academic**Journals**

African Journal of Agricultural Research

Full Length Research Paper

Quantifying biomass and carbon stocks in oil palm (*Elaeis guineensis* Jacq.) in Northeastern Brazil

Carlos Roberto Sanquetta, Sylvio PéllicoNetto, Ana Paula Dalla Corte, Aurélio Lourenço Rodrigues*, Alexandre Behling and Mateus Niroh Inoue Sanquetta

Forest Science Department, Federal University of Paraná, 900 LothárioMeissner Avenue, Curitiba, Paraná, Brazil.

Oil palm (*Elaeis guineensis* Jacq.) is a major raw material for biofuel and food industries in the world. In Brazil, cultivation of this species has evolved much in recent years, but basic information on its growth in the country is still scarce. This study analyzes the biomass and carbon storage in plants selected in three stands located in southern state of Bahia, northeastern Brazil, considering the full rotation cycle. Plants aging 3 to 36 years were cut and measured at biometric variables: Diameter at 50 cm from the ground level, crown diameter, stipe length and total height. Relationships among the biometric variables and the stipe, foliage, root, and total biomasses were analyzed. The Chapman & Richards model was fitted to the total biomass and carbon as a function of age. All the linear correlations between variables were significant at 95% probability. Total height and stipe length were more strongly correlated with age than with the diameter at 50 cm and crown diameter. The total biomass was highly correlated with the stipe variables and age. The percentage participation of stipe and total biomasses increases with age unlike the biomass foliage. The proportion of roots does not change with age. The total dry biomass and carbon stocks at the age of 25 years were estimated at ca. 90 and 35 $t.ha^{-1}$, respectively. It was concluded that oil palm, because of its rapid growth and due to the fact that it is a permanent culture, is able to stock a high amount of biomass and carbon per unit area. If implemented in appropriate places, oil palm cannot be considered a carbon debt crop and represent an important alternative to regional socioeconomics.

Key words: Growth, oil palm, biomass expansion factor, biomass partitioning, biometric relationships.

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is originating from the African continent, whose natural range includes all the west coast of Africa, from Senegal (parallel 16°N) to Angola (Hartley, 1977; Wahid, 2005). It can also be found in the interior of the continent in direction to Congo, and in East Africa, including the Madagascar (Moretzsohn et al., 2002). The adaptability of thisplant

has contributed to the spread of its cultivation to other parts of the world, incorporating to the local flora, both by the formation of oil palm spontaneously regenerated stands or through conventional commercial plantations.

In Brazil, the oil palm was probably introduced with slaves in the 16th century, on the occasion of the people trade from Africa (Savin, 1965). At the time, the Africans,

primarily from Angola, Benin and Mozambique, have transported seeds inside the vessels, which gave rise possibly to the first oil palm spontaneous stands on the coast of Bahia state (Chavez, 1984).

The fruits of oil palm produce two types of oil: palm-oil or dende oil, extracted from the mesocarp (outer part of the fruit); and the nut-oil (palm kernel oil), extracted from the seed. It is possible to obtain up to 22% of oil of the bunch weight from the pulp and up to 3.5% of oil from the nuts (Cardoso, 2010). With extensive use throughout the world, the palm-oil constitutes nowadays a major raw material for food, medicinal, chemical and industrial uses.

Palm crop may reach a yield per unit area of 4 to 5 tons of oil per hectare per year (Moura, 2008). Indonesia and Malaysiaarethelargestproducers ofpalm-oil,   accounting for more than 85% of world production. Brazil occupies the 15th position among the producers, but it has gradually increased its production and has the largest suitable area to this crop in the world (Butler and Laurance, 2009). However, the country still imports more than half of the palm-oil necessary to its factories (Becker, 2010). Para state is the largest Brazilian producer, with about 100 thousand tons per year and 50 thousand hectares planted, accounting for 93% of Brazilian yield (Brazil, 2006; Harada et al., 2008; Furlan et al., 2006; Lange, 2012). Other Brazilian states producers are Amazonas, Amapa and Bahia, which also have relevant crop areas (Lange, 2012).

In the biological and environmental context, the most important aspects for the crop yield are those related to the plant, soil and climate (Brazilio et al., 2012). Nutritional requirements of this plant vary widely, depending on the expected yield, type of genetic material used, spacing, plant age, type of soil and environmental factors (Santos, 2010). The density of planting practiced is of 143 plants per hectare, arranged in an equilateral triangle of 9 m, that is, a spacing of 7.8 m between rows and 9 m between plants in the row (Berthaud et al., 2000). This spacing is also adopted in Southeast Asia.

Today there is a concern with a possible increase of deforestation rates in the Amazon region due to the expansion of the biofuel plantations, based on the critical examples in the Asian continent (Butler, 2011). The cultivation of this species in appropriate areas, on the other hand, can represent social, environmental and economic benefits. Formerly deforested areas for purposes agriculture and cattle ranching should be priority to oil palm plantations, avoiding the practice of shifting cultivation and extensive livestock farming. This can provide more jobs and income for the local population, aggregation of technological and economic benefits, as well as increase in carbon stocks in crop biomass, mitigating partially the emissions generated by deforestation

Most of the studies on biomass and carbon in oil palm plantations have been conducted in Southeast Asia. Works in Africa have been also reported elsewhere (Aholoukpe et al., 2013; Thenkabail et al., 2010). However, in Brazil this issue has not been yet addressed. Little information exists in the literature on biomass partitioning by compartments and carbon stocks from the oil palm stands (Syahrinudin, 2005), even in the most developed countries. This study aims to analyze the biometric relationships of oil palm coming from three industrial plantations located in southern Bahia state, northeastern Brazil. The study evaluates the entire range of cultivation ages, analyzes the biomass partitioning by compartments and provides a growth model for biomass and carbon stock by unit area for this crop. It can be helpful to oil palm management in Brazil and contribute to the formulation of plans to mitigate climate change from land use and land use change.

MATERIALS AND METHODS

Study area

The study was conducted in the municipality of Taperoa, southern of Bahia state, northeastern Brazil. The reference UTM coordinates are the following: X - 486.212 m and Y - 8,504.380 m.The regional climate is tropical, hot and humid, with average temperature of 24°C, classified as Af according to Köppen and Geiger (1928). Rainfall is abundant and happens more frequently between April to August and in the first three months of spring (September to November). Precipitation can reach, on average, up to 100 mm per month. The study site is situated in a zone with the greatest precipitation in the state, with around 1,500 to 2,000 mm per year (Santos, 2010).

Study material and methodological procedures

Commercial plantations with wide range of planting age were selected in the region, varying from 3 to 36 years. Forty two individuals were selected to be harvested in the three selected stands. A minimum distance of 100 m was kept between the palms sampled, being all located far from the edges of the planting area. All sampled palms showed normal phenotype and vitality, without damage or other defects caused by physical or pathological agents.

In the field, the following biometric variables were measured, which can also be visualized in Figure 1:

1. Diameter of the palm at 1.30 m above ground level (dbh), measured with a tape in cm;
2. Diameter of the palm at 50 cm above ground level (d_{50}), measured with a tape in cm;
3. Crown diameter (dc) in cm, using a tape in two cross-measures taken at 90° angles;
4. Total height (ht), measured in m with a tape, after felling the palm;
5. Stipe length (he), measured in m with a tape, after felling the palm.

The 41 palmswhich were cut had their biomasses separated in field by stipe, foliage, roots, bunches and fruits, but bunches and fruits data were not analyzed in this paper. The fresh biomass compartments were weighed separately in the field using a digital dynamometer with 10g precision. Samples of approximately 200 g were collected from each biomass compartment in the field and transported to laboratory, where they were weighed and oven dried at 70°C to constant weight. The fresh weights of palms were
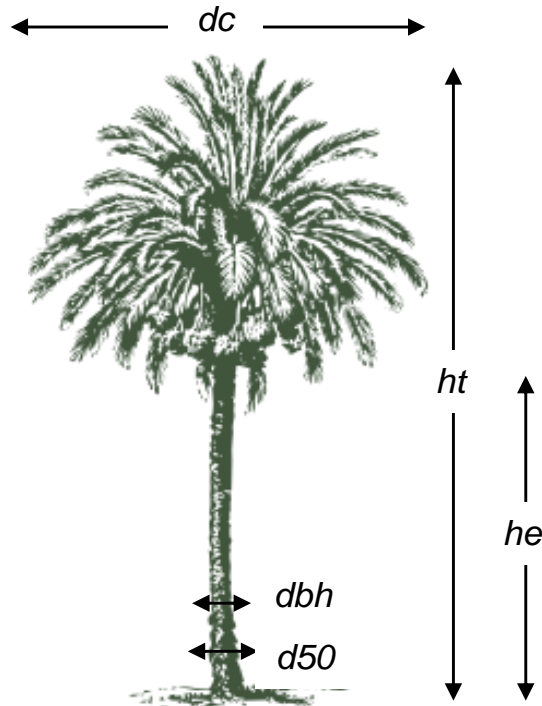
Figure 1. Biometric variables measured in *E. guineensis* in northeastern Brazil.

converted into dry biomass by direct relation between both variables from the samples.

The samples were then manually crushed and processed in a Wiley type mill until reach powder particle size. These were subsequently analyzed in equipment (model LECO C-144) that determines the carbon content of the sample by dry combustion process in an infrared chamber.

The allometric relationships between the biometric variables (Figure 1) with age of the palms and dry biomass of each component were analyzed by the Pearson correlations. The proportions of biomass of foliage and roots in relation to the total biomass of the palm in different ages were also analyzed. Biomass expansion factor of and root-to-shoot ratio were calculated, taking into account the different ages, by the following equations:

$$BEF = \frac{ba}{bt} \tag{1}$$

where: BEF = biomass expansion factor.

$$ba = be + bf \text{ = aboveground biomass} \tag{2}$$

be = stipe biomass; bf = foliage biomass and bt = total biomass.

A growth model for the biomass and carbon stock per unit area (hectare) was adjusted, considering the individual stocks in each age and the planting spacing of 143 palms.ha^{-1}, practiced in the management of the crop. The biological model of Chapman and Richards was used for this purpose, which was fitted by the nonlinear regression method of Levenberg-Marquardt:

$$W = A \times (1 + b \times \exp(-k \times Age))^{(1-1/m)} \tag{3}$$

where: W = total dry biomass (t ha^{-1}); Age = age (years), and A, b, k, m = coefficients of the model.

$$C = \sum_{i=1}^{n} C_i \tag{4}$$

$$C_i = W_i \times TC_i \tag{5}$$

where: TC_i = carbon content of each biomass compartment; W_i = dry biomass of each compartment (t.ha^{-1}), and A, b, k, m = coefficients of the model.

RESULTS AND DISCUSSION

Correlation between the biometric variables

All the linear correlations between the variables were significant at 95% probability. Total height and stipe length were more strongly correlated with age than with the stipe diameter at 50 cm and diameter of the crown. Foliage biomass was more strongly correlated with the palm crown diameter. Stipe biomass was highly correlated with the total height, stipe length and age. The root biomass was more strongly correlated with total height and stipe length, age and stipe biomass. Total biomass was highly correlated with the stipe measures once this compartment composes the largest fraction of the total biomass of the palm. Age also exerts significant influence on total biomass (Table 1), which favors to adjust a growth model for biomass as function of this variable.

Asari et al. (2013) have analyzed the correlations of diameter at breast height (*dbh*), total height, stipe length, age and aboveground biomass in plantations of oil palm in the state of Selangor on the west coast of the peninsular Malaysia. They realized that palm height is more strongly associated with age, particularly the stipe length. They found negative correlations of age with the *dbh*. The biomass was strongly correlated with age and very strongly with stipe length. In this paper *dbh* was not analyzed because this variable could not be measured at younger palms that are lower than 1.3 m. Therefore, the analyses were carried out for d_{50} instead.

The results of Asari et al. (2013), in their majority, corroborate those of the present study, but the reduction of diameter with age was not detected in this work. Jacquemard (1979) also noticed reduction of *dbh* with the advance of age in the studied species. In turn, Hartley (1977) reported a steady increase in the bole diameter during all the first years. However, they noted that the stipe practically ceases its growth in diameter subsequently with the advance of age. This may be related to the absorption of nutrients (Turner and Gilbanks, 1974).

Table 1. Correlations between biometric variables of *E. guineensis* in northeastern Brazil.

	age	d50	dc	ht	he	b_f	b_e	b_r	b_t
age	1.00								
d_{50}	0.62	1.00							
d_c	0.78	0.71	1.00						
h_t	0.94	0.72	0.83	1.00					
h_e	0.95	0.65	0.74	0.97	1.00				
b_f	0.63	0.78	0.81	0.76	0.70	1.00			
b_e	0.90	0.73	0.75	0.93	0.93	0.74	1.00		
b_r	0.83	0.74	0.74	0.86	0.85	0.70	0.87	1.00	
b_t	0.88	0.79	0.81	0.94	0.93	0.85	0.98	0.90	1.00

Where: d_{50} = diameter of the palm at 50 cm above ground level; d_c = crown diameter; h_t = total height; h_e = stipe length; b_e = stipe biomass; b_f = foliage biomass; b_r = root biomass; and b_t = total biomass.

Table 2. Carbon content statistics by biomass compartments of *E. guineensis* in northern Brazil.

Compartment	$\bar{x}$	s^2	CV%	n
Foliage	42.86	0.9942	2.32	41
Stipe	39.73	0.9335	2.35	41
Roots	38.20	2.9985	7.85	41
General (weighted)	40.85	0.9330	2.28	123

Where: $\bar{x}$ = mean, s^2 = variance, CV% = coefficient of variation and n = number of cases.

Carbon contents

The carbon contents determined in this study varied among compartments, being highest in foliage. The average carbon content weighted by biomass of each compartment was calculated at 40.85% (Table 2), consistent with the value of 41.3% reported for plantations in Indonesia (Syahrinudin, 2005). That author detected variations in carbon content among biomass compartments, ranging from 32.3% for fine roots to 44.2% for leaves. Such variations were also noticed in thisstudy,althoughthedifferencesareless remarkable in this work in comparison to the formerly mentioned study.

Castilla (2004), analyzing various methods for quantification of carbon in plantations of *E. guineensis* in Colombia at different ages, mentions that the biomass conversion to carbon is made with carbon contents ranging from 45 to 50%. The percentage of 50%, usually employed in many similar studies (Hamburg, 2000), can be considered unreasonably high for *E. guineensis*. That value has already been subject of analysis and criticism in the literature, which motivated the IPCC (2006) to change its default to 47%. For the species studied here even the default value may represent overestimation in the conversion of biomass to carbon stock.

Partitioning of biomass and carbon

The percentage participation of stipe biomass in relation to total biomass increases asymptotically with age, unlike the foliage biomass, which results in a very clear inverse linear correlation between them. Conversely, the roots proportion does not change with age, showing no trend along time. Biomass expansion factor decreases sharply and asymptotically with age, whereas root-to-shoot-ratio does not show clear trend with age (Figure 2).

There is limited research on the partitioning of carbon in biomass for oil palm (Syahrinudin, 2005). Analyzing plantations in Indonesia, with ages ranging from 3 to 30 years, the author concluded that stipe participation in terms of aboveground biomass may range from 56.7 to 75.3%. His findings corroborate the results of this study regarding the evolution of the participation of root biomass with age.

Asari et al. (2013) have reported prevalence of stipe biomass in comparison to leaf biomass in 60 oil palm plantations with ages ranging from 6 to 23 years in Malaysia. Khalid et al. (1999a) found lowest rates of participation of the stipe biomass in mature plantations in Malaysia, evidencing that the root fraction corresponds to approximately 16% of total dry mass (Khalid et al., 1999b). Castilla (2004) examined several methods forquantification of carbon in plantations of *E. guineensis* of various ages in Colombia and also found an increase in the participation of the carbon stock of the stipe at more advanced ages.

Biomass and carbon stock growth model

The Chapman and Richards model fitted well to the data
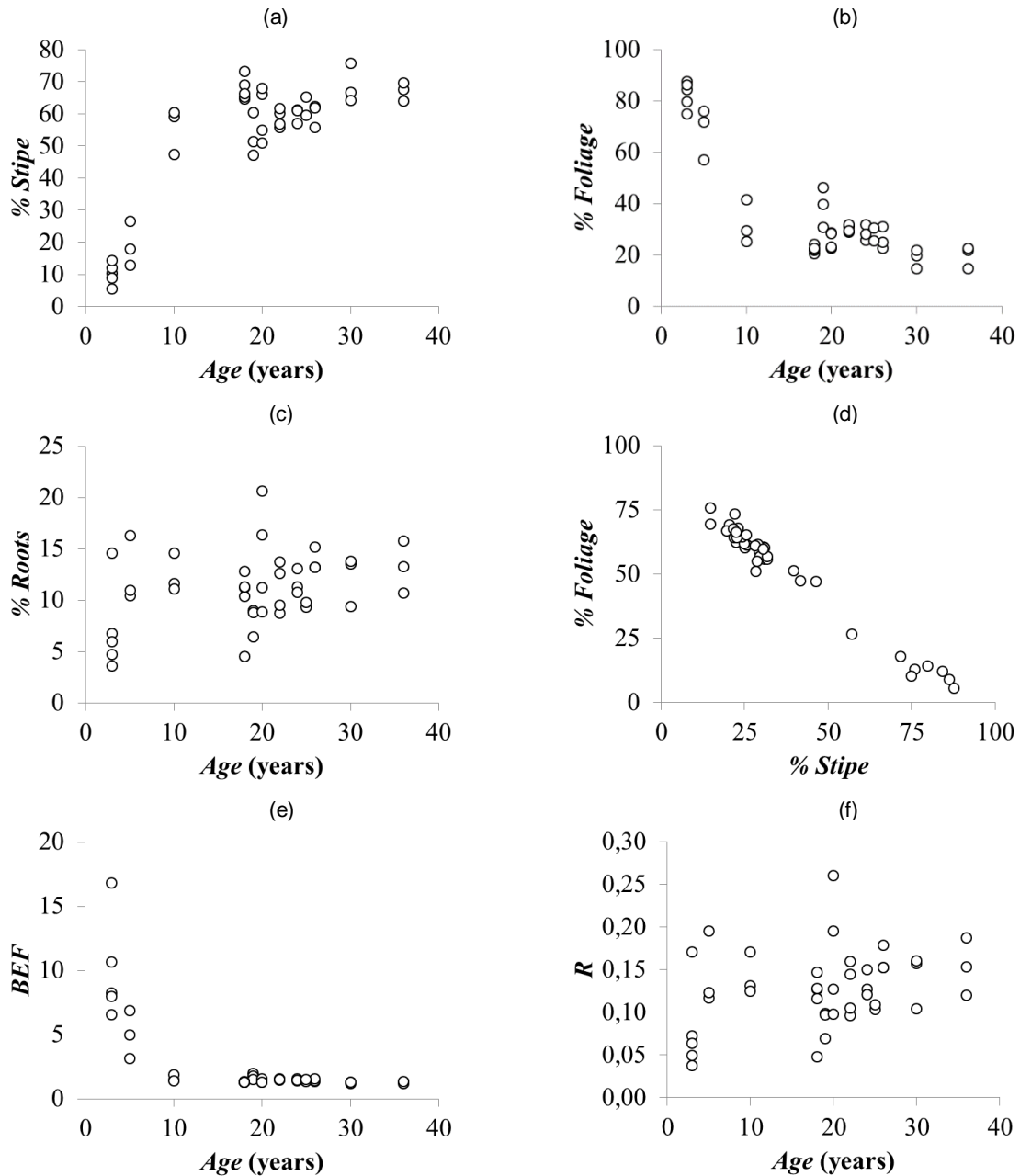
Figure 2. Partitioning of total dry biomass, biomass expansion factor and root-to-shoot ratio as a function of age for *E. guineensis* in northeastern Brazil (a: Stipe participation; b: Foliage participation; c: Root participation; d: Relationship between the stipe and foliage biomass participation; e: Biomass expansion factor; f: Root-to-shoot ratio).

of total biomass of *E. guineensis* as a function of age (Equation 6), as show below:

$$W=142.331(1-(-0.00182\exp(-(0.077365\times Age))^{(1-1/0.000572)} \quad (6)$$

($n = 41$; $R_{adj}^2 = 0.9064$)

The total dry biomass growth curve fitted to actual data (Figure 3) indicates a value of ca. 90 t ha^{-1} at age 25

years, which is considered ideal for the rotation of the species due to the height of the palm and of its palm-oil production. At 40 years, age in which oil productivity is already uneconomical (Villela, 2009), biomass stockreaches approximately a value of 120 t.ha^{-1}.

These values are consistent with those found by Asari et al. (2013), in the state of Selangor on the west coast of peninsular Malaysia, though the authors calculated only the aboveground biomass (excluding the roots). Distinct
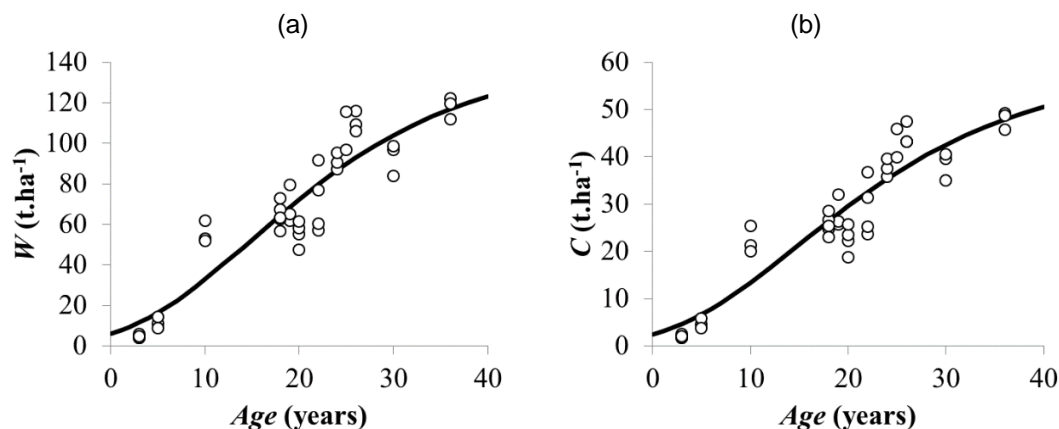
Figure 3. Growth curves of biomass and carbon stocks for *E. guineensis* in northeastern Brazil (a: Total biomass; b: Total carbon). Circles and lines indicate actual and fitted values by the Chapman and Richards model, respectively.

resultsareattributabletodifferencesinclimatic conditions and to variations in the density of plantations in Malaysia, rangingbetween136to148palms per hectare, according to the authors.

Published information on aboveground biomass in oil palm plantations range from 50 to 100 t.ha^{-1} at the end of rotation age, which varies from 20 to 25 years (Klaarenbeeksingel, 2009). Root biomass in Indonesia varied from 40.1 to 52.4 t.ha^{-1} for 20 and 30-year stands, respectively (Syahrinudin, 2005). Therefore, the stocks of biomass found in this study are within the range of values published in Southeast Asia despite the fact that there are differences in climatic conditions and genetic material. This information is also in agreement with the analysis made by Castilla (2004) in Colombia.

Quantifications of carbon in Borneo (Malaysia) made by remote sensing, on the other hand, showed a decrease of aboveground biomass after 20 years due to abscission of foliage (Morel et al., 2011). This was not observed in the present study.

Aboveground carbon stocks for oil palm plantations reported in the literature vary considerably, from 31 to 62 t.ha^{-1} for young cultivations of 10 years and from 96 to 101 t.ha^{-1} in stands of age from 14 and 19 years (Sitompul and Hairiah, 2000). Aboveground carbon stocks reach 9.2 t.ha^{-1} in plantations of 3 years in Sumatra, Indonesia, and 35.4; 41.7 and 55.3 t.ha^{-1} for age classes 10; 20 and 30 years, respectively (Syahrinudin, 2005). The author obtained carbon stocks of 5.4, 10.4, 16.6 and 21.8 t.ha^{-1} for the belowground biomass (roots and stipe base) in 3, 10, 20 and 30 years stands, respectively.

Comparison of carbon stocks in palm-oil cultivation and in other land uses

There are criticisms about the oil palm cultivation in Southeast Asia due to the expansion of this crop for the production of oil, which is preceded by deforestation of tropical forest (Butler, 2011; Fitzherbert et al., 2008). In Malaysia the changes in land use between 1990 and 2007, for example, totaled 1.252 million hectares and 76.3% of this change were resulted from the establishment of oil palm plantations (Malaysia 2007; MPOB, 2008). Wakker et al. (2004) analyzed the social and economic impacts of oil palm crop in Southeast Asia, with emphasis on Indonesia. Their final recom-mendation was a moratorium on any new permitsfor oil palm plantation expansion until the legal framework was modified.

Fargione et al. (2008) evaluated the emissions arising from the establishment of bio-energy crops in Southeast Asia, in the United States and in Brazil. According to the authors the great concern in Brazil is with the expansion of sugar cane biofuel crops, particularly in the Cerrado biome (Savanna). However, criticism of the expansion of oil palm plantations in Brazil, particularly in the Amazon, are constant and of varied background (Becker, 2010).

Despite this criticism, the expansion of oil palm crop in the Amazon has agreat potential to revegetate previously deforested and degraded lands with low economic efficiency.Itcanalso becoupled with increase of biomass and carbon stocks. Obviously, that such expansion shall be made carefully. The appropriate compromise with the social, environmental and cultural territorial development is a condition that will determine the success or failure of this activity (Silva, 2013).

In Brazil oil palm crops have been mostly established in formerly deforested areas occupied by low-production pastures. The regional spatial planning carried out by the Brazilian government encourages the expansion of Oil palmplantationswiththeperspectiveofthe recomposition of disturbed areas and income generation for the local population (Brazil, 2010a).

From the perspective of carbon storage, a permanent

Table 3. Land use and carbon stocks in the region of *E. guineensis* crops in northeastern Brazil.

Land use	tC.ha^{-1}	Main purpose	Biodiversity
Forest*	122.92	Protection	High
Palm (this study)	40.00	Production	Low
Pasture**	8.00	Production	Low
Agriculture**	5.00	Production	Low

Sources: *Brazil, 2010b; **IPCC, 2003.

crop as oil palm shows greater potential compared to temporary agricultural crops and livestock (Table 3). As the cultivation remains producing during 25 years on average, and the palms are large-sized, its carbon storage per hectare is comparably higher, as stated by Castilla (2004).

The expansion of oil palm plantations may represent a carbon debit if the practice is to replace the tropical forest by this crop (Fargione et al., 2008). In the study site natural vegetation type is the Tropical Atlantic Rain Forest (Dense Mixed Forest) whose carbon stocks may reach over 120 tC.ha^{-1} (Brazil 2010b). Loss of this carbon stock may imply in a carbon dioxide emission of about ca. 450 t.ha^{-1}. If one hectare of forest is replaced by oil palm the associated debit related to the emissions of greenhouse gases would be of ca. 304 tCO$_2$.ha^{-1}, taking into account the carbon stock at age 25 years (Table 3). These figures do not accounted for the other emissions due to management of oil palm crop, such as fertilizers and fossil fuel use and the use of fire during land clearing. However, the replacement of tropical forest by seasonal agriculture or pasture may result in an even higher carbon dioxide emission, of 421.37 and 432.37 tCO$_2$eq.ha^{-1}, respectively, derived by this change in land use.

The criticism of the expansion of the oil palm crop in Brazil based upon the carbon debit discussion does not make much sense. The key issue to be addressed is the driver of deforestation regardless if it is oil palm, cash crops or livestock ranching. The growth of human population and the higher living standards of the contemporary society is a major indirect force pushing up the deforestation rates of tropical forest. Migration, inexpensive land prices, low-efficiency agriculture and impunity against lawlessness are the direct and decisive factors. The challenge is to increase productivity, that is, produce more in less space to avoid of the advance of deforestation. Oil palm is efficient in terms of oil production per unit area because its yield per unit area is ten times greater than that of soybean, for instance. Occupying only 5% of the cultivated land for oil in the country it produces 38% of the national production. Such conditions make the cultivation of oil palm a profitable and relatively inexpensive business (Becker, 2010).

The central issue of the environmental discussions associated with the culture of oil palm in Brazil has not

been addressed adequately. The focal point should be to prevent the expansion of this crop in areas of tropical forests, whose main aim is the protection of the environment and the conservation of biodiversity. It makes no sense to compare the biodiversity of a natural forest with a crop. From the perspective of carbon storage oil palm shows advantages in relation to seasonal crops, as shown here. If this crop represents any carbon debit, most other agricultural crops are comparatively much worse. If the planting of oil palm is done in areas previously occupied by pastures and/or agriculture it may conversely represent a carbon credit.

Animportant aspect along this discussion concerns the fact that oil palm has traditionally been considered a monoculture. However, efforts have been made in recent years on integrated pest management programs and intercropping with other plants (Castilla, 2004), which also promotes social inclusion and a more favorable carbonbalance.Inaddition,highconservationvalue (HCV) areaswithinregionsidentifiedforoilpalmcultivation could be left for conservation to rebut critics on monoculture andenhancecarbonconservationinanoilpalm cultivation belt.Further conservative measure could be keeping preserved forest areas located in riparian zonesandinmountainslopes,withinregionsforoilpalm cultivation.

The cultivation of oil palm in Brazil may be a major alternative to regional development by its potential role in the recovery of deforested lands. It can also provide income and employment generation to local people, diversification of production, as well as produce renewable energy and diminish dependence on imported biofuel (Becker, 2010). As demonstrated here oil palm plantations can also contribute positively to mitigate climate change through carbon sequestration.

The great challenge is to confine the cultivation of this species in already deforested areas, avoid the risks of monoculture by means of agroforestry systems and share their socioeconomic benefits to assure the sustainability of its production chain.

Conclusions

1. The biometric variables of oil palm are significantly

correlated. Biomass is more strongly correlated to stipe measures;

2. In mature oil palm stands the stipe represents the largest fraction of biomass and carbon stocks;

3. Due to the strong relationship to total biomass and carbon, age can be used as a predictor variable for growth modeling;

4. Stipe biomass proportion increases with age, whereas foliagebiomassdecreases,androotsremain

practically unchanged;

5. A mature oil palm stores more carbon than agricultural crops and pastures, but less than a tropical forest;

6. Expansion of oil palm plantations in the country must observe the country's regulation, which is directed to formerly deforested lands, particularly degraded crop and pastures, preventing increase of deforestation of the tropical forest.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Aholoukpè H, Dubos B, Flori A, Deleporte P, Amadji G, Jean-Luc C, Didier B (2013). Estimating aboveground biomass of oil palm: Allometric equations for estimating frond biomass. For. Ecol. Manag. 292:122-129.

Asari N, Suratbig MN, Jaafar J, Khalid MM (2013). Estimation of above ground biomass for oil palm plantations using allometric equations. IPCBEE 2013: Proceedings of the 4th International Conference on Biology, Environment and Chemistry pp.110-114.

Becker BK (2010). Récupération des zones déboisées en Amazonie :la culture du palmier à huile serait-elle une solution? Confins Revue Franco-Brésilienne du Géographie. DOI : 10.4000/confins.6609

Berthaud A, Nunes CDM, Barcelos E, Cunha RNV (2000) Implantação e exploração da cultura do dendezeiro. In: Viégas, I.J.M., Muller, A.A., editors. A cultura do dendezeiro na Amazônia Brasileira. Belém: Embrapa Amazônia Oriental & Manaus: Embrapa Amazônia Ocidental.

Brazil (2006). Plano Nacional de Agroenergia 2006–2011. 2nd ed. Embrapa Informação Tecnológica, Brasília.

Brazil (2010a). Macrozoneamento Ecológico-Econômico da Amazônia Legal – Estratégias de transição para a sustentabilidade. Ministério do meio ambiente, Brasília.

Brazil(2010b).SegundaComunicaçãoNacionaldoBrasìlà Convenção-Quadro das Nações Unidas sobre Mudança do Clima. Ministério da ciência e tecnologia.

Brazilio M, Bistachio NJ, Silva VC, Nascimento DD (2012). O Dendezeiro (*Elaeis guineensis* Jacq.) – Revisão. Bioenergia em Revista: Diálogos 2:27-45.

Butler R (2011). In Brazil, palm oil plantations could help preserve amazon. Available in: http://e360.yale.edu/content/feature.msp?id=2415). Access in: nov. 2011.

Butler RA, Laurance WF (2009). Is oil palm the next threat to the Amazon? Trop. Conserv. Sci. 2:1-10.

Cardoso JNO (2010). Conversão in vitro de embriões zigóticos de híbridos de dendezeiro (*Elaeis guineensis* x *E. oleifera*) em plântulas [dissertation]. Universidade Federal Rural da Amazônia, Belém (PA).

Castilla CE (2004). Potencial de captura de carbono por la palma de aceite en Colombia. Palmas 25:366-371.

Chavez C (1984). Mejoramiento genético. Curso de palma aceitera. Palm Research Program, Golfito.

Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P (2008). Land clearing and the biofuel carbon debt. Science 319:1235-1238.

Fitzherbert EB, Struebig MJ, Morel A, Danielsen F, Bruhl CA, Donald PF, Phalan B (2008). How will oil palm expansion affect biodiversity? Trends Ecol. Evol. 23(10):538-545.

Furlan Jr. J, Kaltner FJ, Azevedo GF, Campos IA (2006). Biodiesel: Porque tem que ser dendê. Embrapa, Belém.

Hamburg PS, (2000). Simple rules for measuring changes in ecosystem carbon in forestry-offset projects. Mitig Adapt Strategies Glob. Chang. 5:25-37.

Harada E (2008). AGRIANUAL 2008: Anuário da Agricultura Brasileira. iFNP: São Paulo.

Hartley CWS (1977). The oil palm (*Elaeis guineensis* Jacq). 2nd ed. Longman, London.

IPCC – Intergovernmental Panel on Climate Change (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry.

IPCC – Intergovernmental Panel on Climate Change (2006). Guidelines for National Greenhouse Gas Inventories.

Jacquemard JC (1979). Contribution to the study and the height growth of the stems of *Elaeis guineensis* Jacq. Study of the L2T x D10D cross", Oleagineux. 34:492-497.

Khalid H, Zin Z, Anderson JM (1999b). Quantification of oil palm biomass and nutrient value in a mature plantation. II. Belowground Biomass. J. Oil Palm Res. 2:63-71.

Khalid H, Zin Z, Anderson JM (1999a). Quantification of oil palm biomass and nutrient value in a mature plantation. I. Above-ground Biomass J. Oil Palm Res. 2:23-32.

Klaarenbeeksingel FW (2009). Greenhouse gas emissions from palm oil production: Literature review and proposals from the RSPO Working Group on Greenhouse Gases.

Köppen W, Geiger R (1928). Klimate der Erde. Gotha: Verlag Justus Perthes.

Lange MVA (2012). Mudançadoestoquedecarbonopor transformação da terra e seu uso no inventário de ciclo de vida de produtos de origem renovável: estudo de caso da possível expansão da palma de óleo na Amazônia legal brasileira. [dissertation]. Universidade Tecnológica Federal do Paraná, Curitiba (PR).

Malaysia (2007). Statistics on Commodities 2007. Ministry of agriculture and industry, Kuala Lumpur.

Morel AC, Sassan SS, Yadvinder M, Nicholas JB, Lindsay B, David B, Reuben N, Robert CO (2011). Estimating aboveground biomass in forest and oil palm plantation in Sabah, Malaysian Borneo using ALOS PALSAR data. For. Ecol. Manage. 262:1786-1798.

Moretzsohn MC, Ferreira MA, Amaral ZPS, Coelho J, Grattapaglia D, Ferreira ME (2002). Genetic diversity of Brazilian oil palm (*Elaeis oleifera* H.B.K.) germplasm collected in the Amazon Forest. Euphytica 124:35-45.

Moura JIL (2008). Polinização do Dendezeiro por *Elaeidobius subvittatus* Faust E *Elaeidobius kamerunicus* Faust (COLEOPTERA, CURCULIONIDAE) no Sul do Estado da Bahia [dissertation]. Universidade Estadual Paulista "Júlio de Mesquita Filho", Jaboticabal (SP).

MPOB (2008). Malaysian Oil Palm Statistics 2007. 27th ed. Malaysian Palm Oil Board, Bangi.

Santos EA (2010). Caracterização de dendezeiros subespontâneos com base na produção de frutos e cachos. [dissertation]. Universidade Estadual de Santa Cruz, Santa Cruz (BA).

Savin G (1965). O dendezeiro no Estado da Bahia. Ministério da Agricultura/Instituto de óleos, Brasília.

Silva EP (2013). Desenvolvimento local e óleo de palma na Amazônia: interfaces entre o global e o local. Anais do 5º Colóquio Organizações, Desenvolvimento, Sustentabilidade. UNAMA, Manaus pp. 235-257.

Sitompol SM, Hairiah K (2000). Biomass measurement of home garden. Proceedings of Workshop on LUCC and Greenhouse Gas Emissions, Biophysical Data, IPB, Bogor.

Syahrinudin (2005). The potential of palm oil and forest plantations for carbon sequestration on degraded land in Indonesia. In: Vlek PLG, Denich M, Martinus C, Rodgers C, van de Giesen N, editors. Ecol. Dev. Series No. 27. Cuvillier Verlag, Göttingen.

Thenkabail PS, Nicholas S, Bronson WG, Mark SA, Jan D, Der Meer BV, Enclona E (2010). Biomass estimations and carbon stock

calculations in the oil palm plantations of African derived savannas using IKONOS data. Int. J. Rem. Sen.25:5447-5472.

Turner PD, Gillbanks RA (1974). Oil palm cultivation and management. The Incorporated Society of Planters, Kuala Lumpur.

Villela AA (2009). O dendê como alternativa energética sustentável em áreas degradadas da Amazônia [dissertation]. Universidade Federal do Rio de Janeiro, Rio de Janeiro (RJ).

Wahid BM, Abdullah SNA, Henson IE (2005). Oil palm: achievements and potential. Plant Prod. Sci. 8:288-297.

Wakker E, Watch S, Rozario J (2004). Greasy palms: the social and ecological impacts of large-scale oil palm plantation development in Southeast Asia. Friends of Earth, London.