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CLIMATIC CHANGE

Silvopasture Systems and Climate change: Estimate and prediction of Arboreal Biomass

Sistemas Silvopastoriles y Cambio climático: Estimación y predicción de Biomasa Arbórea

Edwin Rolando Jiménez Ruíz*[1], William Fonseca González[2] and Leticia Pazmiño Pesantez[1]

[1] *Faculty of Life Sciences, Escuela Superior Politécnica del Litoral Campus Gustavo Galindo, Guayaquil, Ecuador.*
[2] *Research Institute and Forestry Services, Universidad Nacional Autónoma de Costa Rica, Heredia, Costa Rica.*

*Corresponding author: ejimenez@espol.edu.ec

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Resumen

En este trabajo se cuantificó la biomasa y el carbono almacenado en la cobertura vegetal de un sistema silvopastoril compuesto por pasto (*Hyparrhenia rufa*) y guasmo (*Guazuma ulmifolia*) establecido en forma natural en el cantón Balzar de la provincia Guayas en Ecuador. A través del método destructivo y con un muestreo aleatorio por medio de parcelas anidadas, se evaluó la cantidad de biomasa arbórea y subterránea de árboles de diámetro promedio, la necromasa y la vegetación herbácea. Se desarrollaron modelos para estimar la biomasa del árbol completo, sus componentes (tronco, raíz, ramas y hojas) y el volumen. La biomasa arbórea es de $16,45\ Mgha^{-1}$ ($8,23\ MgC\ ha^{-1}$) y el aporte de la vegetación herbácea y la necromasa de $1,4$ y $1,9\ Mgha^{-1}$ ($0,7$ y $0,95\ MgC\ ha^{-1}$), respectivamente. Los modelos predicen la biomasa y el volumen en función del diámetro con errores de estimación o sesgos menores al 3% y mostraron ajustes (R^2) mayores a 96%. Adicionalmente, se generó información sobre factores de expansión de biomasa.
Palabras clave: Biomasa, carbono, Guazuma, mitigación, alometría.

Abstract

In this work both the biomass and carbon present in a vegetative cover from a silvopastoral system were quantified. The system, composed of *Hyparrhenia rufa* and *Guazuma ulmifolia*, was established naturally in Balzar, Guayas province of Ecuador. By using a destructive method and a random sampling in nested plots both the arboreous and underground biomass of average-sized trees were measured as well as the necromass and herbaceous vegetation. Models were developed in order to estimate the volume and the biomass of the whole tree and its components (trunk, roots, branches and leaves). The arboreous biomass was estimated in 16.45 Mg/ha (8.23 MgC/ha), whereas the herbaceous vegetation and the necromass were 1.4 and 1.9 Mg/ha (0.7 and 0.95 MgC/ha), respectively. The models predict

the biomass and the volume in dependence of the diameter with less than 3% of error and R^2 values higher than 96%. In addition, information regarding factors that influence the expansion of biomass were generated.
Keywords: Biomass, carbon, Guazuma, mitigation, allometric.

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Orcid IDs:
Edwin Rolando Jiménez Ruíz: http://orcid.org/0000-0001-7930-1081
William Fonseca González: http://orcid.org/0000-0002-4546-9035
Leticia Pazmiño Pesantez: http://orcid.org/0000-0001-7045-8445

1 Introduction

Climate change of anthropic origin has been a highly discussed topic in world-wide forums, and there are abundant studies that refer to this problem (IPCC, 2013; Herrán, 2012). The most polluting emission categories are energy, industrial processes and the use of by-products (MINAE-IMN, 2014). Additionally, the agricultural sector is another important factor since it is known that deforestation and degradation of tropical forests generates between 15 and 35% of the global emissions (Houghton, 2005). The agricultural sector is highly emitter by the consumption of fertilizers, anaerobic decomposition and the release of methane (CH_4) as the case of rice (MINAE-IMN, 2014), or the release of CH_4 generated by livestock (Agarwal et al., 2008). Methane is a greenhouse gas with a high radioactive forcing value 23 times higher than that of CO_2 (Agarwal et al., 2008). Grasslands, associated with livestock, occupy 41% of the land surface and contribute to 18% of the climate change (9% of CO_2 emissions, 37% of methane emissions and 65% of nitrous oxide (Steinfeld et al., 2006).

Worldwide, it is estimated that there are some 3442 billion of hectares with pastures (FAO, 2007), of which 516 million may be covered by agroforestry systems (Nair, Mohan, and Nair, 2009). Cattle breeding is one of the main uses of land in Latin America and in general tropical regions, it is characterized by low levels of productivity and profitability, and is responsible for significant increases in deforestation rates, accompanied by degradation processes of the soil, fragmentation of landscapes, losses of biodiversity, scarcity of water and reduction of the income level (Quero Carrillo, Enríquez Quiroz, and Miranda Jiménez, 2007). The agricultural sector and especially the silvopastoral systems are recognized worldwide for their multiple benefits, as for their meat and milk products for the human consumption, wood products (wood for sawmill and firewood), their trees that provide shelter and food for the wildlife (Alonso, 2011), as they contribute to reversing grassland degradation processes because they protect the soil, contribute to fertility recovery (Nair, Kumar and Nair, 2009), are carbon dioxide (CO_2) fixatives in biomass (Ibrahim et al., 2007; Bacab et al., 2013) and improve the quality and quantity of water resources (Nair, Mohan, and Nair, 2009).

From the point of view of climate change, these are considered a threat to the release of methane product of the excreta of domestic animals (Steinfeld et al., 2006; Agarwal et al., 2008). In Central America and around the world, there are extensive pasture areas with a high potential to contribute to climate change mitigation if managed under silvopastoral systems (Nair, Mohan, and Nair, 2009; FAO, 2010). There is scientific information that recognizes the mitigation potential of agricultural and livestock systems (FAO, 2010) and the topic is discussed under the United Nations Framework Convention on Climate Change (Murphy and Boyle, 2012).

There are silvopastoral systems of *Hyparrhenia rufa* with *Guazuma ulmifolia* and *Samanea saman*. *A G. ulmifolia* in the semi-arid zones of the province of Guayas in Ecuador, which are attributed a wide variety of uses: production of fodder and fruits for cattle, fruits for wild fauna, valuable nectar for the production of high quality honey, good quality of firewood, fruit, leaf, bark, root and flower with medicinal properties and multiple restorative effects (Villa Herrera et al., 2009).

Therefore, the aim of this study is to quantify the climate change mitigation capacity of silvopastoral systems with *G. ulmifolia*, evaluating the amount of tree biomass and under the soil to develop biomass models. Additionally, information was generated on biomass expansion factors and biomass increments that are basic elements for carbon monitoring.

2 Materials and methods

2.1 Area of study

The field work was developed at El Diamante farm, located in the canton Balzar, Guayas Province, Ecuador, at 52 masl with 26°C of annual average and an average precipitation of 834.7 to 1183.7 mm (INAMHI, 2014). The property has an area of 265 hectares, mostly destined for cattle breeding. The soil cover is composed by the combination of *Samanea saman + Hyparrhenia rufa* and Guazuma ulmifolia + H. rufa. *Guazuma ulmifolia* is part of the silvopastoral system since the year 2000, when the owner of the farm decided to protect the regeneration of this species to be used as fodder. The area with Samanea is also the result of a natural regeneration, after a forest fire in 1996. The distance between individuals is irregular in both species.

Table 1. Location of sampling units in the study area.

GRID	UTM	
DATUM	WGS 84	
Description	***Position***	
UPM 4 Guazuma ulmifolia - H. rufa	17 M 615376	9849155
UPM 5 Guazuma ulmifolia - H. rufa	17 M 615280	9848718
UPM 6 Guazuma ulmifolia - H. rufa	17 M 615695	9848589

2.2 Biomass assessment of *G. ulmifolia* and *Hyparrhenia rufa*

Three circular sampling units of 1000 m^2 (17.84 m radius), were installed randomly in each area, and the diameter was measured at 1.3 m above the ground level (DAP) of each of the trees, and the height of the commercial and total stem with a hypsometer Haga (50 trees on average). The plot was divided into quadrants to sample different tree sizes: Iin the complete unit were measured those which presented a DAP > 4.8 cm, in 250 m^2 individuals between 1.6 and 4.7 cm and a subplot of 25 m^2 shrubs between 0.6 and 1.5 cm. *Hyparrhenia rufa* and the mass were evaluated in units of 0.5 m^2. The location of each sampling unit is presented in Table 1. Smalian formula as used to calculate the volume (Prodan et al., 1997).

The average tree was extracted per plot (MacDicken, 1997) in order to calculate the biomass of leaves, branches and roots, and the weight (kg) of each component was determined in the field. The roots, mainly the anchorage, were extracted with a backhoe, and wet samples of approximately 1.0 kg were collected. For the trunk, three samples were taken (from the basal, central and apical) and mixed to obtain a compound. This material was taken to the laboratory and dried in an oven at $75°C$ until a constant weight was obtained. The dry biomass of each component was obtained from the ratio "dry weight/wet weight".

The biomass expansion factor for leaves, branches and roots was calculated with the dry biomass of each component. In order to increase the size of the sample for this calculation, information from the same species was used, generated under the same methodology by the project "Management of climate change through the forestry sector in Costa Rica", developed by the National University of Costa Rica. This factor relates the biomass of each component to that of the stem, and it was used to calculate the total biomass of the trees measured stand. The dry biomass was passed to carbon using the 0.5 conversion factor (IPCC, 2013).

2.3 Adjustment of allometric models

The models were adjusted using the ordinary least squares method with the statistical program Statgraphics Centurion XV. Approximately 20 models were tested to estimate the biomass of each component of the tree (leaves, branches, stem, root), for the complete individual and for the volume. The diametric range used comprised individuals from 3.8 to 30.2 cm.

In all models, the dependent variable was biomass or volume and the independent variable was the diameter. The selection of the best-fit equation was based on the methodology presented by Salas, (2002) and by Segura and Andrade Castañeda, (2008). The assumptions of normality and homoscedasticity were tested by means of the graphical residual analysis of the model. Additionally, the estimated values were plotted compared to those observed to see if the models overestimate or underestimate the calculation of the biomass or volume. Also, the biological behavior of the models was observed by graphic method. The validation of the equations was carried out as described by Moret and Ruiz, (1998) and Barrales, Peña, and Reguera, (2004).

3 Results and discussion

3.1 Accumulation of the biomass and carbon

The amount of biomass accumulated (C fixed) in agrosilvopastoral systems depends on multiple interactions between the components tree, pasture, soil and animal (Shibu, 2009). In forest systems, the carbon accumulates in four components (biomass above the soil, mass, root systems and organic carbon of the soil), and the woody biomass represents the carbon with more permanence (Snowdon et al., 2001) and the largest storage at tree level.

In this study, the total biomass was 19.75 Mg ha^{-1} (9.8 Mg C), and according to the sampling Guazuma ulmifolia trees accumulated 83% (16.45 Mg ha^{-1}; 8.23 Mg C ha^{-1}), while the contribution of mass and pasture was 1.4 and 1.9 Mg ha^{-1} (0.7 and 0.95 Mg C ha^{-1}), with average increments of 1.08 Mg ha^{-1} yr^{-1} and 0.55 Mg ha^{-1} yr^{-1}, respectively. The arboreal component consists of an average of 497 trees ha^{-1}, distributed in a diameter amplitude of 3.8 to 30.2 cm.

These reserves of biomass and/or carbon are compared to those existing in other latitudes in deciduous forests, for example, in silvopastoral systems in the dry tropics of Costa Rica, the native timber species *Dalbergia retusa, Dyphisa robinioides* and *Pithecellobium saman* at the aerial arboreal biomass set annually 0.2; 1.25 and 0.26 Mg C ha^{-1}, respectively (Rojas, Ibrahim, and Andrade, 2009). In Mexico, in areas of dry climate have been reported average values of tree biomass in pasture of 13 Mg ha^{-1} (Hughes Flint, Kauffman Boone, and Jaramillo, 2000) and 5.9 to 7.7 Mg ha^{-1} ("Biomass, carbon, and nitrogen pools in Mexican tropical dry forest landscapes"). Torres Rivera et al., (2011) report for a silvopastoral system with low density of the arboreal component (120 trees ha^{-1}) an accumulation of 2.86 Mg C ha^{-1} at three years. Chará et al., (2009) in Colombia, with the implementation of silvopastoral systems indicate increases in stored C of 0.51 Mg ha^{-1} year^{-1} and in Costa Rica at four years and three months 12.5 Mg C ha^{-1} (Andrade, Brook, and Ibrahim, 2008). Also in wooded paddocks without a defined age (Chacón León and Alice Harvey, 2013) for Costa Rica (Esparza) and Nicaragua (Mitiguás) indicate an average biomass of 10.7 Mg ha^{-1} with variations between 5.3 and 13.5 Mg ha^{-1}. Ibrahim et al., (2007) for these same areas mention figures from 3.2 to 14.2 Mg ha^{-1} in trees scattered in pastures in Esparza, and from 9 to 17.9 Mg ha^{-1} in Matiguás.

In Nicaragua, Ruiz, (2002) found carbon content of 8.2 $\pm$ 3.0 Mg C ha^{-1} in native pastures with trees (100 trees ha^{-1}), and in improved pastures with trees (110 trees ha^{-1}) of 12.5 $\pm$ 3.6 Mg ha^{-1}; while in the Colombian Andes the aerial biomass of Acacia decurrens in silvopastoral system with abundances of 1111 and 407 trees ha^{-1}, showed an annual increase of 9.9 and 11.2 Mg C ha^{-1} (Giraldo, Zapata, and Montoya, 2008).

In the arboreal component, the root accumulated 18% of the total biomass (2.96 Mg ha^{-1}) and the woody components -root, stem and branches- 95% (15.63 Mg ha^{-1}), similar to that quoted by Anguiano, Aguirre, and Palma, (2013) who report figures between 85 and 98% including leaves. The aerial biomass of the trees was 13.49 Mg ha^{-1}. The trunk represents 47.4% of the tree biomass and 57.7% of the aerial biomass, a value that is consistent with what was found by Gómez et al., (2010) for *Gliricidia sepium* (60.9%) and *Leucaena leucpcehala* (58.3%).

The biomass (C) determined in this study is also similar to that reported in agroforestry systems in Changuinola, Panamá, in cocoa sown at 3×3 m plus bay at 6×6 m and 12×12 m; the carbon stored in 25 years varied between 43-62 Mg C ha^{-1}, whose annual increase was 1.7 and 2.5 Mg C ha^{-1} (Ortiz, Riascos, and Somarriba, 2008). According to Umaña and Conde, (2013), in Tolima, Colombia, in agroforestry systems of avocado + plantain, cocoa + avocado and cocoa + plantain, the annual carbon fixation was 2.23; 4.14 and 0.52 Mg, respectively.

The root in the arboreal component, although it represents a carbon of higher permanence, it has been little studied because it is attributed to a high difficulty degree (Dixon, 1995; Schlegel, 2001), despite representing between 10 and 40% of the total biomass (Cairns et al., 1997; MacDicken, 1997; Andrade and Ibrahim, 2003). In this study, the root accumulates 18% of the tree biomass. Quantifying radical biomass is an effort to be recognized in this study because of the low availability of existing information for species diversity. Using general values instead of local and species-specific information can generate very vague calculations.

It should bear in mind that although the amount of biomass or carbon determined in this study is similar or in the range of what is reported in the literature, there will always be differences influenced by the diversity of spatial arrangements of the silvopastoral systems, species diversity and methodological variations to quantify the biomass.

3.2 Models of biomass, volume and expansion factors

The models to estimate the biomass of the different tree components and for the total biomass presented very good adjustments ($R^2 > 96$, with $P < 0.0001$) and very low values for the other statisticians. It is important to highlight that the prediction error does not exceed 3.1% (Table 2, Figure 1 and 2). In addition, they are very simple and practical models that show little difficulty degree in calculating the biomass by using only the diameter as a regressive variable. Similar adjustment characteristics (prediction) with tree models have been achieved in silvopastoral systems, whose architecture is different from that of trees in pure plantation and natural forest, for example, for scattered trees of *Freziera canescens* Cabrera et al., (2007) obtained an adjustment of $R^2 = 89.61$ to estimate aerial biomass as a function of DAP, and lower adjustment 71.81; 87.60; 87.57, when height, volume and basal area, respectively were used as independent variable. Gómez et al., (2010) achieved lower adjustments for *Gliricidia sepium* (R^2 between 75 and 86), and 61 to 87% in *Leucaena leucocephala*.

It is surprising the good aadjustment for branches and leaves, components that in other investigations have a lower adjustment as reported by Fonseca, Alice, and Rey, (2009) for species in secondary forest (83.04% in leaves, 88.25% in root), for *Vochysia guatemalenis* (89.05% in leaves) and *Hieronyma alchorneoides* (89.69% in root), or R^2 above 70%, with estimation errors exceeding 25% (Fonseca et al., 2016). Low correlations between the biomass of leaves and branches with the diameter were also reported by Montero and Kanninen, (2002), Návar, González, and Graciano, (2011) and Pérez and Kanninen, (2003).

The model chosen to estimate the total volume of the stem has the same characteristics of the models for the biomass (Table 2, Figure 1 and 2). The goodness of the adjustment achieved ($R^2 = 96.2\%$) is equal to or greater than the one obtained for other species (Da Cunha and Guimarães Finger, 2009; Barrios, López, and Nieto, 2014; Ramos et al., 2014).

The leaf biomass expansion factor was 0.1 ($S = 0.03$), 0.66 ($S = 0.15$) for branches and 0.39 ($S = 0.10$) in root, values that are in the range reported in different studies with different species and for other latitudes (Fonseca, Alice, and Rey, 2009; Schlegel, 2001; Segura et al., 2000).

Table 2. Models for estimating the biomass and the volume of the stem. The sample size was 148 in all cases. All models have $P < 0,0001$ confidence.

Model	R^2 (%)	EEE	EMA	DW	ECM	DA	E (%)	AIC
$Btotal = (-0.180763 + 58.812 * DAP)^2$	96.21	0.6038	0.4438	0.656768 ($P = 0.0000$)	9.971	0.351	2.909	2.308
$Bstem = (-0.124328 + 40.4522 * DAP)^2$	96.22	0.4152	0.3053	0.656758 ($P = 0.0000$)	4.717	0.166	2.909	1.564
$Bbranches = (-0.0984273 + 32.0264 * DAP)^2$	96.22	0.3287	0.2417	0.656857 ($P = 0.0000$)	2.957	0.104	2.909	1.1
$Broot = (-0.0770575 + 25.0645 * DAP)^2$	96.22	0.2573	0.1892	0.656732 ($P = 0.0000$)	1.81	0.06	2.909	0.614
$Bleaves = (-0.0399297 + 12.983 * DAP)^2$	96.22	0.1333	0.098	0.656575 ($P = 0.0000$)	0.486	0.017	2.907	-0.683
$Vol = (-0.00532694 + 1.80282 * DAP)^2$	96.24	0.0184	0.0134	0.682172 ($P = 0.0000$)	0.009	0	3.107	-4.408

Btotal: total tree biomass (kg); *Bfuste*: stem biomass (kg); *Bramas*: branch biomass (kg); *Braz*: root biomass (kg); *Bhojas*: leaves biomass (kg); *DAP*: normal diameter (m); *Vol*: volume (m^3); R^2: determination coefficient; *EEE*: standard stimation error; *EMA*: absolute mean error; *ECM*: mean cuadratic error; *DA*: added difference; $E(\%)$: prediction error of the model; *AIC*: Akaike index.

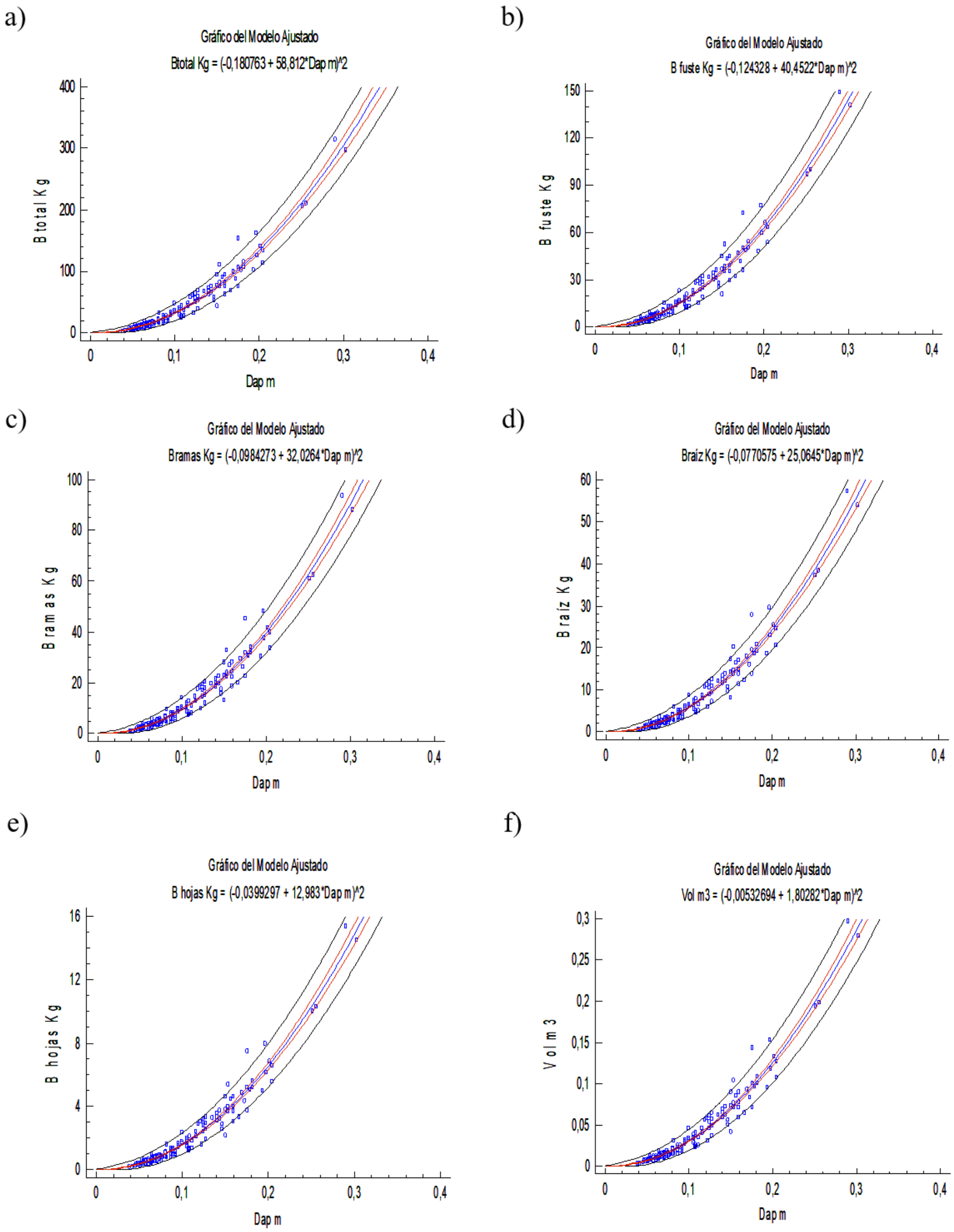

Figure 1. Models for estimating biomass and volume. a)total biomass, b) stem biomass, c) branch biomass, d) root biomass, e) leaf biomass, f) stem volume.

4 Conclusions

Silvopastoral systems represent a significant contribution to climate change mitigation, a benefit that can be increased by introducing management techniques.

The equations to estimate the biomass and the volume of the trees help to reduce the cost of carbon inventories for those organizations that are in the process of seeking carbon neutrality or for the definition of policies at the national level. The use of diameter as a predictor variable facilitates its applica-

tion and reduces estimation errors, in addition, the prediction capacity of these models ($R^2 > 96\%$) and the low estimation error ($E < 3\%$) provide a lot of reliability in the estimates.
Quantifying radical biomass is an effort to be recognized in this study because of the low availability of existing information for species diversity. The use of general values can generate calculations with inaccuracies instead of local and specific information by species.

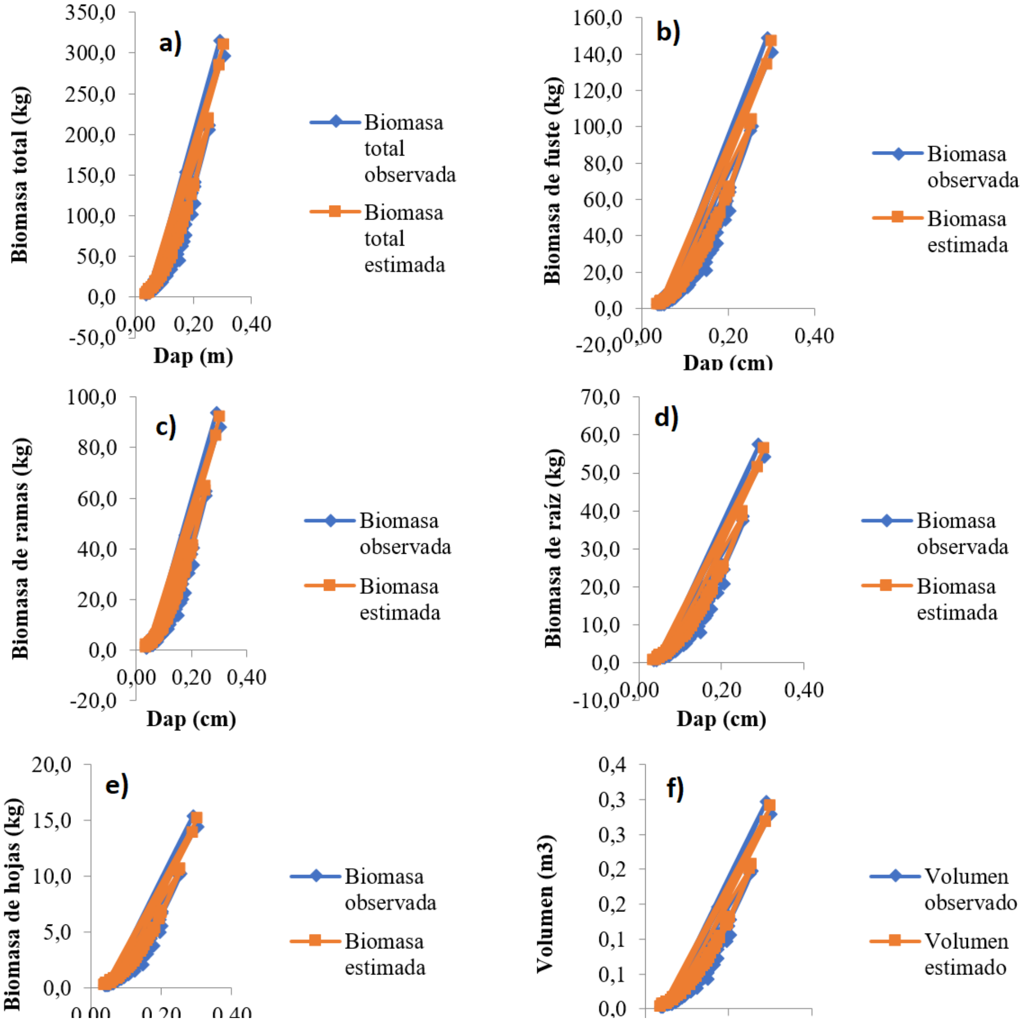

Figure 2. Estimation of biomass and volume from the diameter: a) total biomass [$Btotal = (-0.180763 + 58.812 * DAP)^2$], b) stem biomass [$Bstem = (-0.124328 + 40.4522 * DAP)^2$], c) branch biomass [$Bbranches = (-0.0984273 + 32.0264 * DAP)^2$], d) root biomass [$Broot = (-0.0770575 + 25.0645 * DAP)^2$], e) leaves biomass [$Bleaves = (-0.0399297 + 12.983 * DAP)^2$], f) stem volume [$Vol = (-0.00532694 + 1.80282 * DAP)^2$].

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References

Agarwal, Neeta et al. (2008). "In vitro methanogenesis, microbial profile and fermentation of green forages with buffalo rumen liquor as influenced by 2-bromoethanesulphonic acid". In: *Asian-Australasian Journal of Animal Sciences* 21.6, 818–823. Online:https://bit.ly/2tDmkEU.

Alonso, J. (2011). "Los sistemas silvopastoriles y su contribución al medio ambiente". In: *Revista Cubana de Ciencia Agrícola* 45.2, 107–115. Online: https://bit.ly/2T4G8jF.

Andrade, Hernán J., Robert Brook, and Muhammad Ibrahim (2008). "Growth, production and carbon sequestration of silvopastoral systems with native timber species in the dry lowlands of Costa Rica". In: *Plant and Soil* 308.1-2, 11–22. Online:https://bit.ly/2GTKQdN.

Andrade, Hernán and Muhammad Ibrahim (2003). "¿ Cómo monitorear el secuestro de carbono en los sistemas silvopastoriles?" In: *Agroforestería en las Américas* 10.39-40, 109–116. Online:https://bit.ly/2XBlWoi.

Anguiano, J. M., J. Aguirre, and J. M. Palma (2013). "Secuestro de carbono en la biomasa aérea de un sisema agrosilvopastoril de Cocos nucifera, Leucaena leucocephala Var. Cunningham y Pennisetum purpureaum. Cuba CT-115". In: 17.1, 149–160. Online:https://bit.ly/2SzC71K.

Bacab, H. M. et al. (2013). "Los sistemas silvopastoriles intensivos con Leucaena leucocephala: una opción para la ganadería tropical". In: *Avances en Investigación Agropecuaria* 17.3, 67–81. Online:https://bit.ly/2Nydtxj.

Barrales, V., R. Peña, and Pedro Fernández de la Reguera (2004). "Validación de modelos: un enfoque aplicado". In: *Agricultura técnica* 64.1, 66–73. Online:https://bit.ly/2UcqCPo.

Barrios, Alonso, Ana M. López, and Víctor Nieto (2014). "Predicción de volúmenes comerciales de Eucalyptus grandis a través de modelos de volumen total y de razón". In: *Colombia forestal* 17.2, 137–149. Online:https://bit.ly/2H68aUT.

Cabrera, G. et al. (2007). "Estimación de la biomasa aérea y captura de carbono en árboles dispersos en potreros con motilon silvestre (Freziera canescens) en el Municipio de Pasto Nariño – Colombia". In: *Revista de Ciencias Agrícolas* 24.12, 46–55. Online: https://bit.ly/2NAtO4S.

Cairns, Michael A. et al. (1997). "Root biomass allocation in the world's upland forests". In: *Oecologia* 111.1, 1–11. Online:https://bit.ly/2EAKpm6.

Chacón León, Mario and Celia Alice Harvey (2013). "Reservas de biomasa de árboles dispersos en potreros y mitigación al cambio climático". In: *Agronomía Mesoamericana* 24.1, 17–26. Online:https://bit.ly/2BPXXsb.

Chará, J. et al. (2009). *Evaluación ambiental del proyecto de ganadería colombiana sostenible*.

Da Cunha, Thiago Augusto and César Augusto Guimarães Finger (2009). "Modelo de regresión para estimar el volumen total con corteza de árboles de Pinus taeda L. en el sur de Brasil". In: *Revista Forestal Mesoamericana Kurú* 6.16, 1–15. Online:https://bit.ly/2XBpbMu.

Dixon, Robert K. (1995). "Sistemas agroforestales y gases invernadero". In: 2.7, 22–26. Online:https://bit.ly/2GPFY99.

FAO (2010). *Challenges and opportunities for carbon sequestration in grassland systems. A technical report on grassland management and climate change mitigation.* ntegrated Crop Management 9. Roma, Italia. Online: https://bit.ly/1ElclQJ: Food and Agriculture Organization of the United Nations.

FAO, Food and Agriculture Organization of the United Nations (2007). *State of the world's forests 2007*. FAO.

Fonseca, W. et al. (2016). *Construcción de Funciones Alométricas para Costa Rica en el Contexto del Proyecto de Protección Ambiental a través de la Protección de los Bosques de Centro América (Informe final)*. Tech. rep. Online:https://bit.ly/2VnJcE7: Cooperación Internacional entre la Universidad Nacional y la Agencia de Cooperación Alemana (GIZ), 1–30. Online:

Fonseca, William, Federico Alice, and José María Rey (2009). "Modelos para estimar la biomasa de especies nativas en plantaciones y bosques secundarios en la zona Caribe de Costa Rica". In: *Bosque (Valdivia)* 30.1, 36–47. Online:https://bit.ly/2H6zGRW.

Giraldo, A., M. Zapata, and E. Montoya (2008). "Captura y flujo de carbono en un sistema silvopastoril de la zona Andina Colombiana". In: *Archivos Latinoamericanos de Producción Animal* 16.4, 241–245. Online:https://bit.ly/2Nvrege.

Gómez, H. et al. (2010). "Estimaciones de biomasa aérea y carbono almacenado en Gliricidia sepium (lam.) y Leucaena leucocephala (jacq.) y su aplicación en sistemas silvopastoriles." In:

Información Técnica Económica Agraria 106.4, 256–270. online: https://bit.ly/2H7CLBg.

Herrán, Claudia (2012). *El cambio climático y sus consecuencias para Amércia Latina*. Online:https://bit.ly/1zLUkwX: Friedrch-Ebert-Stiftung.

Houghton, Richard A. (2005). "Tropical deforestation as a source of greenhouse gas emissions". In: *Tropical deforestation and climate change* 13, 13–20. Online:https://bit.ly/2T1TeOG.

Hughes Flint, R., J. Kauffman Boone, and Víctor J. Jaramillo (2000). "Ecosystem-scale impacts of deforestation and land use in a humid tropical region of Mexico". In: *Ecological Applications* 10.2, 515–527. Online:https://bit.ly/2H5wENV.

INAMHI (2014). *Anuario Meteorológico. Nro. 51-2011*. Tech. rep. Quito, Ecuador. Online: https://bit.ly/2EjXfE1: Instituto Nacional de Meteorología e Hidrología,

IPCC (2013). *Cambio climático 2013: bases físicas. Contribución del Grupo de trabajo I al Quinto Informe de Evaluación del Grupo Intergubernamental de Expertos sobre el Cambio Climático*. Resumen para responsables de políticas. públicas. Online: https://bit.ly/2q1RItV: Panel Intergubernamental de Expertos sobre Cambio Climático.

Ibrahim, M. et al. (2007). "Almacenamiento de carbono en el suelo y la biomasa arbórea en sistemas de usos de la tierra en paisajes ganaderos de Colombia, Costa Rica y Nicaragua". In: *Agroforestería en las Américas* 45, 27–36. Online: https://bit.ly/2T7wo8q.

Jaramillo, Víctor J. et al. "Biomass, carbon, and nitrogen pools in Mexican tropical dry forest landscapes". In:

MINAE-IMN (2014). *Tercera comunicación nacional-Convención Marco de las Naciones Unidas sobre cambio climático.* Tech. rep. San José, Costa Rica. Online: ttps://unfccc.int/resource/docs/natc/crinc3.pdf: Ministerio del Ambiente y Energía-Instituto Meteorológico Nacional.

MacDicken, Kenneth G. (1997). "A guide to monitoring carbon storage in forestry and agroforestry projects". In: *Forest Carbon Monitoring Program*, 87. Online:https://bit.ly/2SuBoP9.

Montero, Marcelino and Markku Kanninen (2002). "Biomasa y Carbono en plantaciones de Terminalia amazonia en la zona sur de Costa Rica." In: *Recursos Naturales y Ambiente* 39-40. Online:https://bit.ly/2VpNATb.

Moret, A. Y. and P. Ruiz (1998). "Determinacion de ecuaciones de volumen para Mureillo (Erisma uncinatum) en la Unidad C4 de la Reserva Forestal Imataca, Bolivar-Venezuela." In: *Revista Forestal Venezolana* 42.2, 187–197. Online:https://bit.ly/2H68G54.

Murphy, D. and J. Boyle (2012). *Agriculture and Climate Change: post-Durban issues for negotiators. IISD Food Security and Climate Change Initiative*. Tech. rep. Online:https://bit.ly/2UaXHv5: International Institute for Sustainable Development (IISD), p. 13.

Nair, P. K., Kumar B. Mohan, and V. D. Nair (2009). "Agroforestry as a strategy for carbon sequestration". In: *Journal of plant nutrition and soil science* 172.1, 10–23. Online:https://bit.ly/2XsTIfp.

Návar, J., N. González, and J. Graciano (2011). "Ecuaciones para estimar componentes de biomasa en plantaciones forestales de Durango, México." In: *Simposio Internacional Medición y Monitoreo de la Captura de Carbono en Ecosistemas Forestales*. Valdivia. Online: https://bit.ly/2Vqt98u.

Ortiz, Ángela, Lorena Riascos, and Eduardo Somarriba (2008). "Almacenamiento y tasas de fijación de biomasa y carbono en sistemas agroforestales de cacao (Theobroma cacao) y laurel (Cordia alliodora)". In: *Agroforestería en las Américas* 46, 26–29. Online:https://bit.ly/2VugBgJ.

Prodan, M. et al. (1997). *Mensura forestal.(CATIE: Série Investigación y Educación en Desarrollo Sostenible)*. Tech. rep. Online:https://bit.ly/2BRlwR9: IICA-BMZ-GTZ.

Pérez, D. and M. Kanninen (2003). "Aboveground biomass of Tectona grandis plantations in Costa Rica". In: *Journal of Tropical Forest Science* 15.1, 199–213. Online: https://bit.ly/2ElNF3l.

Quero Carrillo, Adrián Raymundo, Javier Francisco Enríquez Quiroz, and Leonor Miranda Jiménez (2007). "Evaluación de especies forrajeras en América tropical, avances o status quo". In: *Interciencia* 32.8, 566–571. Online:https://bit.ly/2XundNB.

Ramos, José A. et al. (2014). "Ecuaciones y tablas de volumen para dos especies de Pinus de la Sierra Purhépecha, Michoacán". In: *Revista mexicana de ciencias forestales* 5.23, 92–109. Online:https://bit.ly/2EAyWD8.

Rojas, Jairo, Muhammad Ibrahim, and Hernán J. Andrade (2009). "Secuestro de carbono y uso de agua en sistemas silvopastoriles con especies maderables nativas en el trópico seco de Costa

Rica". In: *Ciencia y Tecnología Agropecuaria* 10.2, 214–223. Online:https://bit.ly/2Svm84r.

Ruiz, A. (2002). *Fijación y almacenamiento de carbono en sistemas silvopastoriles y competitividad económica en Matiguás, Nicaragua*. Tech. rep. Online:https : / / bit . ly / 2Ie8mCa: Centro Agronómico Tropical de Investigacion y Enseñanza.

Salas, E. C. (2002). "Ajuste y validación de ecuaciones de volumen para un relicto del bosque de Roble-Laurel-Lingue". In: *Bosque* 23.2, 81–92. Online:https://bit.ly/2VnEs1p.

Schlegel, Bastienne (2001). "Estimación de la Biomasa y Carbono en Bosques del Tipo Forestal Siempreverde". In: *Valdivia*, Online:https://bit.ly/2Xse0FS.

Segura, M. and Hernán J. Andrade Castañeda (2008). "¿Cómo construir modelos alométricos de volumen, biomasa o carbono de especies leñosas perennes?" In: *Agroforestería en las Américas* 46, 89–96. Online:https://bit.ly/2Ub1clb.

Segura, Milena et al. (2000). "Almacenamiento y fijación de carbono en bosques de bajura de la zona atlántica de Costa Rica". In: *Revista Forestal Centroamericana (CATIE)* 30, 23–28. Online:https://bit.ly/2U69Tgq.

Shibu, Jose (2009). "Agroforestry for ecosystem services and environmental benefits: an overview". In: *Agroforestry systems* 76.1, 1–10. Online:https://bit.ly/2GP7dB2.

Snowdon, P. et al. (2001). *Protocol for sampling tree and stand biomass.* Tech. rep. 31. doi 10.13140/RG.2.1.2825.8967. National Carbon Accounting System, Australian Greenhouse Office.

Steinfeld, Henning et al. (2006). *Livestock's long shadow: environmental issues and options*. Online:https://bit.ly/1gUpXqK: Food & Agriculture Org.

Torres Rivera, José Antonio et al. (2011). "Secuestro de carbono en potreros arbolados, potreros sin árboles y bosque caducifolio de Huatusco, Veracruz". In: *Tropical and Subtropical Agroecosystems* 13.3, 543–549. Online:https://bit.ly/2EgDugx.

Umaña, J.A and A. Conde (2013). "Huella de carbono en los sistemas de producción agrícola dominantes en el municipio de Falan, Tolima." In: *Revista Ciencia Animal* 6, 11–27. Online: https://bit.ly/2NC07jW.

Villa Herrera, Adán et al. (2009). "Utilización del guácimo (Guazuma ulmifolia Lam.) como fuente de forraje en la ganadería bovina extensiva del trópico mexicano". In: *Tropical and Subtropical Agroecosystems* 10.2, 253–261. Online:https://bit.ly/2Sysmkp.