Carbon stored in forest plantations in The Mariano Dámaso Beraún District, Huánuco – Perú

Carbono almacenado en plantaciones forestales en el distrito de Mariano Dámaso Beraún, Huánuco - Perú

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Abstract

The objective of the research work was to estimate the carbon stored in the forest plantations in the district of Mariano Dámaso Beraún, and for this allometric equations were used, which allowed determining the biomass and this, in turn, the above-ground carbon; Soil organic carbon (COS) was also estimated and the relationship between them was determined. The study was carried out in three 1,5 year old forest plantations, located in the following altitudinal strata: 787 masl (Quesada), 1.153 masl (Chincamayo) and 1.455 masl (Corazón de Jesús), located in the Mariano Dámaso Beraún district. , Leoncio Prado province, Huánuco department. The established species were: *Schizolobium amazonicum* Huber ex Ducke (spiny pine), *Licaria trianda* (Swartz) Kostermans (cinnamon moena), *Inga edulis* C. Martius (guaba), *Swietenia macrophylla* G. King (mahogany) and *Juglans neotropica* Diels (walnut); and as a result, the aerial biomass was 2,34 t/ha for the altitude of 787 msnm., 1,77 t/ha for the altitude of 1.153 msnm., and 1,63 t/ha for the altitude of 1.455 msnm.; therefore, the total airborne carbon stored was 1,17 t/ha for the altitude of 787 msnm., 0,89 t/ha for the altitude of 1.153 msnm., and 0,82 t/ha for the altitude of 1.455 msnm.; the total content of organic carbon in the soil was 67,22 t/ha for the altitude of 787 msnm., 68,77 t/ha for the altitude of 1.153 msnm., and 90,09 t/ha for the altitude of 1.455 msnm.; and according to Pearson's correlation, it indicates that there is no statistically significant relationship between the total airborne carbon content with the soil organic carbon in the district under study.

Keywords: biomass, carbon, trees, soil, altitudinal strata.

Resumen

El objetivo del trabajo de investigación fue estimar el carbono almacenado en las plantaciones forestales del distrito de Mariano Dámaso Beraún, y para ello se utilizaron ecuaciones alométricas, que permitieron determinar la biomasa y esta, a su vez, el carbono superficial; También se estimó el carbono orgánico del suelo (COS) y se determinó la relación entre ellos. El estudio se realizó en tres plantaciones forestales de 1,5 años, ubicadas en los siguientes estratos altitudinales: 787 msnm (Quesada), 1.153 msnm (Chincamayo) y 1.455 msnm (Corazón de Jesús), ubicados en el distrito Mariano Dámaso Beraún. , Provincia Leoncio Prado,

departamento de Huánuco. Las especies establecidas fueron: *Schizolobium amazonicum* Huber ex Ducke (pino espinoso), *Licaria trianda* (Swartz) Kostermans (canela moena), *Inga edulis* C. Martius (guaba), *Swietenia macrophylla* G. King (caoba) y *Juglans neotropica* Diels (nuez); y como resultado, la biomasa aérea fue de 2,34 t / ha para la altitud de 787 msnm., 1,77 t / ha para la altitud de 1,153 msnm. y 1,63 t / ha para la altitud de 1,455 msnm.; por lo tanto, el carbono total almacenado en el aire fue de 1,17 t / ha para la altitud de 787 msnm., 0,89 t / ha para la altitud de 1,153 msnm. y 0,82 t / ha para la altitud de 1,455 msnm.; el contenido total de carbono orgánico en el suelo fue de 67,22 t / ha para la altitud de 787 msnm., 68,77 t / ha para la altitud de 1.153 msnm. y 90,09 t / ha para la altitud de 1.455 msnm.; y de acuerdo con la correlación de Pearson, indica que no existe una relación estadísticamente significativa entre el contenido total de carbono en el aire con el carbono orgánico del suelo en el distrito en estudio.

Palabras clave: biomasa, carbono, árboles, suelo, estratos altitudinales.

Introduction

Climate change is made up of a series of alterations that the planet suffers, which are manifested mainly by the increase in temperature, changes in rain patterns and increase in sea levels (Ciesla, 1996; Ruiz, 2007). This phenomenon occurs as a consequence of the increase in the atmospheric concentration of greenhouse gases (GHG).

For their part, Llactayo et al. (2013) report for the Peruvian Amazon a deforestation rate of 103,380 ha, whose main cause is migratory agriculture; Therefore, in the shadow of the COVID-19 crisis, the Amazon is quietly suffering one of its worst moments in the face of its particular pandemic: deforestation, which only in 2020 destroyed 2.3 million hectares in the jungle, an area larger even than the entire extension of the country of El Salvador (Gestión, 2020). In any case, it is necessary to limit in this regard, that the Mariano Dámaso Beraún district is not alien to this problem, since its upper parts have been deforested in 43.31% (33,187 ha) of its extension, and only 10, 64% of this percentage (3,532 ha) is used by agriculture in different crops (District Municipality Mariano Dámaso Beraún, 2020).

In this context, forest plantations represent one of the main alternatives to mitigate climate change, since they can remove CO₂ particles from the environment through the photosynthesis process and store carbon in biomass and in the soil (Ortiz and Kanninen, 2000; Montero and Kanninen, 2006). These ecosystems in turn provide goods

(wood) and diverse ecosystem services (Montagnini et al., 2011), becoming an alternative to develop reforestation projects in the form of the Clean Development Mechanism (CDM), which is why it is important to obtain information on tree biomass as a means to mitigate the effects of CO₂ over-accumulation in the atmosphere.

Faced with this situation, the purpose of the work was to estimate through the method of allometric equations, biomass production and airborne carbon stored in contemporary forest plantations in the massif, located in three altitudinal strata of the Mariano Dámaso Beraún district; to estimate soil organic carbon (SOC) stored in contemporary massif forest plantations and determine the relationship between air carbon content and soil organic carbon stored in the plantations under study.

Materials and Methods

The research took place in three 1.5-year-old forest plantations, located in different altitudinal strata, politically located in the Mariano Dámaso Beraún district, Leoncio Prado province, Huánuco department. Each area or altitude stratum is located in the Quesada, Chincamayo and Corazón de Jesús villages. The climate is hot, humid and rainy. According to data (micro station of the Micro-basin of Las Pavas), it presents an average rainfall of 3,483.60 mm / year, maximum temperature of 29.20 ° C, minimum temperature 17.50 ° C and an average temperature of 23.35 ° C. A mechanical

vernier was used to measure the diameter of the trees and / or shrubs; 5 m winch to measure the total height of trees and / or shrubs; and straight shovel, Uhland cylinders (270 cm³) and polyethylene bags of 5 kg capacity, For the purposes of to estimate the carbon stored in the living aerial biomass (BAV), all the plants of each forest system or planted area were evaluated; p For individuals with diameters greater than or equal to 10 cm, the biomass was estimated using the equation proposed by Chave et al. (2005):

$$BAV = \sum_{i=1}^n [(Exp(-2,557 + 0,940 \times \ln(\rho_i D_i^2 H_i))] \times 0.002$$

Where:

BAV_{≥10} = Live aerial biomass (t * ha⁻¹) of trees with Dap ≥ 10 cm.

n = Number of trees in the plot.

ρ_i = Basic density of wood (g / cm³), which will be obtained from research carried out for each species.

Gave = Diameter at the height of the chest of the tree (cm).

H_i = Total height of the tree (m).

0.001 = Conversion factor (100 x 100 m plot).

In plants with a diameter greater than or equal to 5 cm. and less than 10 cm., it has been measured at 30 cm. above ground level, and biomass was estimated using the equation suggested by Chave et al. (2005), with the only variant that the diameter was measured at 30 cm above the ground. For bushes with a diameter greater than or equal to 2.5 cm. and less than 5 cm., an adaptation of the equation proposed by Chave et al. (2005) and Nascimiento and Laurance (2001), developed specifically to estimate the biomass of small plants; the Substitution was carried out because the latter does not consider the height or the basic density of the wood for the estimation of stored aerial biomass, which is why the results showed an oversizing (even higher than shrubs with diameters greater than 5 cm.).

Besides, Soil sampling consisted of taking 16 samples distributed by a zig-zag line throughout each 1-ha plot; Each sampling unit consisted of a 25x25x30 cm deep pit, in which three horizons were defined: 0-10 cm, 10-20 cm and 20-30 cm. The apparent density of the soil per horizon of each sampling unit for each altitudinal stratum was determined using the cylinder method, which consisted of introducing into each horizon of the pit, or cylinder Uhland with which a subsample was extracted; later, all of them (144) were taken to the laboratory to be dried in the oven at 105°C for 72 hours, thus obtaining the dry weight. With the values of dry weight and constant volume of the cylinder, the average apparent density of the soil (g / cm³) was calculated. The organic matter content of the soil, on the other hand, was obtained in the laboratory by the Walkley and Black method, using the samples of each horizon by altitudinal stratum; and carbon of live aerial biomass (t / ha) was obtained assuming that in tropical forests the biomass of living trees contains approximately 50% carbon (Macdicken, 1997; Chave et al., 2005) yet the content of soil organic carbon (SOC) in each horizon (0-10 cm, 10-20 cm, and 20-30 cm), was estimated using the formula suggested by Macdicken (1997).

Calculation of the carbon of the living aerial biomass plus the SOC of the plot, in t / ha:

$$CT (t / ha) = CBAV + COS$$

Where:

CT = aboveground carbon plus SUT COS, in t / ha

CBAV = carbon of living aerial tree biomass, in t / ha

COS = soil organic carbon, in t / ha

Likewise, the basic statistics and Pearson's correlation were used, assuming that each altitudinal stratum constitutes a treatment. The basic statistical analysis that was developed for the biomass and aboveground carbon variables was to calculate the average (mean), represented by the following formula:

$$\text{Mean} = \frac{\text{Sum of the data}}{\text{Amount of data}}$$

In order to know the approximate confidence intervals for the mean, the standard error (se) was used. The following expressions were used to calculate the confidence limits above and below 95% (where the sample mean was considered, (ee) was equal to the standard error for the sample mean and 1.96 is the quantile 0.975 of the normal distribution):

- Above 95% : Limit = mean + ee * 1.96.

- Below 95% : Limit = mean - ee * 1.96.

In order to determine the dispersion of the data, the coefficient of variation was used as proposed by Calzada (1976). Finally, in order to determine the existing relationship between aerial carbon and edaphic carbon stored in each of the planted areas, the Pearson correlation coefficient was applied, where the main factor was the determination coefficient (R²).

Results

Biomass air and air carbon stored in contemporary forest plantations in the massif, located in three altitudinal strata

Average biomass and carbon per tree and / or shrub increase as diameter classes expand.

Table 1.

Distribution of biomass and average aerial carbon by plant and diameter class, in three altitude strata

Altitudinal stratum	Diameter class	Biomass (kg / plant) *	Carbon (kg / plant)	CV (%)
787 masl	2.50 - 4.99 cm	0.75 ± 0.01	0.37 ± 0.005	28.29
	5.00 - 9.99 cm	1.72 ± 0.04	0.86 ± 0.02	44.93
	≥ 10.00 cm	12.97 ± 0.29	6.48 ± 0.15	23.13
1,153 masl	2.50 - 4.99 cm	0.32 ± 0.01	0.16 ± 0.004	68.13
	5.00 - 9.99 cm	3.33 ± 0.14	1.66 ± 0.07	67.31
	≥ 10.00 cm	13.82 ± 0.42	6.91 ± 0.21	21.32
1,455 masl	2.50 - 4.99 cm	0.29 ± 0.01	0.14 ± 0.004	70.22
	5.00 - 9.99 cm	3.07 ± 0.16	1.54 ± 0.08	75.38
	≥ 10.00 cm	13.50 ± 0.32	6.75 ± 0.16	18.15

* Average ± standard error. CV: Coefficient of variation.

Table 2.

Total airborne carbon stored in forest plantations located in three altitudinal strata

Altitudinal stratum	Diameter class	Number of plants	Airborne carbon (t / ha / diameter class)	Airborne carbon (t / ha)
787 masl	2.50 - 4.99	473	0.18	1.17
	5.00 - 9.99	364	0.31	
	≥ 10.00	105	0.68	
1,153 masl	2.50 - 4.99	628	0.10	0.89
	5.00 - 9.99	265	0.44	
	≥ 10.00	fifty	0.35	
1,455 masl	2.50 - 4.99	670	0.10	0.82

5.00 - 9.99	217	0.33
≥ 10.00	57	0.39

The total aerial biomass per hectare in the plantation located at 787 masl reached the maximum value of 2.34 t / ha, followed by the plantation established at 1,153 masl that registered 1.77 t / ha, and the plot located at 1,455 masl that only obtained 1.63 t / ha. Similarly, total airborne carbon stored per hectare decreases in content as altitude increases (Figure 1).

Figure 1.

Biomass and total airborne carbon stored per hectare in three altitudinal strata.

Soil organic carbon stored in contemporary forest plantations in massif, located in three altitudinal strata

Table 3.

Distribution of soil organic carbon (SOC) in three altitudinal strata.

Altitudinal stratum	Soil depth (cm)	COS (t / ha / depth)	Total COS (t / ha / altitudinal stratum)
787 masl	0-10	25.76	67.22
	10 - 20	23.36	
	20 - 30	18.10	
1,153 masl	0-10	28.18	68.77
	10 - 20	19.98	
	20 - 30	20.60	
1,455 masl	0-10	36.64	90.09
	10 - 20	25.52	
	20 - 30	27.93	

In general, an inversely proportional relationship is evidenced between the soil organic carbon content versus the sampling depth, registering a greater relationship in the 787 masl stratum that generated an equation of the form $Y = -0.3829 X + 30.066$, being "Y" is the organic carbon of the soil and "X" is the depth of soil sampling, with a coefficient of determination of 0.9552, which allows us to affirm that the depth of the soil has a 95.52% effect on its carbon content organic. In the case of the remaining altitudinal strata, this relationship was lower because the values of the coefficient of variation were lower (Figure 2).

Figure 2.

Distribution of soil organic carbon with respect to depth in three altitudinal strata.

Relationship between the content of aerial carbon and organic carbon of the soil stored in contemporary forest plantations in massif

Pearson's correlation analysis shows that there is no statistically significant relationship between the total airborne carbon content with the soil organic carbon, evaluated at a depth of 30 cm.

Table 4.

Relationship between the content of aerial carbon and total organic carbon of the soil stored in the three altitudinal strata.

Variable	Statistics	Edaphic carbon
Air carbon	Pearson's correlation	-0.669ns
	Significance (bilateral)	0.507

ns: there is no statistical significance.

As can be seen in Table 4, the amount of total aerial carbon and total soil organic carbon stored in the plantations of the three altitudinal strata did not generate statistical significance, which is why only the equation of the form $Y = -47.751X + 121.09$, with a coefficient of determination of 0.4918, which shows an influence of 49.18% of stored air carbon on soil organic carbon (Figure 3).

Figure 3.

Relationship between aerial carbon and soil organic carbon stored in forest plantations of three altitudinal strata.

Discussion

Biomass air and air carbon stored in contemporary forest plantations in the massif, located in three altitudinal strata

The total aerial biomass in the plantation of the 787 masl altitude stratum, reached the maximum value of 2.34 t / ha, followed by the plantation established at 1,153 masl. having a value of 1.77 t / ha and the plot located at 1,455 meters above sea level. with a value of 1.63 t / ha. Consequently, there is an inversely proportional relationship between altitude and total airborne carbon stored per hectare (1.17, 0.89 and 0.82 t / ha for 787, 1,153 and 1,455 meters above sea level, respectively). In this regard, Anaya (2010) in an investigation carried out in Tingo María, Huánuco - Peru, found that the carbon stored in a plantation of white bolaina (*Guazuma crinita* Martius), one year old, was 1.18 t / ha; Obviously, this result is very close to those found in the present study, especially in the plantation of the altitudinal stratum 787 meters above sea level,

On the other hand, Molina and Paíz (2002) found that the plantations of trees with short rotation and rapid growth can store from 8 to 78 tC / ha depending on the species, places and duration of the rotation; Although the aforementioned results are higher than those obtained in the study, the lower limit (8 tC / ha) does not represent an excessive difference, and as explained by the researcher himself, it may be due to the species and planting places; Therefore, it is feasible to infer that the combination of fast growing species (*Schizolobium amazonicum* Huber ex Ducke and *Inga edulis* C. Martius), medium growth (*Juglans neotropica* Diels and *Licaria triandra* (Swartz) Kostermans) and slow growing (*Swietenia macrophylla* G. King), the altitudinal gradients and even the age of the plants (1.5 years). On the other hand, Ibrahim et al. (2007) affirm that in young secondary forests of Nicaragua values of 17.6 tC / ha have been determined; also reports a similar

situation for carbon in the biomass of the arboreal component in pastures, being found in native pastures with trees (100 trees ha⁻¹) carbon content of 8.2 ± 3.0 tC / ha and in improved pastures with trees (110 trees ha⁻¹) content of 12.5 ± 3.6 t / ha. So too, Brown et al. (1997) have estimated that the carbon (C) in the biomass of primary and secondary forests varies between 60 and 230 and between 25 and 190 t / ha, respectively. It is clearly noted that the contents of airborne carbon stored in the present study are lower than those reported by the aforementioned researchers,

Regarding the relationship of altitude with the structural variables analyzed, various studies in tropical forests have reported a marked and inversely proportional relationship with variables such as basal area and aerial biomass (Moser et al., 2011; Girardin et al., 2013), especially when analyzing broad altitudinal gradients. This relationship according to Girardin et al. (2013), has been quite documented, even though altitude is not considered a direct control factor of the functional characteristics of forests, but a biophysical characteristic associated with temperature, species composition, and other topographic variables and physicochemical properties of soils, which determine structural variations at landscape scales. Segura and Kanninen (2002) also argue that the accumulation of carbon stored in forest plantations is directly related to the species, the intensity of management applied, the age of the plantation and the environmental conditions of the site.

Soil organic carbon stored in contemporary forest plantations in massif, located in three altitudinal strata

The total content of soil organic carbon (SOC) stored up to a depth of 30 cm, shows a directly proportional relationship with altitude (67.22, 68.77 and 90.09 t / ha for 787, 1,153 and 1,455 meters above sea level, respectively). On the subject, Brown et al. (1997) has estimated that the carbon (C) in the soil can vary between 60 and 115

t / ha. For their part, Ibrahim et al. (2007) when evaluating soil organic carbon (SOC), found a range between 95.1 and 139.5 tC / ha for forest plantations and improved pastures without trees, respectively; By comparing the results of the study, it is evident that those obtained in the three strata are within the range reported by Brown et al. (1997) and close to the lower limit found by Ibrahim et al. (2007),

However, it is worth relating the results of this study with those found by Herrera (2013) in forest plantations located in Costa Rica, when evaluating trees with Dbh ≥ 10 cm at an altitude between 400 and 700 meters above sea level, where it is reported that the average carbon stored in the soil of three forest plantations was 246.16 t / ha, and by strata and species it was 257.56 t / ha on average; values much higher than those obtained in the research. The difference in these results may be due to the site, the original amount of carbon in each place before establishing the forest plantation, the apparent density of the soil, the fertility of the soil, the number of trees per area, the species installed and the management. silvicultural provided. Secondly, When carrying out an analysis of the relationship between the total content of soil organic carbon (SOC) and altitude (67.22, 68.77 and 90.09 t / ha for 787, 1,153 and 1,455 masl, respectively), Parras et al. (2015) found that SOC reserves increased with altitude; likewise, a study carried out in Venezuela by Reynolds et al. (2005) showed that there is a positive and highly significant correlation between the sampling altitude and the carbon content in soils ($r^2 = 0.77$). In this regard, according to Reynolds et al. (2005), the differences found in the SOC reserves in the different topographic positions could be related to the differential in the decomposition speed of organic matter due to the decrease in atmospheric temperature as one ascends in the altitudinal gradient.

Confirming the aforementioned, Ochoa et al. (2000) identifies a positive correlation between soil organic carbon content and altitude. Rojas (1987) corroborates this trend, stating that the content of organic matter in soils increases as the average

annual temperature decreases. Charan et al. (2012) refer on the subject that lower temperatures decrease the decomposition rate of soil organic matter (SOM) and lead to a longer residence time of organic carbon (CO) in the soil, as a result of a decrease in soil edaphic respiration, which reduces carbon (C) losses. In this sense, it was found that SOC reserves were increasing due to the decrease in temperature in the altitudinal gradient. The reasons for giving credit to the statements above, is that in the altitudinal stratum 1,455 meters above sea level. (Caserío Corazón de Jesús), the average temperature determined after four own evaluations was 20 ° C.

Lal et al. (1998) also affirms that the carbon content in the soil depends on the factors related to its formation, but can be modified by changes in its use and management. Climatic factors and soil factors allow explaining carbon storage over long periods, while land use and vegetation changes are considered in shorter periods. The great differences in the existence of carbon between different ecological zones are presented in relation to temperature and rainfall, varying from 4 kg / m² (40 t / ha) in arid zones, from 8 to 10 kg / m² (80 to 100 t / ha) in the tropics and 21 to 24 kg / m² (210 to 240 t / ha) in the polar or boreal regions; The aforementioned data, especially for tropical areas, support the results obtained in the study.(67.22, 68.77 and 90.09 t / ha).

Finally, Montagnini and Finney (2011) state that it has been proven for the Caribbean region of Costa Rica that, after the soil, the vegetation above it is the second largest carbon reservoir in agroforestry systems (SAF) and forest plantations, a fact that it was evidenced in the research, given that the SOC far exceeded the aerial carbon stored in the forest plantations.

Relationship between the content of aerial carbon and organic carbon of the soil stored in contemporary forest plantations in massif

In the present study, Pearson's correlation analysis shows that there is no statistically significant relationship between total airborne carbon content and soil organic carbon at a depth of 30 cm. In this regard, various studies developed along altitudinal

gradients have concluded that as altitude increases, aerial biomass decreases (Girardin et al., 2013, Moser et al., 2011), possibly in response to limitations in growth. that supposes the decrease in temperature, steep slopes, changes in precipitation, wind speed, or cloudiness (characteristics of high areas). And regarding the influence of relief, according to Stevenson (1982), it is a determining factor in the variation of SOC levels both in quantity and quality,

What was previously discharged confirms the inversely proportional relationship between stored air carbon and altitude, and directly proportional between SOC and altitude, evidenced in the present investigation and reaffirming that there is an inversely proportional relationship between stored air carbon and SOC in 1.5-year-old forest plantations, located in different altitudinal strata (1.17 for 67.22 t / ha, 0.89 for 68.77 t / ha and 0.82 for 90.09 t / ha, respectively); highlighting that there is no statistical significance in this relationship. However, it should be noted that elevation may not be the most important factor to explain the variability in aerial biomass (Slik et al., 2010); according to Mascaro et al. (2011), the slope of the terrain and according to Culmsee et al. (2010), including the composition of species, could determine the distribution pattern of aerial biomass in tropical forests.

Conclusions

The total aerial biomass in the plantation of the altitudinal stratum 787 masl, reached the maximum value of 2.34 t / ha, followed by the plantation established at 1,153 masl. with a value of 1.77 t / ha and the plot located at 1,455 meters above sea level. with a value of 1.63 t / ha.

There is an inversely proportional relationship between altitude and total airborne carbon stored per hectare, being 1.17, 0.89 and 0.82 t / ha for 787, 1,153 and 1,455 meters above sea level, respectively.

In the 787 masl altitude stratum, the diameter classes with the highest stored airborne carbon content were: 2.50 - 4.99 cm. with a value of 0.18 t / ha / diameter class and ≥ 10.00 cm. with a value

of 0.68 t / ha / diameter class; for its part, in the stratum 1,153 meters above sea level, the class 5.00 - 9.99 cm. achieved the highest concentration of stored aerial carbon, having the value of 0.44 t / ha / diameter class.

The total content of soil organic carbon (SOC) stored up to a depth of 30 cm, shows a directly proportional relationship with altitude: 67.22, 68.77 and 90.09 t / ha for 787, 1,153 and 1,455 meters above sea level, respectively.

Pearson's correlation analysis shows that there is no statistically significant relationship between total airborne carbon content and soil organic carbon at a depth of 30 cm.

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