,948.4 FCFA. It varies between plant formations (Figure 2). Among these plant formations, the woodland has a higher carbon credit value (3,894,590.7 FCFA) than the other plant formations, whose credit values range from 7,886.2 FCFA to 1,957,100.9 FCFA. What justifies the higher value of woodland is its tree composition: the trunks of the trees that make it up are well-developed, whereas in other plant formations (tree, shrubby and grassy savannahs). In the case of the grassy savannah, the trees are small in diameter or absent. What's more, natural resources are regularly exploited in these plant formations, as they are easily accessible to local residents. The carbon credit value assessed in this work is higher than that found by Guéulou *et al*. (2020), who worked in the Lamto Scientific Reserve (Côte d'Ivoire).This difference in credit value is probably linked to the size of the areas sampled by the various authors (0.64 ha) compared with 12.82 ha in our case. This significant difference could also be due to the allometric equations used in these two studies. Indeed, Guéulou *et al*. (2020) use the equation integrating diameter and specific density, which could underestimate the results. In the present study, the equation used only integrates diameter, which could also lead to overestimates.

When the sampling data are extrapolated to the entire surface of the plant formations, we obtain, respectively, a value of 3,645,032.2 tonnes for total biomass, 904,936.31 tonnes of sequestered carbon and 3,307,459.19 tonnes of CO_2 equivalent. The financial cost of the CO_2 sequestration rate for MNP plant formations therefore amounts to 46,304,428.84 Euros or 30,329,400,896.46 F CFA for REDD+ markets.

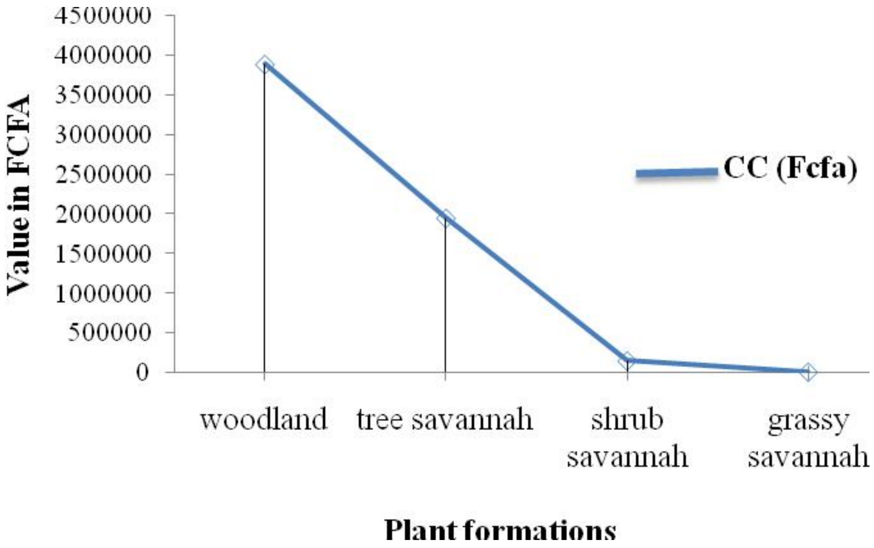

Figure 2: Variation of carbon credit in (FCFA) and according to plant formations

Conclusion

The aim of this study was to estimate the carbon stock of plant formations in Manda National Park. The aim was to evaluate the biomass in order to deduce the quantities of atmospheric carbon sequestered. This study enabled us to determine the vegetation cover of the MNP, estimated at 12.82 ha in the plant formations sampled. These plant formations have a biomass (above and below ground) of 24,956.4 t/ha, sequestering 180.93 tC/ha and total atmospheric carbon (CO_2) of 354.52 tonnes. The results of this study, which contribute to understanding the contribution of each plant formation to carbon sequestration, showed that woodland has a higher sequestration potential than savannahs, which are very low due to carbon destocking actions. The study also showed that trees are the main carbon reservoirs compared with shrubs and grasses. These results contribute to understanding the impact of changes in plant formations on the global carbon cycle. This will enable decisions to be taken for the sustainable management of this park and the protection of the environment. In view of the REDD+ process to be implemented in Manda National Park, it is necessary to combat deforestation and the degradation of forest cover. Park management must be seen as an integrated approach to reducing deforestation and degradation of forest ecosystems, maintaining and conserving biodiversity and preserving carbon stocks in these environments.

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