# BIOMASS AND CARBON STOCK IN *Jatropha curcas* L.

Carlos Moreira Miquelino Eleto Torres[1], Laércio Antônio Gonçalves Jacovine[2], Diego de Paula Toledo[3], Carlos Pedro Boechat Soares[2], Sabina Cerruto Ribeiro[4], Maria Cristina Martins[5]

(received: February 23, 2010; accepted: April 28, 2011)

**ABSTRACT:** This study aims to quantify the biomass and carbon stock in a crop of physic nut *Jatropha curcas* in Viçosa-MG at age three years. For biomass quantification, the direct or destructive method was applied to sample plants selected according to height, crown diameter and number of branches. For the determination of dry biomass in the field, the proportionality method was used. The determination of total carbon content was done in the Laboratory of Forest Soils of the Federal University of Viçosa, and the estimation of $CO_2$ equivalent was based on the 3.67 factor. The carbon stock found in the third year of cultivation was 4.182 $tC.ha^{-1}$ (15.349 $tCO_{2-e}.ha^{-1}$) and the mean annual increment (MAI) was 1.394 $tC.ha^{-1}.year^{-1}$. Results revealed that the potential carbon increment in the physic nut crop is similar to values found in other crops and natural forests yet lower than in eucalyptus crops.

Key words: Carbon credits, carbon sequestration, physic nut.

# ESTOQUE DE BIOMASSA E DE CARBONO DE *Jatropha curcas* L.

***RESUMO:*** *No presente estudo, objetivou-se quantificar a biomassa e o estoque de carbono da cultura de Jatropha curcas no município de Viçosa – MG aos três anos de idade. Para a quantificação da biomassa foi utilizado o método direto ou destrutivo, aplicado às plantas-amostras selecionadas segundo medidas de altura, diâmetro de copa e número de ramos. A determinação da biomassa seca no campo foi obtida pelo método da proporcionalidade. O teor de carbono total foi determinado no laboratório de solos florestais da Universidade Federal de Viçosa e a estimativa do* $CO_2$ *equivalente pelo fator 3,67. O estoque de carbono encontrado para o terceiro ano da cultura do pinhão manso foi de 4,182* $tC.ha^{-1}$ *(15,349* $tCO_{2-e}.ha^{-1}$*) e o incremento médio anual (IMA) de 1,394* $tC.ha^{-1}.ano^{-1}$*. Os resultados encontrados evidenciam que a cultura apresenta um incremento potencial de carbono próximo à outras culturas e às florestas naturais, entretanto, abaixo de plantios de eucalipto.*

*Palavras-chave: Créditos de carbono, sequestro de carbono, pinhão manso.*

## 1 INTRODUCTION

Increasing emissions of greenhouse gases (GHG) resulting from massive economic and industrial expansion has been a major cause of concern to humankind in recent years. According to the Centro de Gestão e Estudos Estratégicos - CGEE (2008), the burning of fossil fuels since the beginning of the industrial revolution is the main cause of this increase in GHG concentrations in the atmosphere, potentially retaining heat and affecting both the thermal and climatic balance of planet Earth.

Scientists have defended that these changes in the thermal and climatic balance of the planet potentially cause severe damage to the ecosystems and humankind, including rising sea levels and agricultural losses. These evidences have prompted a series of international meetings in an attempt to devise public policies to try and minimize the effects of GHG.

One of the most important related events was the third session of the Conference of the Parties (COP 3), held in Kyoto, Japan, which is when the Kyoto Protocol was adopted. This treaty has been regarded so far as the most important practical measure aimed at reducing the levels of GHG emissions. According to the Protocol... (1997), industrialized countries, referred to as Annex I countries, must reduce GHG emissions by 5.2% from 1990 levels, between 2008 and 2012. To facilitate compliance with this commitment, the Protocol allows these countries to use flexible mechanisms.

The only flexible mechanism in the Kyoto Protocol allowing for participation of developing countries (non-Annex I), including Brazil, is the Clean Development Mechanism (CDM). The CDM emerged from a proposal made by the Brazilian government in which participants gain credits for 'producing' reductions in GHG emissions (RIBEIRO, 2007). The CDM allows developed countries

[1]Forest Engineer, M.Sc. Candidate in Forest Science – Universidade Federal de Viçosa/UFV – 36570-000 – Viçosa, MG – carlos.eleto@ufv.br
[2]Forest Engineer, Professor Ph.D. in Forest Science – Departamento de Engenharia Florestal – Universidade Federal de Viçosa/UFV – 36570-000 – Viçosa, MG – jacovine@ufv.br, csoares@ufv.br
[3]Forest Engineer, M.Sc. in Forest Science – Universidade Federal de Viçosa/UFV – 36570-000 – Viçosa, MG – diegoptoledo@yahoo.com.br
[4]Forest Engineer, Ph.D. Candidate in Forest Science – Universidade Federal de Viçosa/UFV – 36570-000 – Viçosa, MG – sabina_ribeiro@yahoo.com.br
[5]Degree in Tourism, M.Sc. in Forest Science – Universidade Federal de Viçosa/UFV – 36570-000 – Viçosa, MG – maria.martins@ufv.br

to gain Certified Emission Reductions (CERs) by financing emissions-reducing projects in developing countries, or Parties.

There are 2,597 CDM projects currently under way worldwide, registered until December 14, 2010, out of which only 18 address afforestation and reforestation (A/R), helping remove 648,261 tons of $CO_2$ equivalent per year (UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE – UNFCCC, 2010). To date there is no definition as to what commitments will be assigned to Annex I countries in the second commitment period of the Kyoto Protocol, nor whether developing countries such as China, India and Brazil will have reduction commitments. However, the Brazilian government has established voluntary emissions-reducing targets regardless. According to the National Policy on Climate Change (Law no. 12187/2009), Brazil is committed to reducing its emissions by 36.1% to 38.9% for the period until 2020, based on the Inventário Brasileiro de Emissões e Remoções Antrópicas de Gases de Efeito Estufa (BRASIL, 2009a).

Within this context, *Jatropha curcas* (physic nut) emerges as a potential species for use in CDM projects. This type of crop not only helps mitigate climate change through sequestration and storage of carbon in the biomass, but it also helps produce renewable energy, by replacing fossil fuels, as its seeds can be used for biofuel production.

According to Cotta et al. (2008), carbon sequestration by forest species that have a long life span and whose exploration is intended for purposes other than timber production—as is the case with physic nut, cocoa and rubber trees—, brings comparative advantages over use of species with a short life span intended for timber production. Where the purpose of a crop is other than timber production, it is assumed that carbon will be stocked over the entire life span of the crop, this life span usually exceeding the duration of afforestation and reforestation projects for generation of carbon credits, usually up to 30 years.

Bearing the above in mind, this study aims to quantify the biomass and carbon stock in a crop of *Jatropha curcas* (physic nut), on which to base development of carbon credit projects.

## 2 MATERIAL AND METHODS

### 2.1 Study site

The study site is located in Viçosa-MG, at coordinates 20º 48' S and 42º 52' W, at an average altitude of 700 m. The crop covers a total area of 4.53 ha, with a spacing pattern of 3.5 m x 3.0 m, amounting to 4,300 planted seedlings of physic nut. Once the crop was established, data were collected annually until the third crop year.

Under the Köppen climate classification, the local climate is Cwa type, a humid subtropical climate zone characterized by hot, humid summers and cold, dry winters. The average annual maximum and minimum temperatures in the region are 26.1 $^0$C and 14 $^0$C respectively, with average annual precipitation of around 1,341.2 mm and average annual relative humidity of 80% (OLIVEIRA JÚNIOR, 2005).

The local relief is predominantly steep and mountainous, having rugged terrain with narrow, marshy lowland. On the hilltops and hillside slopes of elevated land the alic Red-Yellow Latosol soil type predominates, while on terraced land the cambic Red-Yellow Podzolic soil type predominates (MEIRA NETO, 1997).

### 2.2 Sample plant inventory and selection

Once the study site was defined, four rows were randomly selected each year for measurements of number of branches, height and crown diameter. With measurements at hand, the mode of number of branches was calculated, along with the mean height and mean crown diameter.

Based on the above measurements, for the quantification of biomass in shoot components (leaves and branches) and root system (taproot, fine roots and coarse roots), the criterion used was to select plants having the number of branches closer to the mode and having height and crown diameter closer to the mean.

### 2.3 Biomass quantification

The direct or destructive method was used for determining biomass, as proposed by Watzlawick et al. (2002). For shoot biomass, eight plants were selected each year. The shoot portion was divided into leaves and branches, with the stem being ignored as it was somewhat undistinguished and branches were protruding almost level with the ground. And for root biomass, four plants were selected each year.

Each plant sample was defoliated and leaves were gathered, bagged and weighed. Then branches were cut and weighed.

The sampling of fine roots was done by the furrow method, opening furrows of 1.50 m between plants, 1.75 m between rows and 0.40 m in depth. The soil removed was sieved and the fine roots remaining were gathered and weighed. The coarse roots and taproot were removed and weighed, then representative samples of the shoot and root components were gathered and weighed for dry matter weight determination.

The fresh samples of leaves, branches and root system were then taken to a laboratory and placed in a forced air oven set at around 75ºC, until dry weight stabilized.

The dry biomass in the field was determined by the proportionality method, used also by Soares and Oliveira (2002), and given by the following equation:

$$MS(C) = \frac{Mu(c) * Ms(a)}{Mu(a)}$$

where: MS (C) = total dry weight in kg; Ms (a) = dry weight of samples in kg; Mu (a) = fresh weight of samples in kg; Mu (c) = total fresh weight in the field, in kg.

The total plant biomass (leaves, branches and coarse roots) was quantified by multiplying the average dry biomass of one individual by the number of trees per hectare. For that, a density of 952 trees per hectare was considered as reference, following 3.5 m x 3.0 m spacing. For the fine roots, an extrapolation was done of biomass present in 2.625 $m^2$, the furrow area, and depth of 0.4 m, to one hectare with equivalent depth.

### 2.4 Total carbon content

For the determination of total carbon content in each tree component (roots, branches and leaves), composite samples were formed from the dry matter samples of this material. These samples were crushed in a cutting mill, gathering three 1g samples of each component and submitting them to analysis at the Laboratory of Forest Soils of the Federal University of Viçosa.

Each 1g sample was placed in a lidless porcelain crucible and taken to a muffle furnace set at 550°C for three hours, until calcination was completed. The sample was then removed and cooled in a desiccator to be later weighed. Carbon content was calculated by the following equation:

$$CT = \left(\frac{M_s}{M_r}\right) * 100$$

where: CT = Carbon content, in %; Ms = dry sample residue weight, after calcination, in g; Mr = dry sample weight, in g.

### 2.5 Conversion of carbon into $CO_2$ equivalent

As market trading of carbon credits is based on $CO_2$ equivalent ($CO_{2\text{-}e}$), converting carbon into $CO_2$ became mandatory. According to the Intergovernmental Panel on Climate Change - IPCC (2006), one ton of carbon equals 3.67 tons of $CO_{2\text{-}e}$, which is the ratio of molecular weight of $CO_2$ to carbon (44/12).

## 3 RESULTS AND DISCUSSION

### 3.1 Analysis of dispersion

At ages 12, 24 and 36 months, measurements of mean crown diameter were 0.75 ± 0.327 m, 1.96 ± 0.498 m and 2.12 ± 0.430 m respectively, and measurements of mean height were 1.39 ± 0.466 m, 2.39 ± 0.369 m and 2.51 ± 0.380 m respectively (Figure 1).

### 3.2 Biomass and carbon stock quantification for the physic nut crop

The dry weight of the tree components of the crop at 12, 24 and 36 months corresponded to 24.58%, 25.76% and 22.81% of the fresh weight respectively.

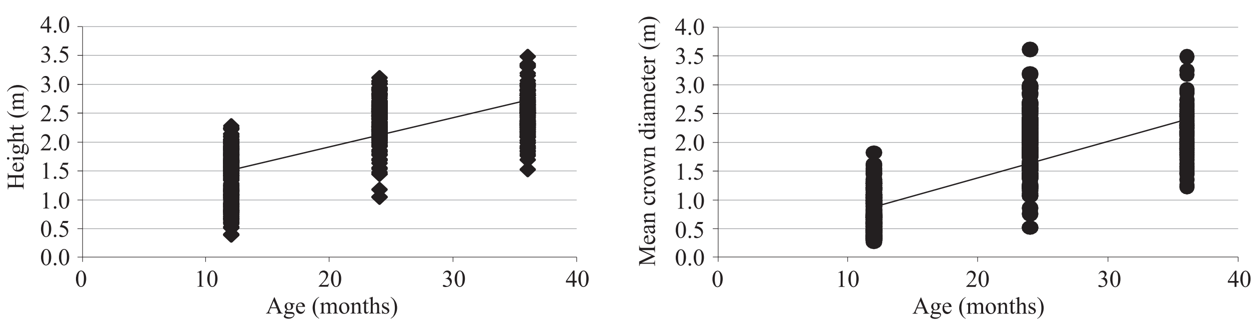


**Figure 1 –** Data scatter concerning height and crown diameter of a physic nut crop according to age in months.

***Figura 1 –** Dispersão dos dados de altura e diâmetro de copa médio da cultura de pinhão manso em relação à idade em meses.*

The biomass of the shoot portion and roots in the first year corresponded to 65.79% and 34.21% of the total, respectively. In the second year the shoot portion corresponded to 70.89% while the roots, to 29.11% of the total. In the third year the roots corresponded to 28.60% and the shoot portion, to 71.40% of the total dry weight (Table 1). The proportion between tree components and roots in the first year was lower than in other years, possibly due to the need for plants to focus on root formation and thus ensure greater efficiency in obtaining nutrients while settling.

In the third year of cultivation, the biomass stock was found to be 8.658 $t.ha^{-1}$ (Table 1). Drumond et al. (2008b) studied tree species from semiarid climate in Petrolina (PE) and found 21.6 $t.ha^{-1}$ and 51.6 $t.ha^{-1}$ of total biomass, respectively, for *Mimosa tenuiflora* (Willd.) Poir and *Caesalpinia velutina* (Britton & Rose) Standley, at age eight years. Caldeira (2000) found a biomass total of 12.4 $t.ha^{-1}$ in *Acacia mearnsii* De Wild, in Butiá, RS, at age 2.4 years. For the same species, at age 8 years, Barichello et al. (2005) found 132.1 $t.ha^{-1}$ of total biomass, in Minas do Leão, RS. A comparison of these studies with results in this work demonstrates that physic nut has potential for use in biomass production.

As regards total carbon content in each tree portion, higher levels were found in the roots, with 51.06%, followed by leaves, with 48.96%, then branches, with 46.7%. Values found in the leaves and branches are lower than reference values used by the IPCC (2003), Losi et al. (2003) and Soares and Oliveira (2002), who suggest that carbon present in biomass corresponds to 50%, yet values are higher than results found by Koehler et al. (2002) and Vieira et al. (2009).

A significant increase was observed in the carbon stored in tree components from the first to the third year, particularly in the coarse roots and taproot and in the branches (Figure 2). Values found in the fine roots were very close throughout.

The value found of total carbon stored in the third year of crop cultivation was 4.182 $tC.ha^{-1}$, corresponding to 15.349 $tCO_{2-e}.ha^{-1}$, a mean annual increment (MAI) of 1,394 $tC.ha^{-1}.year^{-1}$. This value is lower than the MAI value found for eucalyptus at age 7 years in Bom Despacho and Carbonita - MG, namely 12.38 $tC.ha^{-1}.year^{-1}$ (NISHI et al., 2005; REIS et al., 1994), also lower than the MAI value found for a rubber tree crop at age 34 years in Igrapiúna-BA, namely 2.50 $tC.ha^{-1}.year^{-1}$, as reported by Cotta (2005) with rubber-cocoa intercropping. However, the MAI value

**Table 1 –** Fresh and dry matter weight in different tree portions, and percentage of each tree component in relation to the total annual biomass, in the first three years of cultivation, for a physic nut crop in Viçosa-MG.

***Tabela 1 –*** *Massa de matéria úmida e de matéria seca nos diferentes compartimentos arbóreos, e percentagem de cada componente arbóreo em relação à biomassa total anual, nos três primeiros anos da cultura de Jatropha curcas, Viçosa – MG.*

| | Year 1 | | Year 2 | | Year 3 | |
|---|---|---|---|---|---|---|
| | Fresh weight ($t.ha^{-1}$) | Dry weight ($t.ha^{-1}$) | Fresh weight ($t.ha^{-1}$) | Dry weight ($t.ha^{-1}$) | Fresh weight ($t.ha^{-1}$) | Dry weight ($t.ha^{-1}$) |
| Shoot Portion | | | | | | |
| Trunk and branches | 3.060 (52.42 %) | 0.712 (49.64 %) | 11.443 (63.17 %) | 2.919 (62.54 %) | 21.216 (55.91 %) | 4.838 (55.88 %) |
| Leaves | 0.774 (13.26 %) | 0.232 (16.15 %) | 1.467 (8.10 %) | 0.390 (8.35 %) | 5.778 (15.22 %) | 1.344 (15.52 %) |
| Subtotal | 3.834 (65.68 %) | 0.944 (65.79 %) | 12.910 (71.27 %) | 3.309 (70.89 %) | 26.994 (71.13 %) | 6.182 (71.40 %) |
| Roots | | | | | | |
| Coarse roots & taproot | 1.855 (31.78 %) | 0.431 (30.04 %) | 5.024 (27.73 %) | 1.301 (27.88 %) | 10.714 (28.23 %) | 2.405 (27.78 %) |
| Fine roots | 0.149 (2.54%) | 0.060 (4.17 %) | 0.181 (1.00 %) | 0.057 (1.23 %) | 0.243 (0.64) | 0.071 (0.82 %) |
| Subtotal | 2.004 (34.32 %) | 0.491 (34.21 %) | 5.205 (28.73 %) | 1.358 (29.11 %) | 10.957 (28.87 %) | 2.476 (28.60 %) |
| Total | 5.838 | 1.435 | 18.115 | 4.667 | 37.951 | 8.658 |

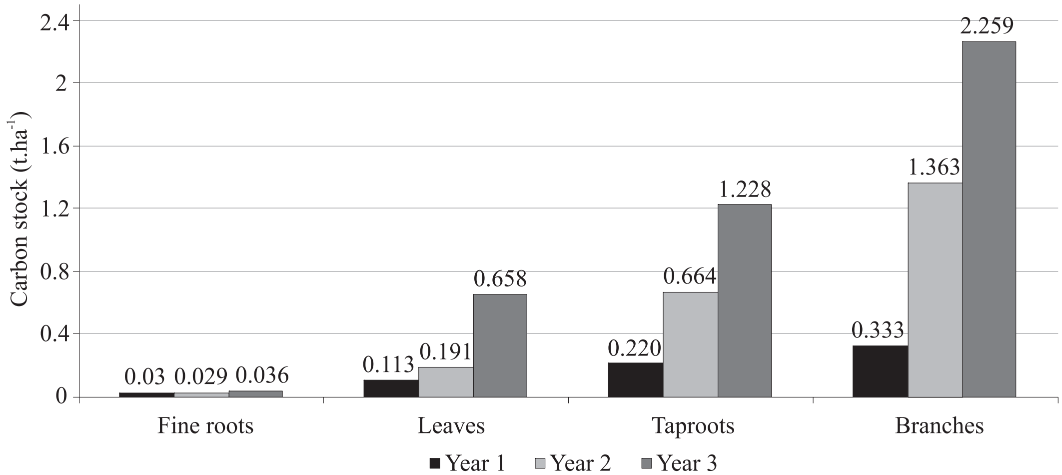


**Figure 2 –** Carbon stock per tree component, expressed as tons per hectare, in the first three years of cultivation, for *Jatropha curcas*, in Viçosa-MG.

***Figura 2 –*** *Quantidade de carbono estocado por compartimento arbóreo, em toneladas por hectare, nos três primeiros anos da cultura de Jatropha curcas, Viçosa–MG.*

found in this study was higher than the MAI value of 0.87 $tC.ha^{-1}.year^{-1}$ found for a cocoa crop at age 6 years in Igrapiúna-BA (COTTA, 2005) and close to the value found by Boina (2008) for a *semideciduous* mesophytic *forest in the* Atlantic Forest domain, Vale do Rio Doce-MG, between 2002 and 2007, namely 1.34 $tC.ha^{-1}.year^{-1}$.

Prior to the crop being introduced, the study site was covered by pastureland possibly with a history of degradation, which is common in the region. The introduction of a physic nut crop helped increase $CO_2$ removal from the atmosphere in comparison with the degraded pastureland, which confirms the additionality of the project. Physic nut crops may be eligible for carbon credits in reforestation projects, provided UNFCCC criteria are met and provided the project ensures additionality in relation to what would have occurred in the absence of the project, contributing to meet the targets of sustainable development as defined by the host country.

With regard to sustainable development, the crop addressed in this study is part of a joint project between some local government bodies and a private sector company. The idea was to foment producers by providing them with seedlings and training such as field days, workshops and lectures. These activities helped improve crop quality and boost the income of local people as a result.

Conceiving $CO_2$ removal projects within CDM scope, however, entails high costs and red tape. In order for these projects to be feasible in small communities it would be interesting to form cooperatives or associations with which to encourage a tighter union among farmers and foment the search for information (costs, markets etc), with help from specialized people.

Another important factor related to forestry CDM is non-permanence, that is, the likelihood that $CO_2$ sequestered by the trees be reemitted to the atmosphere at any time due to, for instance, a forest fire or death from pests (BRASIL, 2009b). Yet no occurrences have been detected of forest fires resulting from land cultivated by farmers. As for pests and disease, knowledge is yet insufficient about the crop being studied here.

That said, several studies are being conducted nationwide, including by Dias et al. (2007), Drumond et al. (2008a), Saturnino et al. (2005) and Silva et al. (2009), as well as international studies by Behera et al. (2010), Gao et al. (2008) and Maes et al. (2009), all aimed at improving and adapting this specific crop accordingly. Additionally, there are two projects awaiting validation by the UNFCCC, aimed at introducing physic nut crops for recovery of degraded areas, one in the Democratic Republic of the Congo and another in the Republic of Mali, both in Africa.

Physic nut being a perennial crop, it can be beneficial in CDM projects, in comparison with annual crops or crops subjected to cuttings. Since credit issuance is based on average carbon storage over the span of a project, the permanence of a continual uncut crop enables greater carbon storage over a given time interval.

According to BlueNext (2010), the 'spot' price (immediate delivery) of carbon credits in December 2010 was €11.71 per ton of $CO_2$ equivalent. This credit price and a carbon stock of 15.349 $tCO_{2(eq.)}.ha^{-1}$, which is the value found in the third crop year, demonstrate the potential of the physic nut crop for generating income with inclusion of carbon credits.

## 4 CONCLUSIONS

Results led to the following conclusions:

- an increase was observed in weight ($t.ha^{-1}$) in all tree components over the crop years, yet the ratio of shoot portion to roots increased with the passing of years;

- trunk and branches, followed by coarse roots and taproot, accumulated the highest carbon stock in the third crop year;

- the annual increment of carbon stock in the physic nut crop (1,394 $tC.ha^{-1}.year^{-1}$) is close to the increment found in other similar crops and native forests;

- the crop studied here has potential for carbon storage and for use in CDM projects.

## 5 ACKNOWLEDGMENTS

The authors wish to thank CNPq for granting funds and providing M.Sc., scientific initiation, and academic work-based scholarships. The authors also wish to thank CAPES for providing a Ph.D. scholarship, and Mr. Paulo Afonso for allowing access to the study site.

## 6 REFERENCES

BARICHELLO, L. R. et al. Quantificação da biomassa de um povoamento de *Acacia mearnsii* De Wild. na região sul do Brasil. **Ciência Florestal**, Santa Maria, v. 15, n. 2, p. 129-135, 2005.

BEHERA, S. K.; SRIVASTAVA, P.; TRIPATHI, R.; SINGH, J. P.; SINGH, N. Evaluation of plant performance of *Jatropha curcas* L. under different agro-practices for optimizing biomass: a case study. **Biomass & Bioenergy**, Oxford, v. 34, n. 1, p. 30-41, Jan. 2010.

BLUENEXT. **Closing prices**: spot. Disponível em: <http://www.bluenext.eu/>. Acesso em: 10 dez. 2010.

BOINA, A. **Quantificação de estoques de biomassa e se carbono em floresta estacional semidecidual, Vale do Rio Doce, Minas Gerais**. 2008. 98 p. Dissertação (Mestrado em Ciência Florestal) - Universidade Federal de Viçosa, Viçosa, 2008.

BRASIL. **Lei nº 12.187**, de 29 de dezembro 2009. Institui a Política Nacional sobre Mudança do Clima - PNMC. Brasília: Presidência da Republica, 2009a. 6 p.

BRASIL. Ministério da Ciência e Tecnológia. **MDL ilustrado**. Versão 8.0. Brasília, 2009b. 101 p.

CALDEIRA, M. V. W. Quantificação da biomassa e do conteúdo de nutrientes em diferentes procedências de acácia-negra (*Acacia mearnsii* De Wild.). **Ciência Rural**, Santa Maria, v. 30, n. 1, p. 195-196, 2000.

CENTRO DE GESTÃO E ESTUDOS ESTRATÉGICOS. **Manual de capacitação sobre mudança do clima e projetos de mecanismo de desenvolvimento limpo (MDL)**. Brasília, 2008.

COTTA, M. K. **Quantificação de biomassa e análise econômica do consórcio seringueira-cacau para geração de créditos de carbono**. 2005. 89 f. Dissertação (Mestrado em Ciência Florestal) - Universidade Federal de Viçosa, Viçosa, 2005.

COTTA, M. K.; JACOVINE, L. A. G.; PAIVA, H. N.; SOARES, C. P. B.; VIRGENS FILHO, A. C.; VALVERDE, S. R. Quantificação de biomassa e geração de certificados de emissões reduzidas no consórcio seringueira-cacau. **Revista Árvore**, Viçosa, v. 32, n. 6, p. 969-978, 2008.

DIAS, L. A. S. et al. **Cultivo de pinhão manso (*Jatropha curcas* L.) para a produção de óleo combustível**. Viçosa, MG: UFV, 2007. 40 p.

DRUMOND, M. A.; ARRUDA, F. P.; ANJOS, J. B. dos. **Pinhão-manso - *Jatropha curcas* L.** Petrolina: Embrapa Semi-Árido, 2008a. 15 p. (Documentos, 212).

DRUMOND, M. A. et al. Produção e distribuição de biomassa de espécies arbóreas no semi-árido brasileiro. **Revista Árvore**, Viçosa, v. 32, n. 4, p. 665-669, 2008b.

GAO, S.; YAN, R.; CAO, M.; YANG, W.; WANG, S.; CHEN, F. Effects of copper on growth, antioxidant enzymes and phenylalanine ammonia-lyase activities in *Jatropha curcas* L. seedling. **Plant Soil and Environment**, The Hague, v. 54, n. 3, p. 117-122, Mar. 2008

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. **Good practice guidance for land use, land-use change and forestry**. Tokyo: Institute for Global Environmental Strategies, 2003.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. **IPCC guidelines for national greenhouse gas inventories**: agriculture, forestry and other land use. Tokyo: Institute for Global Environmental Strategies, 2006. v. 4.

KOEHLER, S. H.; WATZLAWICK, L. F.; KIRCHER, F. F. Fontes e níveis de erros nas estimativas do potencial de fixação de carbono. In: SANQUETTA, C. R. et al. (Eds.). **As florestas e o carbono**. Curitiba: UFPR, 2002. p. 251-264.

LOSI, C. J.; SICCAMA, T. G.; CONDIT, R.; MORALES, J. E. Analysis of alternative methods for estimating carbon stock in young tropical plantations. **Forest Ecology and Management**, Amsterdam, v. 184, n. 1/3, p. 355-368, 2003.

MAES, W. H.; TRABUCCO, A.; ACHTEN, W. M. J.; MUYS, B. Climatic growing conditions of *Jatropha curcas* L. **Biomass & Bioenergy**, Oxford, v. 33, n. 10, p. 1481-1485, Oct. 2009.

MEIRA NETO, J. A. A. **Estudos florísticos, estruturais e ambientais nos estratos arbóreo e herbáceos-arbustivo de uma floresta estacional semidecidual em Viçosa, MG**. 1997. 154 f. Tese (Doutorado em Ciências Biológicas) – Universidade Estadual de Campinas, Campinas, 1997.

NISHI, M. H. et al. Influência dos créditos de carbono na viabilidade financeira de três projetos florestais. **Revista Árvore**, Viçosa, v. 29, n. 2, p. 263-270, 2005.

OLIVEIRA JUNIOR, J. C. **Precipitação efetiva em floresta estacional semidecidual na reserva Mata do Paraíso, Viçosa, Minas Gerais**. 2005. 72 f. Dissertação (Mestrado em Ciência Florestal) – Universidade Federal de Viçosa, Viçosa, 2005.

PROTOCOLO de Quioto. Brasília: Ministério da Ciência e Tecnologia, 1997.

RIBEIRO, S. C. **Quantificação do estoque de biomassa e análise econômica da implementação de projetos visando a geração de créditos de carbono em pastagem, capoeira e floresta primária**. 2007. 128 p. Dissertação (Mestrado em Ciência Florestal) - Universidade Federal de Viçosa, Viçosa, 2007.

SATURNINO, H. M.; PACHECO, D. D.; KAKIDA, J.; TOMINAGA, N.; GONÇALVES, N. P. Cultura do pinhão-manso (*Jatropha curcas* L.). **Informe Agropecuário**, Belo Horizonte, v. 26, p. 44-78, 2005.

SILVA, E. B.; TANURE, L. P. P.; SANTOS, S. R. Sintomas visuais de deficiências nutricionais em pinhão-manso. **Pesquisa Agropecuária Brasileira**, Brasília, v. 4, n. 4, p. 392-397, 2009.

SOARES, C. P. B.; OLIVEIRA, M. L. R. Equações para estimar a quantidade de carbono na parte aérea de árvores de eucalipto em Viçosa, Minas Gerais. **Revista Árvore**, Viçosa, v. 26, n. 5, p. 533-539, 2002.

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE. **CDM statistics**. Disponível em: <http://cdm.unfccc.int/Statistics/index.html>. Acesso em: 14 dez. 2010.

VIEIRA, G.; SANQUETTA, C. R.; BARBEIRO, L. da S. S. Estoque individual de biomassa e carbono em *Nectandra grandiflora* Nees (canela-amarela). **Floresta**, Curitiba, v. 39, n. 3, p. 547-554, jul./set. 2009.

WATZLAWICK, L. F.; KIRCHER, F. F.; SANQUETTA, C. R.; SCHUMACHER, M. V. Fixação de carbono em floresta ombrófila mista em diferentes estágios de regeneração. In: SANQUETTA, C. R. et al. (Eds.). **As florestas e o carbono**. Curitiba: UFPR, 2002. p. 153-173.