

Floristic diversity, carbon storage and structure of Cocoa Agro-ecosystems in Southeastern Cameroon

Abstract

The study was carried out in two localities surrounding the national park of Lobeke in Cameroon. The aims were to evaluate floristic diversity and carbon stock in Cocoa agro-ecosystems. We took place 44 plots (25 x 25 m) in 15 agro-ecosystems of different ages to identify all timbers of at least 10 cm of Diameter of Breast Height (DBH). 2,676 individuals of timbers and 42 bananas belonging to 32 families, 68 genera and 74 species were recorded. The most abundant families were Malvaceae (80.1%), Mimosaceae (4.6%), Euphorbiaceae (2.5%), Cecropiaceae (2.3%), Moraceae (1.3%), and Apocynaceae (1.1 %). Theobroma was the most abundant genus (79.2%), followed Albizia (4.33 %), Myrianthus (1.57 %), Macaranga (1.12 %) and Antiaris (1.08 %). Biomass was estimated at 140 Mg C.ha⁻¹. In timbers, carbon stock was estimated at 11.7 Mg C.ha⁻¹.yr⁻¹. That of litters was estimated at 0.7 Mg C.ha⁻¹.yr⁻¹; herbs at 0.23 Mg C.ha⁻¹.yr⁻¹; roots at 0.13 Mg C.ha⁻¹.yr⁻¹ and bananas at 0.046 Mg C.ha⁻¹.yr⁻¹. Carbon stocks from this agro-ecosystem were compared to data recorded in Costa Rica and India. Several species used as non-timber forest products during dry season were recorded. Cocoa agro-ecosystems could be assimilated to a carbon well; and consequently as an attenuation and adaptation measure in mitigating climate changes.

Key words: Adaptation, agro-ecosystems, attenuation, biodiversity, carbon stocks, climate change.

1. INTRODUCTION

Climate change is a global phenomenon that increases the average temperature (from - 18 °C to 15 °C), due to excessive emissions of greenhouse gases (GHG) (Kandel, 1998; 2004). The area of rainforest in Southeastern of Cameroon has a great diversity of flora and fauna (Ghogue, 2007). Forests are a lung which absorbs these GHG and stores carbon dioxide. Some human activities (deforestation, degradation,...) were identified as causes of climate changes. In recent years there has been a growing concern in understanding the economic value of agricultural land for community livelihood. Increasing global population within environmental limits has been identified to be the major reason for such concern. In Africa for example, 80 percent of the population depend on agriculture for their livelihoods (ADBG, 2010).

34 Slash and burn agriculture have many ecological consequences, ranging from the
35 reduction of carbon stock to desertification, through declining soil fertility (Duchaufour,
36 1983). The forests of Congo basin, second largest forest area after the Amazon basin are a
37 source of livelihood for its people. According to several authors that agriculture accounts for
38 about 30 percent of total carbon dioxide emissions and greenhouse gases and land-clearing
39 for agricultural use, including croplands and shifting cultivation as well as deforestation
40 are the most important sources of these emissions (Thomas, 1998; Pagiola and Holden,
41 1999; Pagiola and Holden, 1999; Coxhead and Southgate, 2000). Throughout Africa as a whole,
42 nearly 60% of new agricultural land was derived from intact forests, and another 35% came
43 from disturbed forests. The remaining 5% of new agricultural land was taken from shrub
44 lands (Gibbs *et al.*, 2009). Climate change is placing additional stress on agricultural
45 productive areas exacerbated by recent pressure for biofuels production. As a result, land
46 conversion and land degradation are currently taking place at an alarming rate resulting to
47 low agricultural productivity and substantial release of greenhouse gases when forests are cut.

48 For other countries (Spain, France, England) it is an important warehouse wood. The
49 main causes of forest destruction are slash and burn agriculture and logging, at a rate of
50 700,000 ha per year (Anonymous, 2006). Deforestation has negative environmental
51 consequences, including the loss of biodiversity, land degradation and climate changes. It is
52 responsible for about a third of the increase of the rate of atmospheric carbon (Locatelli,
53 1993). International concern about GHG and their impact on global warming and
54 consequently climate changes were used to study the potential of plants in the carbon
55 sequestration. Human, being conscious of their action on climate changes, has developed
56 many measures of adaptation against the phenomenon; in Africa, the surrounding peoples of
57 forests used to collecting Non-Timber Forest Products for feeding and commercialization
58 during dry seasons (Michael, 2006; Chidumayo *et al.*, 2011). Several same measures are
59 known as individual responses of populations in connection with climate changes. These
60 measures were assigned as an autonomous adaptation (IPCC, 2001). In that way, if people of
61 forest regions could develop adaptation measures against climate changes, they could also
62 fight against the phenomenon by developing attenuation measures. We can identify several
63 attenuation measures developed by those people, namely reforestation and conservation. One
64 of a best attenuation measure known in Africa is agro-ecosystems that can be identified as
65 carbon wells. In consequence, cocoa plantations are the most common agro-ecosystems
66 known in Africa, particularly in Cameroon. Cocoa, the main cash crop, is practiced in

combination with fruit, medicinal herbs, and various species. These species are deliberately protected or planted in cocoa for feeding or for their economic value, and then to provide shade when necessary (Zapfack, 2005). This combination makes complex agro-ecosystems (Loschet *et al.*, 1995; Gockowskiet *et al.*, 2004a, b).

The investigations harvested in a cocoa agro-ecosystem in Pendiki had led to the conclusion that such agro-ecosystems is measure of attenuation of climate changes (Noiha *et al.*, 2015a). The aim of this study was to show the importance of agro-ecosystems in the process of carbon sequestration issued at a time when natural ecosystems are under severe degradation.

2. MATERIAL AND METHODS

2.1. Study site

The work was carried out in two localities Yenga and Mambele, along Yokadouma-Moloundou axis. These localities are located in the Eastern Region in the sub-division of Boumba and Ngoko. Mambele is located at 60 km from Moloundou, while Yenga is at 40 km from Yokadouma. Mambele is located geographically at 2°26' N and 15° 25' E with an elevation of 562m (Letouzey, 1982; 1985). The geographical coordinates of Yenga are 2° 16' N and 15° 20' E and 606m of elevation. The two localities are separated by a distance of 20 km (Fig. 1).

2.2. Floristic inventory

Plots method was used to assess the floristic diversity in the area. Sampling was carried out in plots of 25 x 25m (625 m²) according to the methodology developed by Hall and Swaine (1976 in Zapfack, 2005). The sampling was done in each band of 125 m² to reduce counting errors (Fig. 2). A plot is assigned to a survey; 44 surveys were conducted in 15 cocoa agro-ecosystems. Cocoa is classified into age group: young cocoa (JCA, 0-15 years), medium-sized cocoa (MCA, 15-20 years) and old cocoa (VCA, 20-30 years).

2.3. Above Ground Biomass (AGB)

AGB concerns trees of Diameter of Breast Height (DBH, at 1.3 m) of at least 12.5 cm, litter and herb understorey. Trees were collected in the plots of 25 x 25 m²; herbs in sub-plots of 1 x 1 m² and litter in sub-plots of 0.5 x 0.5 m² subdivided in the 25 x 25 m² plots (Fig. 2).

2.4. Below Ground Biomass (BGB)

Small roots and rootlets of soil were ~~concerned~~. These roots were extracted from soil in sub-plots of 0.2 x 0.2 m² at 0.2 m of depth (Fig. 2). In each survey of 625 m², 4 sub-plots of 0.2 x 0.2 m² were demarcated.

2.5. Data analysis

2.5.1. Floristic diversity

~~The indexes for their importance have been used in this work:~~

-Shannon diversity index (ISH) (Frontier and Pichod-Viale, 1992)

ISH = $-\sum (N_i/N) \log_2(N_i/N)$, with N_i = size of species i , N = size of all species. ISH is expressed in bits.

-Pielou evenness (EQ) $EQ = ISH / \log_2 N$. It is the ~~ratio between the observed diversity and the maximum possible diversity of the number of species (N). Fairness is a low importance of a few dominant species (Dajoz, 1982).~~

~~-Simpson diversity index (D)~~

~~(D) = $1/D'$ (Begon *et al.*, 1998), where $D' = \sum (N_i/N)^2$ (Colinvaux, 1986 in Sonke, 1998). This index gives the probability that two individuals taken at random from the studied population belong to the same species.~~

- Sorensen's similarity between two communities

$K = (2c/a+b) \times 100$, with a = number of species of survey 1 ; b = number of species of survey 2; c = number of the same species in surveys.

2.5.2. Above Ground Biomass (AGB)

The following allometric equations were used (Brown *et al.*, 1989; Shave *et al.*, 2004; Shave *et al.*, 2005):

- Brown *et al.* (1989) : $Y_1 = 38.4908 - 11.7883 \cdot D + 1.1926 D^2$.

- Shave *et al.* (2005) : $Y_2 = \alpha \exp[-1.499 + 2.148 \cdot \ln(DBH) + 0.207 \cdot (\ln(DBH))^2 - 0.0281 \cdot (\ln(DBH))^3]$.

- Shave *et al.* (2004) : $Y_3 = (\alpha / 0.6) \exp[-3.742 + 3.450 \cdot \ln(DBH) - 0.148 \cdot (\ln(DBH))^2]$.

Y_1 , Y_2 and Y_3 are biomass (kg), D (DBH) is the diameter (cm) at 1.30 m above the ground, α is the specific density of the wood. Otherwise $\alpha = 0.58 \text{ g/cm}^3$, and the correlation coefficient $R^2 = 0.78$. From this biomass, the amount of carbon (kg/ha) is obtained by multiplying the biomass by 0.47, then it will be converted into ~~tones~~ of carbon per ha.

- In Musaceae, the following formula was used: $Y = 0.0303 \cdot D^{2.1345}$, where Y is biomass, and D the diameter (cm).

- In Palmae, the following formula was used: $Y = 10.0 + 6.4 \cdot H$, where Y = biomass, H = total height (m).

2.5.3. Below Ground Biomass (BGB)

Small roots and rootlets were dried at constant temperature and their biomass was obtained by weighing until getting constant weight.

Total carbon was obtained by summing the carbon in timbers, bananas, undergrowth (grass), litters, and roots.

2.5.4. Analysis of variance (ANOVA)

The analysis of variance was conducted through ANOVA tests, and multiple comparisons (MCP) using Fisher's test.

3. RESULTS

3.1. Floristic inventory

We recorded and identified 2,676 timbers and 42 bananas belonging to 32 families, 68 genera and 74 species. The most important families were Malvaceae (80.1 %), Mimosaceae (4.6%), Euphorbiaceae (2.5%), Cecropiaceae (2.3%), Moraceae (1.3%) and Apocynaceae with 1.1% (Fig. 3). The genus *Theobroma* was the most abundant (79.2%), followed *Albizia* (4.33 %), *Myrianthus* (1.57 %), *Macaranga* (1.12 %) and *Antiaris* (1.08 %).

Beside *Theobroma cacao* which is the main species of the agrosystem, *Albizia zygia* (21.17%), *Macaranga hurifolia* (7.66 %), *Celtis zenkeri* (5.47%), *Oncoba gilgiana* (5.29%), *Bridelia micrantha* (4.19 %) *Markhamia lutea* (4.01 %) were the most abundant species; while *Ricinus communis* (one of species used as spice), *Pterisanthus macrocarpus*, *Omphalocarpum*, *Rauvolfia macrophylla*, *Zanthoxylum heitzii* were rare.

3.2. Indexes of diversity

Only timbers were concerned in this analysis. The different indexes are recorded in table I. The Shannon index has almost the same value in all three habitats: young cocoa (1.91), medium cocoa (1.75) and old cocoa (1.53).

The index shows a large number of rare species, namely *Pycnanthus angolensis*, *Piptadeniastrum africanum*, *Nesogordonia paverifera* (red data listed, IUCN criteria; see Noiha et al., 2015), *Markhamia tomentosa*, *Lannea welwitschii*). The Pielou evenness is near to

zero in all type of cocoa. This low value explains that a few dominant species namely *Theobromacacao*, *Albiziazygia*, *Macaranga hurifolia*, *Celtis zenkeri*, *Oncoba gilgiana* and *Musanga cecropioides* were very important in the flora. The value of the Simpson index was the same in all type of cocoa groups.

3.3. Specific richness and relative diversity

The greatest species richness was in old cocoa for a relative diversity of 75.67%. Medium Cocoa represents 63.51% of relative diversity. Young cocoa had low diversity with 45% relative diversity compared to others. The number of species per hectare gave a more accurate view of species richness.

The same indices were calculated without taking into account *Theobromacacao*. Values are much higher than those previously computed with *Theobromacacao* (Table 1). Values justify that there was floristic diversity in these habitats in spite of the strong dominance of *Theobromacacao*.

3.4. Sorensen's similarity

Similarity coefficient of Sorensen assessed the floristic affinity between the two surveys. The three studied habitats form a single plant community. Young, medium, old cocoa farms have between them over 50% similarities (Table 2).

3.5. Carbon stocks

The carbon stock of timbers was estimated at 11.7 Mg C.ha⁻¹.yr⁻¹. That of litters was estimated at 0.7 Mg C.ha⁻¹.yr⁻¹, herbs represented 0.23 Mg C.ha⁻¹.yr⁻¹, roots 0.13 Mg C.ha⁻¹.yr⁻¹ and bananas 0.046 Mg C.ha⁻¹.yr⁻¹ (Table 3).

3.6. Analysis of variance

The P value was 0.0065; $p < 0.05$. Therefore, the test was considered highly significant between Brown and Chave (2004) formula and the average variation between the columns is significant. The average variation between the equation of Brown *et al.*, (1989) and that of Shave *et al.* (2004) was not significant. The two equations (Brown *et al.*, 1989; Shave *et al.*, 2004) gave the same result. The variation of the average and that of Shave *et al.* (2005) was highly significant.

The curves of the three linear regressions of the allometric formulas are represented by Figure 4. The equations of Brown *et al.* (1989) and Shave *et al.* (2004) are similar; there is no significant difference between them. They are applicable in tropical forests.

4. DISCUSSION

4.1. Abundance and diversity

The flora is less diverse in cocoa agro-ecosystem which constitutes a homogeneous ~~densely~~ of *Theobromacacao* ~~stand~~. The most important families were Malvaceae (80.15 %), Mimosaceae (4.63%), Euphorbiaceae (2.57 %), Cecropiaceae (2.39 %), and Moraceae (1.34 %). Herbaceous species richness is less important because the undergrowth is regularly cleaned by the farmers. The physiognomy of the agrosystem is dominated by secondary forest species. The Shannon (ISH) index (1.74 %) presents a strong homogeneity of cocoa with a high density of *Theobroma cacao*. It has almost the same value in all types of cocoa. A high value of ISH indicates a large number of rare species (*Pycnanthus angolensis*, *Piptadeniastrum africanum*, *Nesogordonia papaverifera*, *Markhamia tomentosa*, *Lannea welwitschii*).

A high ISH (6.3 bits) corresponds to favourable conditions of environment that lead to the ~~installation~~ of many species represented by a small number of indexes (Dajoz, 1982). Pielou's evenness tends to 0 in all habitats.  According to the Simpson index and Pielou evenness, each type of cocoa has a similar level of diversity. The results of floristic inventories in the studied agrosystem show that the floristic richness of the community is low but not negligible. In addition to the intensification of cocoa by farmers, there are also species of primary forest (*Entandrophragma cylindricum*, *E. utile*, *Pericopsis elata*, *Klainedoxa gabonensis*, *Khaya ivorensis*), secondary forests (*Alstonia boonei*, *Terminalia superba*, *Eriobroma oblongum*, *Antiaris africana*, *Ceiba pentandra*), fruity species (*Persea americana*, *Mangifera indica*) and useful non-timber forest products (NTFPs). Indices of Shannon and Simpson also show that the community is dominated by a few species; the most representative is *Theobromacacao*.

4.2. Coefficients of similarity

The similarity coefficients are greater than 50 %; indicating that all types of cocoa studied belongs to the same plant community. Cocoa forms a group because ~~these habitats after disturbance~~ are awaiting regeneration or degradation by farmers. Degradation will be

exacerbated by the cutting of shade tree that permits to fight against brown rot of cocoa trees, and possible conversions of cocoa into food crops. Distribution of trees/shrubs using class of diameter shows that the cocoa stands are comparable to a secondary forest in different stages of development. In addition to the intensification of cocoa-cultivation by farmers, cocoa are rich in species of primary and secondary forests. As we can see, agrosystem could lead to the regeneration of the previous vegetation.

4.3. Biomass

For the entire work, the biomass is estimated at 140.20 tC/ha. This value represents more than ¼ of the biomass harvested in a homogeneous natural forest of *Gilbertiodendron dewevrei* in the Dja biosphere reserve in Cameroon (Djuikouo *et al.*, 2010) and approximately comparable with many anterior results in trunks (Clark and Clark, 2000; Dewalt and Chave, 2004; Chave *et al.*, 2005; Lewis *et al.*, 2009a, Zapfack *et al.*, 2016). These data were as important as the work carried out in Tanzania in some agroforestry practices such as parklands, homegardens and woodlot (Richard *et al.* 2014). Carbon stocks were significant and much higher than those obtained in agro-ecosystems in the centre of the Himalayas in India, in tropical moist lowland forests in Costa Rica and in young stands of *Annona reticulata* and *Annona squamosa* in the Campus of Aurangabad University (Prakash & Lodhiyal, 2009; William *et al.*, 2011; Chavan and Rasal, 2012). Although this work is not taken into account the carbon stock of soil as considered in Costa Rica, the importance of the stock is depended of the age of agro-ecosystems; in Costa Rica, carbon stocks were evaluated in plantations of 0-16 years and those in India in the plantations of 0-8 years. This study shows that the age of the ecosystem is an important feature in carbon sequestration. As the natural forests are under degradation, such ecosystems could be used as a measure of attenuation of climate changes.

4.4. Analysis of variance

Analysis of variance of the three allometric formulas show that there is a highly significant difference between them (5.24, 44, 0.0065), while two formulas have no significant difference (Brown *et al.*, 1989 and Shave *et al.*, 2004); these formulas are appropriate in tropical African forests. Therefore, formula of Shave *et al.* (2005) is not applicable in tropical Africa. This analysis leads to another problem which is the need of establishing a standard formula for the TNS and the Congo Basin.

5. CONCLUSION

The physiognomy of the cocoa agro-ecosystem is close to that of secondary forests; in fact, ~~most species were those usually found in secondary forests namely~~ *Terminalia superba*, *Albizia zygia*, *Musangacecropioides*, *Antiaris africana*, *Funtumia elastica*, *Cola lateritia*.

Even though, the values of diversity indices were low, several species of the previous ecosystem were recorded (secondary and primary forest species); agro-ecosystems could offer ~~necessary~~ conditions to endogenic species to regenerate after deforestation. It is also a refuge for some endangered species such as *Nesogordonia papaverifera*, a red data listed of IUCN. Carbon stocks were compared to those harvested in Costa Rica and India and represented more than $\frac{1}{2}$ of data recorded in selected natural stand in the Dja biosphere reserve. Several species used as non-timber forest products during dry season were also recorded. Cocoa agro-ecosystems could be assimilated to a carbon well; and consequently as an attenuation and adaptation measure in mitigating climate changes.

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363 **Table 01. Indices of diversity**

364

Indices	Shannon (H')		Pielou		Simpson		Number	Number	Number	S. (ha)
Type of cocoa	with Theo.	without Theo.	with Theo.	without Theo.	with Theo.	without Theo.	of species	of individual	of family	
JCA	1.91	4.54	0.22	0.68	1.74	18.31	33	413	22	0.375
MCA	1.75	4.40	0.177	0.57	1.64	9.41	47	949	24	1.0625
VCA	1.53	4.75	0.147	0.60	1.48	14.98	54	1214	28	1.3125

365 JCA : [Yong](#) cocoa ; MCA : Middle cocoa; VCA: Old cocoa; Theo: Theobroma

366 **Table 02. Indexes of similarity**

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	JCA	MCA	VCA
JCA	100		
MCA	55	100	
VCA	55.17	63.37	100

368 JCA : [Yong](#) cocoa ; MCA : Middle cocoa; VCA: Old cocoa

369 **Table 03. Comparison of biomass following the allometric formulae**

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	Timbers	Herbs	Litter	Roots	Musa	Total
Brown <i>et al.</i> (1989)	11.7	0.7	0.23	0.13	0.046	12.85
Shave <i>et al.</i> (2004)	13.08	0.7	0.23	0.13	0.046	14.2
Shave <i>et al.</i> (2005)	8.38	0.7	0.23	0.13	0.046	9.5

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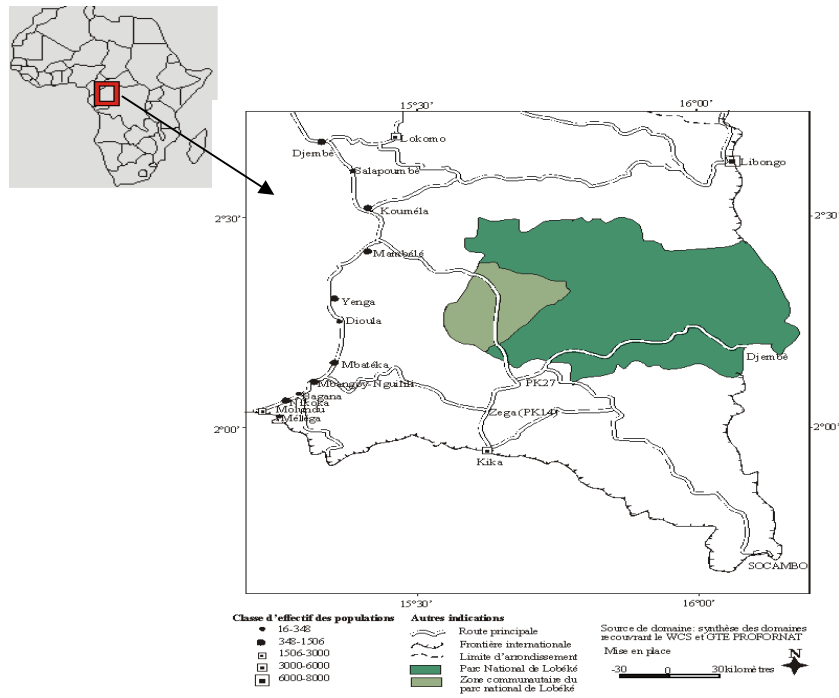


Figure 01. Localization of site

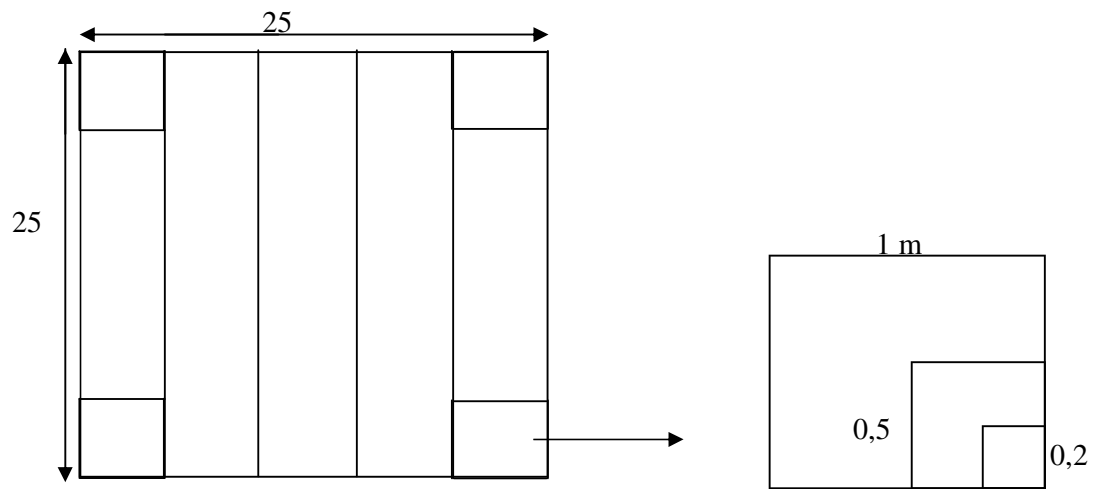
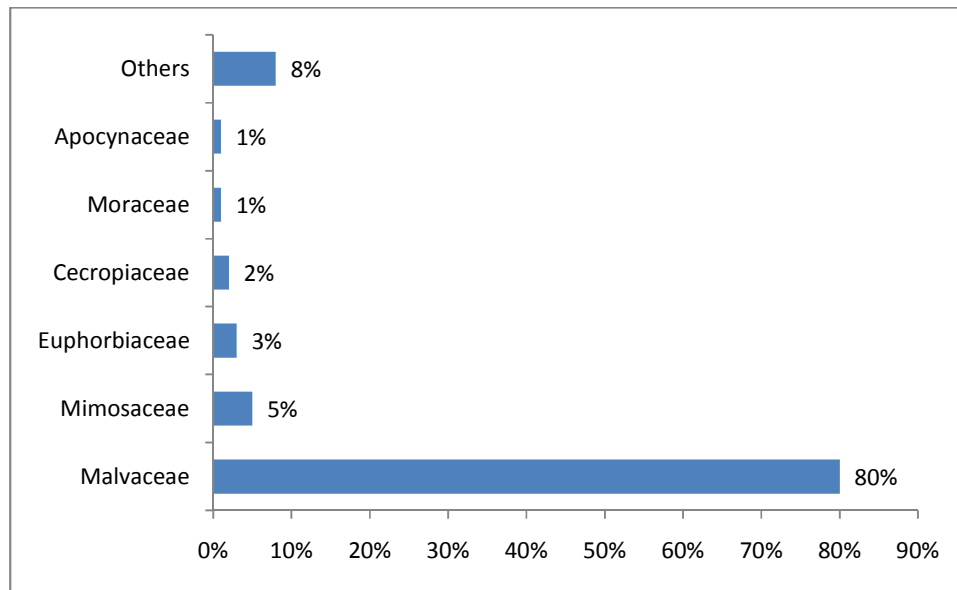


Figure 02. Sampling plots (at right 625 m²; at left detail of carbon sampling method for herbs, litter and small roots.

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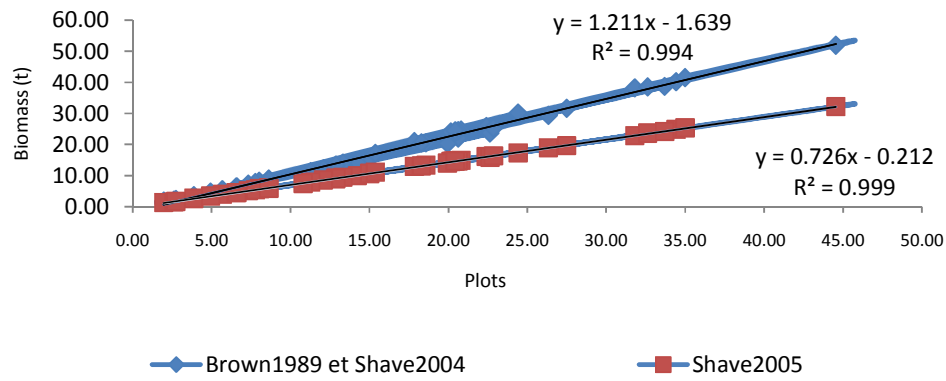
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Figure 03. Proportion of families

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410 **Figure 04.**Curves of regression showing similarity between Brown *et al.* (1989) and Shave *et*
 411 *al.* (2004) allometric equation.