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Carbon sequestration in the aerial biomass of a plantation of *Eucalyptus grandis* W. Hill

Secuestro de carbono en la biomasa aérea de una plantación de *Eucalyptus grandis* W. Hill

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ABSTRACT

Land use change and the burning of fossil fuels increase the concentrations of carbon dioxide in the environment. This gas is considered to have the greatest impact on global warming because of its concentration levels in the atmosphere. In order to determine the amount of carbon sequestered by the *Eucalyptus grandis* plantation located in the experimental farm "La Favorita", the biomass was quantified by means of the relation between fresh weight and percentage of dry matter of the shaft, bark, branches and leaves of a sample of 32 trees. The sequestered carbon was obtained by multiplying the biomass by the conversion factor of 0.5. The research was carried out with a sample of 0.8 ha in a 48-year plantation on the Ecuadorian coast. The average aerial carbon sequestered was 0.75 t / tree and 312.10 t / ha. The 81.20 % of carbon sequestered in the aerial biomass of the plantation is found in the shaft, 7.57 % in bark, 8.87 % in branches and 2.36 % in leaves. The alometric equation derived from the combination of the variables diameter at 1.30 m and total height (Di2ht), showed 98 % adjustment for the prediction of carbon of the plantation. These results show the high potential of the of *Eucalyptus grandis* plantations as carbon sinks and as an alternative for mitigation and adaptation to climate change. The values of sequestered carbon are higher than other plantations of the same species.

Keywords: global warming; mitigation; adaptation; climate change; alometric equation.

RESUMEN

El cambio de uso de suelo y la quema de combustibles fósiles incrementan las concentraciones de dióxido de carbono en el ambiente. Este gas es considerado como el de mayor impacto sobre el calentamiento global por sus niveles de concentración en la atmósfera. Con el objetivo de determinar la cantidad de carbono secuestrado por la plantación de *Eucalyptus grandis* ubicada en la granja experimental «La Favorita», se cuantificó la biomasa mediante la relación entre peso fresco y porcentaje de materia seca del fuste, corteza, ramas y hojas de una muestra de 32 árboles. El carbono secuestrado se obtuvo con la multiplicación de la biomasa por el factor de conversión de 0,5. La investigación se realizó con una muestra de 0,8 ha en una plantación de 48 años, de la costa ecuatoriana. El promedio de carbono aéreo secuestrado fue de 0,75 t/árbol y 312,10 t/ha. El 81,20 % deL carbono secuestrado en la biomasa aérea de la plantación se encuentra en el fuste, el 7,57 % en cortezas, el 8,87 % en ramas y el 2,36 % en hojas. La ecuación alométrica derivada a partir de la combinación de las variables diámetro a 1,30 m y altura total (Di^2ht), mostró el 98 % de ajuste para la predicción de carbono de la plantación. Estos resultados muestran el alto potencial de las plantaciones de *Eucalyptus grandis* como sumideros de carbono y como una alternativa de mitigación y adaptación al cambio climático. Los valores de carbono secuestrado son superiores a otras plantaciones de la misma especie.

Palabras clave: calentamiento global; mitigación; adaptación; cambio climático; ecuación alométrica.

INTRODUCTION

Global warming due to the concentration of Greenhouse Gases (GHG) in the atmosphere is a proven phenomenon in Molina, Sarukhan and Carabias (2017). The burning of fossil fuels, the change in land use and deforestation produce an increase in carbon dioxide (CO2) in the environment, which together with the presence of GHGs such as methane (CH4), nitrous oxide (NO2) and chlorofluorocarbons (CFCs), naturally non-existent in the atmosphere Lopez and others (2016), ratify the impact of anthropogenic activities on the climatic variation of the planet.

Forest ecosystems constitute one of the main carbon sinks of the planet Yepes and others (2015). By sequestering carbon in their biomass and reducing the pressure on native forests for wood, forest plantations are an alternative to mitigate climate change López *et al.,* (2016). The amount of carbon sequestered by the ecosystem will depend on the species, age, management, climate and soil Somarriba *et al.,* (2013).

Despite the importance of forest plantations in reducing carbon in the atmosphere, in Ecuador most of these are established only for timber production purposes (Ministry of Agriculture and Livestock, 2018).

cosystem services such as CO2 sequestration are linked and studied almost exclusively in Cadilhac and other natural formations (2017). Given the state's interest in reducing emissions from the forest sector equivalent to 25.35 % of the total emissions generated by the country (Ministry of the Environment of Ecuador, 2016), it is necessary to generate specific data on the contribution of forest plantations; all the more so considering that Ecuador is the first country to receive funds from the program of policies and positive incentives for reducing emissions due to deforestation and forest degradation (REDD+) (Ministry of the Environment of Ecuador, 2017).

Until 2014, commercial plantations in Ecuador covered an area of 132 072 ha (*Food and Agriculture Organization*, 2014), which supported 66.80 % of the country's legal timber production with 2 411 271.52 m^3 (Ministry of Environment of Ecuador, 2014a). The 42.41 % of these plantations were established in the coastal region with species of rapid growth, of which stand out for the surface they cover: Teca (*Tectona grandis* L.f.), Pachaco [*Schizolobium parahyba* (Vell.) S.F. Blake], and Eucalyptus (*Eucalyptus grandis* and *Eucalyptus "urograndis*"), respectively (Ministry of Agriculture, Livestock, Aquaculture and Fisheries, 2013).

Eucalyptus grandis plantations located in Colombia stored 239 t/ha of carbon at the age of seven, Martínez *et al.,* (2018), which represents more than double the carbon captured by the Amazon Evergreen Lowland Forest, which, according to Ecuador's first national forest assessment, is the natural ecosystem with the highest carbon capture rate with 108.69 t/ha, Ecuador's Ministry of Environment, (2014b). Despite the presence of the species in several plantations along the Ecuadorian coast and the potential for carbon sequestration, there are no data available to quantify this contribution in the country.

Therefore, the objective of this research was to determine the amount of carbon sequestered by the *Eucalyptus grandis* plantation located in the experimental farm "La Favorita".

MATERIALS AND METHODS

Characteristics of the study site

The research was carried out on an 8.03 ha plantation of *Eucalyptus grandis*, established in March 1970 on the experimental farm "La Favorita", owned by the Technical University of the North. It is located at 0°13' S latitude and 78°47' W longitude, in the Chiriboga sector, San José de Alluruquín parish, Santo Domingo canton, Santo Domingo de los Tsachilas province. The altitude of the farm ranges between 1 700 and 2 300 masl, with an average annual rainfall of 3 000 mm and an average temperature of 16 °C. The plantation was considered healthy according to the criteria of Murillo and Camacho (1997), despite not receiving silvicultural treatments at any stage of its development.

Forest Inventory

The inventory used a sampling intensity of 10 %, double that recommended by the Subsecretariat of Forest Production for plantations of this area (Ministry of Agriculture, Livestock, Aquaculture and Fisheries, 2017). Sixteen rectangular plots 20 m wide by 25 m long (500 m^2) were systematically established. For the location of the plots in the field, the coordinates from a grid superimposed on the plantation map were used. Within the plots diameter measurements were made at 1.30 m (Di) and total height (ht).

Quantification of biomass

For the quantification of biomass, two trees were felled in each sample unit in order to have 36 individuals, higher than that recommended by Pardé and Bouchon, (1988) for homogeneous coverages such as plantations smaller than 15 ha Picard, Saint-André and Henry, (2012). The selected trees were

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those that showed values of Di Y ht similar to the average of the plot Vélez and Arango, (2002). Once in the ground, the shaft was separated from the branches. This was cut into 5 m long sections, except for the first section which measured 4.70 m to compensate for the tree's cutting height. Finally, the average diameter of each section (with and without bark) was measured. To determine the volume of the shaft with and without bark, the Huber formula (equation 1) was applied to each Riaño and Lizarazo section (2017).

$$v=ð/4*Dm2*L \quad (1)$$

Where:
v=volume of the section (with and without bark).
Dm=diameter in the middle of the log (with and without bark).
L= section length (5 m).

Finally, the volume of the bark was obtained by the difference between the volume of the shaft with bark and without bark.

From each tree a 4 cm thick slice of the shaft was obtained, which was weighed in the field with and without bark (green weight). Each slice and its bark were packed and coded to be sent to the laboratory, where they were subjected to a constant temperature of 105 °C inside an oven. When they reached constant weights, they were recorded as dry weight. The biomass value of the slice and bark was obtained using equation 2, which is presented below. These values were extrapolated to the volume of the shaft to obtain the total amount of biomass of the components Segura and Andrade, (2008).

$$B=(Pf*Ms)/100 \quad (2)$$

Where:
B(kg)=biomass.
Pf= fresh weight (kg).
Ms= dry matter (%)

To determine the biomass of branches and leaves, a branch was selected that was bifurcated directly from the shaft and located in the center of the crown (in order to have an average value). The branch was divided into partial sections of 0.5 m and a slice of 1 cm thick was obtained, in order to obtain the biomass of the branch with the methodology used in the shaft. The foliage of the branch was weighed in the field and dried in an oven, equation 2 was applied and the value of the leaf biomass was obtained. Finally, the values obtained were multiplied by the number of branches and an estimate of the biomass of branches and leaves was obtained.

Alometric formula adjustment

With the aerial biomass values of the 32 individuals, a single and multiple regression analysis was performed in order to obtain the best fit predictor equation. The independent variables for the multiple regression analysis were Di and ht, while the simple regression analysis was performed as a function of the combinatorial variable Di*ht. The selection parameter in the simple regression was the adjusted R^2. In the multiple regression, a Stepwise debugging was performed and the best adjustment was selected based on the Mallows coefficient, the standard error of the estimate and the adjusted R2. Picard, Saint-André and Henry, (2012).

Carbon Quantification

The best fit alometric model was obtained and applied to the data collected in the forest inventory (Di and ht), obtaining the aerial biomass values of the study plots. This value was weighted to average individual, unit of area (hectare) and plantation. Each weighting was multiplied by a conversion factor of 0.5 Penman et al. (2003) and sequestered carbon was obtained.

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RESULTADOS Y DISCUSIÓN

Forest inventory

The plantation has 1 610 individuals equivalent to 201 trees/ha. Di's average is 0.44 m with a range of 0.14 m to 0.88 m. The average total height of the plantation is 32.44 m, with values ranging from 10 m to 65 m. The ranges registered in the dasometric variables Di and HT, show certain heterogeneity in the plantation due to the lack of silvicultural treatments, which is ratified with the statistical estimators (Table 1).

Tabla 1. Resúmenes estimadores estadísticos.

ESTIMADOR	HT (m)	Di (m)	g (m^2/ha)	Vol (m^3/ha)
PROMEDIO	32.44	0.44	38.95	988.47
S	8.25	0.14	10.18	357.89
CV (%)	25.43	31.67	26.13	36.21

Leyenda: HT: altura total**; Di:** diámetro a 1.30 m**; g:** área basal**; Vol:** volumen**; S:** desviación estándar de la muestra**; CV:** coeficiente de variación

Plantations in Colombia register yields of up to 200 m3/ha in shifts of six to eight years Gómez, Ríos and Peña, (2012). In Argentina, volumes of 525 m3/ha are registered in plantations of 12 years Aparicio and López, (1995). The studied plantation shows a higher volumetric yield, attributable to the 40 years that allowed a greater growth in Di and HT; however, the average Di of the plantation is lower than the potential of the species with the application of silvicultural treatments, which reaches 0.45 m at 14 years. Sepliarsky, (2002)

Additionally, the lack of these treatments could generate competition for light among individuals, which could be one of the reasons for the growth in disproportionate height to the Di. The Average Annual Increase (IMA) of the plantation was 24.71 m^3/ha/year, similar to the 25 m3/ha/year registered in Colombia Gómez, Ríos and Peña, (2012) and lower than the 43.75 m^3/ha/year observed in Argentina Aparicio and López, (1995).

Plantation biomass

The total aerial biomass of the plantation was 5 012.31 t, corresponding to 624.20 t/ha. Of this value 81.20 % was concentrated in the shafts, 7.57 % in barks, 8.87 % in branches and 2.36 % in leaves. This distribution can be attributed to the specific characteristics of the species. Paixão et al., (2006) in their research determined a similar aerial biomass distribution. 81,84 % concentrated in the shaft, 8,05 % in the bark and 7,74 % in branches and leaves. A similar trend occurs in the work of Ribeiro *et al.,* (2015), who mention that 82 % of the aerial biomass is concentrated in the shaft, 8 % in the bark, 7 % in the branches and 3 % in the leaves.

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Alometric formula

The allometric equation for predicting sequestered carbon in *Eucalyptus grandis* plantations showed a good fit with an R2 of 0.98. The best fit equation was obtained based on the combination of the Di and ht variables (Figure 1), which shows the importance of these variables in the sequestered carbon estimate. The use of Di2ht as a predictor of carbon content is consistent with research conducted by Pacheco *et al.,* (2007), Zewdie, Olsson and Verwijst, (2009) and Ribeiro *et al.,* (2015). In a separate analysis it was shown that Di has a greater influence than ht on the carbon present in each individual. Given the adjustment of the equation, this could be used in the estimation of carbon sequestered in plantations of similar characteristics.

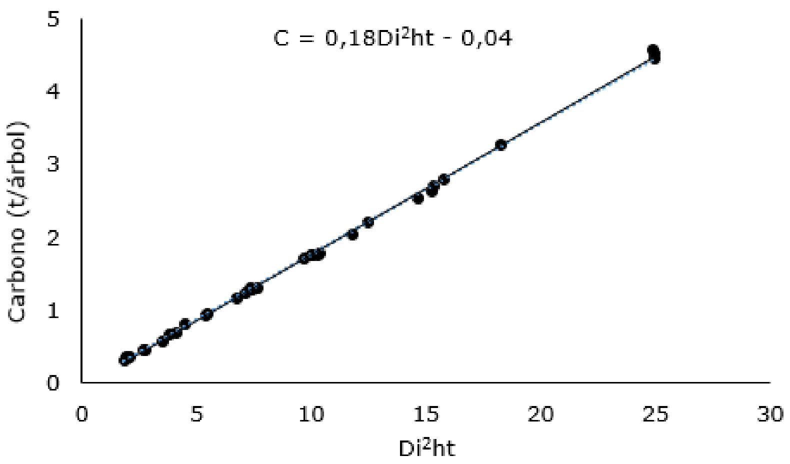

Fig. Relación entre biomasa aérea total y la variable Di^2ht.

The use of the Di and ht variables separately showed a good fit, however, the adjusted R^2 was less than the equation obtained with the combined Di2ht variable. This despite the fact that in the case of multiple regressions the R^2 increases due to the number of variables, which causes it to lose representativeness in this type of regressions; therefore, the Cp of Mallows and the standard error of the estimation were analyzed, ratifying the equation of best fit as the one obtained with the combined variable. The complexity of the resulting formulas with the variables separately and their.

Tabla 2. Ecuaciones alométricas y parámetros de selección.

Ecuación	R² Aj	Cp Mallows	s
CC = 0.18 Di^2ht-0.04	0,98	2	0,14
CC = 6.7Di^2-0.64Di+0.03ht-0.79	0,97	4	0,19
CC = 6.17Di^2+0.03ht-0.91	0,96	3	0,22
CC = 7.28Di+0.01ht-2.28	0,94	3	0,31
CC = 7.28Di+0.0005ht^2-0.02ht-1.82	0,92	4	0,31

Leyenda: CC: contenido de carbono**; Aj:** ajustado**; Cp:** Coeficiente**; ht:** altura total**; Di:** diámetro a 1,30 m**; s:** error de estimación estándar.

Plantation Carbon

The carbon sequestered per tree was on average 0.75 t, equivalent to 312.10 t/ha and 2506.16 t throughout the plantation, indicating that the carbon sequestered in the aerial component of eight-year plantations was 63.7 t/ha Ribeiro *et al.,* (2015). These data are similar to those obtained by Paixão *et al.,* (2006), who recorded values of 47.7 t/ha in plantations of the same age. The difference in comparison to the present research lies in the ratio of six to one of age. It should be noted that the generic fraction of 50 % carbon per unit of biomass was used in the study, which may have led to Lamlom and Savidge overestimates (2003).

The carbon content sequestered in the aerial biomass of *Eucalyptus grandis* showed the potential of the species as a carbon sink. The largest amount of aerial plantation biomass was found in the shaft. For the study conditions, the alometric equation based on the combination of DAP and ht (DAP2ht) showed the best fit, which simplifies calculations and predicts carbon values closer to the real ones.

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