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# Effect of Geographic Altitude on Carbon Stock in two Physiographic Units of the Reserved Forest of the Universidad Nacional Agraria de la Selva

**M. Reategui*, D. Reategui**, E. Morales***(****)†, R. Reategui***** and C. Aguirre********

*Escuela Profesional de Ingeniería Ambiental, Universidad Nacional Intercultural de la Selva Central Juan Santos Atahualpa, Av. Perú 612, Pampa del Carmen, Chanchamayo, Perú

**Laboratorio Central de Investigación, Universidad Nacional Agraria de la Selva, Carretera central km 1.2, Tingo María, Perú

***Facultad de Ciencias Naturales y Aplicadas, Universidad Nacional Intercultural Fabiola Salazar Leguía de Bagua (UNIFSLB), Bagua 01721, Perú

****Instituto de Ciencias de Datos, Universidad Nacional de Jaén, Cajamarca, Perú

*****Facultad de Ingeniería, Universidad Nacional Amazónica de Madre de Dios, Av. Jorge Chávez N°1160 - Ciudad Universitaria 2do. Piso Biblioteca Central, Madre de Dios, Perú

******Facultad de Recursos Naturales Renovables, Universidad Nacional Agraria de la Selva, Carretera central km 1.2, Tingo María, Perú

†Corresponding author: E. Morales; emorales@unibagua.edu.pe

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## ABSTRACT

The objective of the research was to evaluate the effect of geographic altitude on the carbon stock in two physiographic units of the Reserved Forest of the Universidad Nacional Agraria de la Selva, Tingo Maria-Huanuco. The methodology used was the field manual for the remeasurement and establishment of plots of the Amazon Forest Inventory Network (RAINFOR), for which 2 hectares were permanently established (one hectare in low and high hills) in which the diameter (greater than or equal to 10 cm) and the height of the trees were measured. Finally, the density of the wood was obtained from previous studies. The pantropical model formula was used to estimate the carbon stock. The results show that geographic altitude significantly affects carbon stock ($p < 0.05$) in low and high-hill forests, concluding that this may be due to differences in meteorological variables such as precipitation, temperature, and humidity.

## INTRODUCTION

Forests around the world sequester important carbon stocks, which are responsible for carbon fluxes between the land and the atmosphere through photosynthesis and respiration (Jandl 2001, Tipper 1998). Approximately 80% of the total carbon in all terrestrial vegetation is stored in tropical forests (Clark 2007, Gitay et al. 2002, Phillips & Gentry 1994) and is located in stems, branches, leaves, roots, and organic matter (Leith & Whithacker 1975, Raev et al. 1997).

The International Panel on Climate Change - IPCC (1996) estimated in its second assessment report that 60 and 87 gigatons (Gt) of carbon could be conserved or sequestered in forests by 2050 (Yáñez 2004).

Global warming is a priority that today afflicts various countries of the world, which is also reflected in the geographical altitude modifying the temperature, precipitation, humidity, etc., of tropical forests (Pilco 2020).

Peruvian forests are an important carbon reserve at the global level and occupy more than half of the national territory (56.9%), with the Amazon being the region with the largest forest area in the country (94%) (WWF 2021).

**ORCID details of the authors:**

**M. Reategui**
https://orcid.org/0000-0002-5417-6509
**D. Reategui**
https://orcid.org/0000-0001-6689-2345
**E. Morales**
https://orcid.org/0000-0002-8623-3192
**R. Reategui**
https://orcid.org/0000-0003-1532-991X
**C. Aguirre**
https://orcid.org/0000-0003-0683-8675

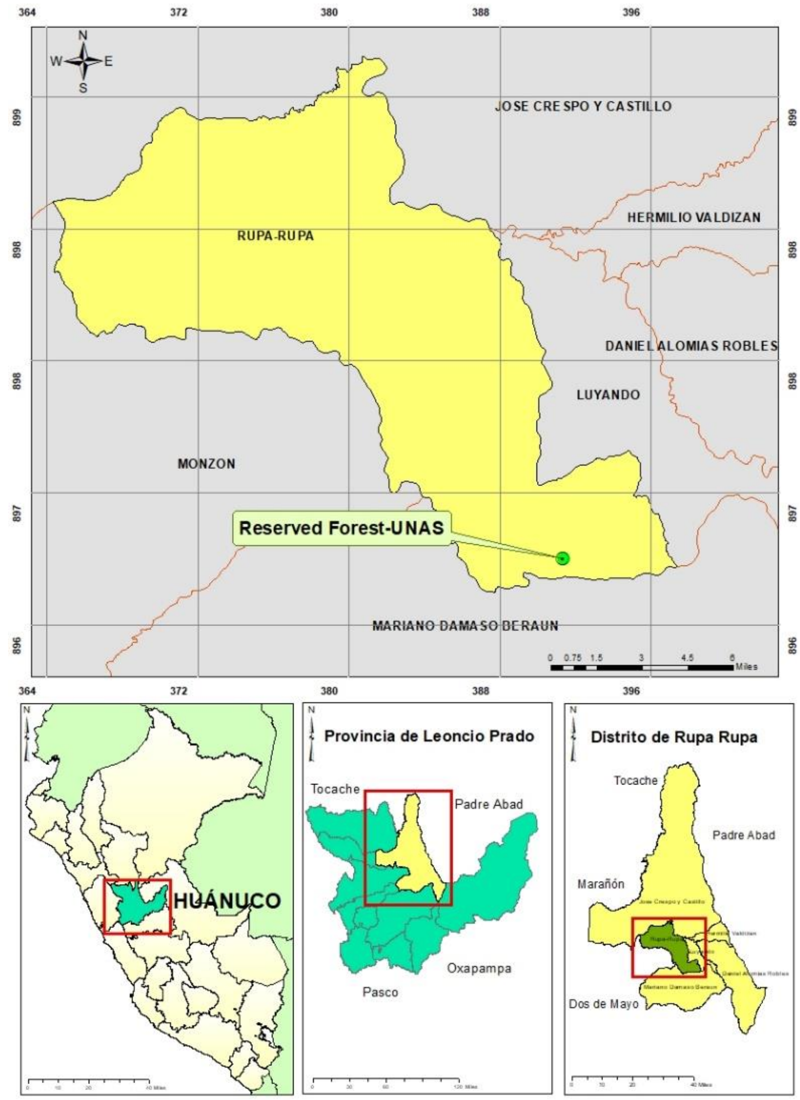


Fig. 1: Map of the location of the Reserved Forest of the Universidad Nacional Agraria de la Selva.

In research carried out between 1983 and 2007 with field data and forest flora inventories, the concentrations of stored carbon were calculated to be between 2.782 and 13.241 megatonnes (Mt) of carbon (Gibbs et al. 2007). On the other hand, in the study of aboveground carbon stored in the Peruvian Amazon, it was reported that the forests with the highest carbon content are located in the lowland and sub-mountain regions of the Amazon (Asner et al. 2014)

Based on the above, the objective of this study was to evaluate the effect of geographic altitude on the carbon stock in two physiographic units of the Reserved Forest of the Universidad Nacional Agraria de la Selva.

## MATERIALS AND METHODS

### Scope of Study

The geographical area was the Reserved Forest of the Universidad Nacional Agraria de la Selva, with an area of 217.22 ha and a perimeter of 6 935.36 m; whose UTM coordinate is 391359 East - 8970535 North Fig. 1, with 667 to 1092 masl (Puerta 2007), in the Department of Huánuco, Province of Leoncio Prado, District of Rupa Rupa, where two physiographic units were identified, low hill and high hill.

### Location and Demarcation of Permanent Plots

The low hill is located at 391084 East, 8970688 North,

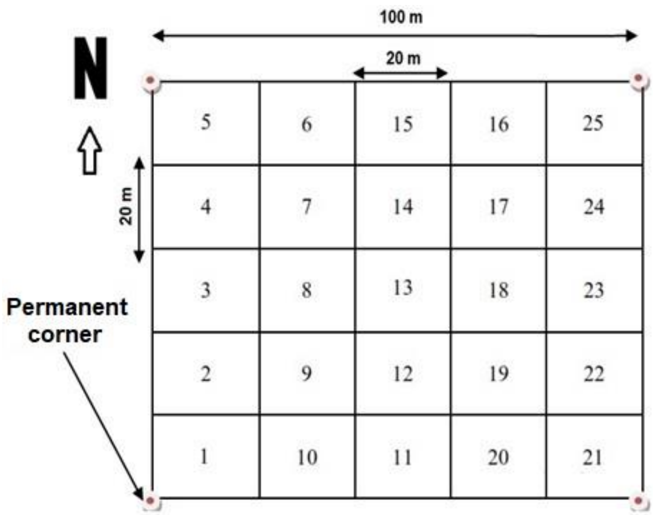


Fig. 2: Subdivision of plots into the low hill and high hill.

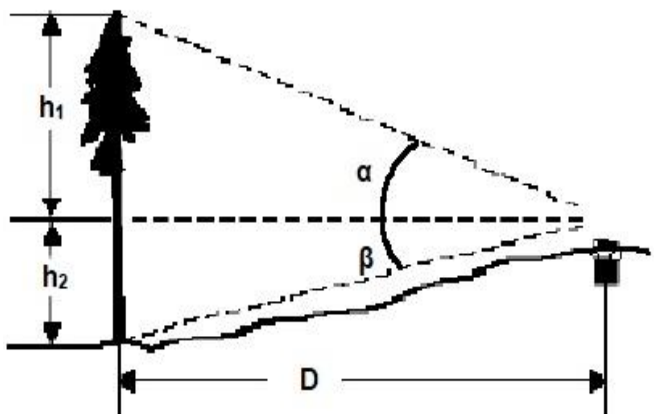


Fig. 3: Tree height measurement in low and high hills; source: Romero (2014).

and 750 meters above sea level, while the high hill is located at 391540 East, 8970335 North, and 900 meters above sea level. For each hill, the area under study was one hectare, where it was divided into 25 subplots of 20 x 20 m Fig. 2.

### Data Collection

To determine the sample, all trees more significant than 10 cm in diameter at breast height were counted, and the same number of trees was selected for both hills. In this sense, the sample consisted of 512 trees for 1024 trees. The diameter of the trees was measured with a diametric tape. The wood density was obtained from the database of Soto (2016), and the height of the trees was measured using a winch and clinometer Fig. 3, then the height was calculated using the following formula:

$$Ht = D * [\tan(\alpha) + \tan(\beta)]$$

Where: Ht = Height of the tree; α = Angle towards the tip of the crown; β = Angle towards the base of the tree; D = Distance (15 - 20 m).

### Estimation of the Stock of Aboveground Biomass Stored Per Tree ($AG_{Best}$)

Using the variables of diameter (D), height (H), and wood-specific density (p), we proceeded to replace the allometric equation for tropical trees, where it obtained a better fit (Chave et al. 2014):

$$AGB_{est} = 0{,}0673 * (pD^2H)^{0{,}976}$$

Where:

p = Wood density ($g.cm^{-3}$); D = Tree diameter (cm); H = Tree height (cm).

The results obtained were expressed in weight units in grams (g) and were therefore converted to tons (t).

Table 1: Sum of measurement variables in low and high hill forests.

| Measurement variables | Low hill (trees) | High hill (trees) |
|---|---|---|
| Density of wood [$g.cm^{-3}$] | 290.669 | 304.175 |
| Tree diameter [cm)] | 10 560.29 | 12 806.05 |
| Tree height [cm] | 849 997.50 | 1 122 254.15 |

### Estimated Biomass Stock Total Stored Area ($AGB_{total}$)

To calculate the total aboveground biomass stored per hectare, all values obtained per tree were summed (Chave et al. 2014):

$$AGB_{total} = \sum_{i}^{n} AGBest / A$$

Where:

$AGB_{total}$ = Aerial biomass stored per tree (t); A = Plot area (ha)

### Data Analysis

For the normality of the data, the Kolmogorov-Smirnov test was applied, resulting in the distribution not being expected. We proceeded to apply a nonparametric test in function by means of a nonparametric test (Mann-Whitney U) to identify significant differences between data from the plots. The software used was SPSS version 26 (SilvaParra 2018).

## RESULTS

### Carbon Stock

Table 2: Sum of measurement variables in low and high hill forests.

| | | Carbon stock- Lower Hill |
|---|---|---|
| N | | 512 |
| Normal parameters[a,b] | Media | 13049.34 |
| | Deviation | 18097.21 |
| Maximum external differences | Absolute | .255 |
| | Positive | .224 |
| | Negative | -.255 |
| Test statistic | | .255 |
| Asymptotic sign (bilateral) | | .000[c] |

a. The test distribution is normal.
b. Calculated from data
c. Lilliefors significance correction

Table 1 shows the sum of wood densities, diameters, and heights of trees in low and high-hill forests.

Fig. 4 shows that the highest amount of carbon stored is in the high hill forest with 17.07 t/ha, while the lowest value of carbon stored is in the low hill.

### Inferential Analysis

**Normality:** Table 2 shows that $p = 0.00 < p = 0.05$; therefore, the data in low-hill forests do not have a normal distribution. Of the 512 trees, the mean carbon stock was 13049.34 with a standard deviation of 18097.21.

Table 3, which $p = 0.00 < p = 0.05$ therefore, the data

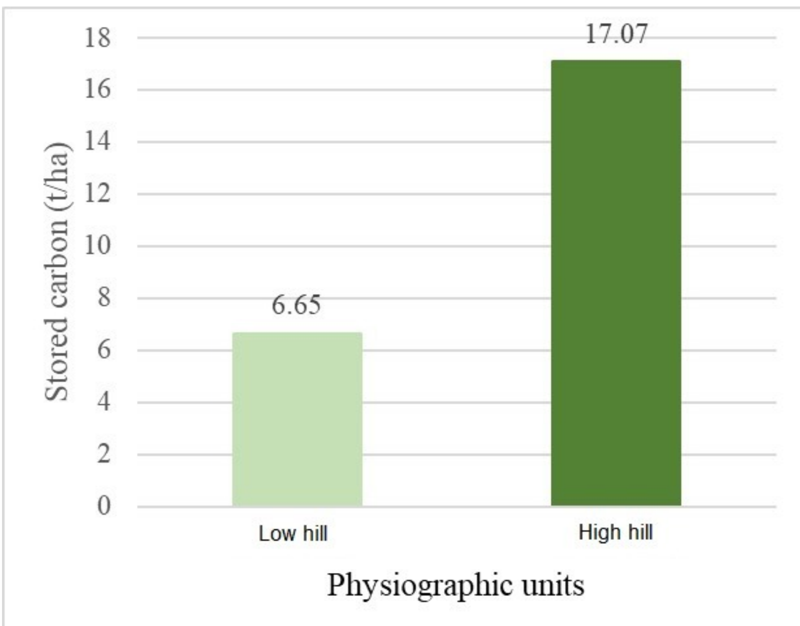


Fig. 4: Carbon stock stored in low and high-hill forests.

Table 3: Kolmogorov-Smirnov normality test for carbon stock in tall hill forest.

| | | Carbon Stock-High Choline |
|---|---|---|
| N | | 512 |
| Normal parameters[a,b] | Media | 33338.99 |
| | Deviation | 80611.43 |
| Maximum external differences | Absolute | .344 |
| | Positive | .287 |
| | Negative | -.344 |
| Test statistic | | .344 |
| Asymptotic sign (bilateral) | | .000[c] |

a. The test distribution is normal.
b. Calculated from data.
c. Lilliefors significance correction.

Table 4: Average rank and the sum of ranks in carbon stock in low and high-hill forests.

| | Altitude | N | Average range | Sum of ranks |
|---|---|---|---|---|
| Carbon Stock | Low hill | 512 | 462.41 | 259877 |
| | High hill | 512 | 619.92 | 317398 |
| Total | | 1074 | | |

in high hill forests do not have a normal distribution. The mean was 33338.99, with a standard deviation of 80611.43.

**Effect of geographic altitude on carbon stock in low and high hill forests:** Table 4, the $p = 0.00 < p = 0.05$; therefore, the geographic altitude in two physiographic units (low and high hill) affects the carbon stock of the Reserved Forests of the Universidad Nacional Agraria de la Selva.

Table 5 shows the carbon stock statistics for the low and high hills with an asymptotic significance of 0.00, which confirms that the carbon stock is a function of the number of trees and altitude.

## DISCUSSION

The carbon stored is related to the tree's species, density, diameter, and height (Cámara-Cabrales et al. 2013). Also, different researchers mention that the carbon content stored varies according to the forest species (Gayoso & Guerra 2005, Martin & Thomas 2011). For this reason, these variables were contemplated for the estimation of carbon.

Table 5: Mann-Whitney U test between carbon stock in low and high-hill forests.

| | Carbon Stock |
|---|---|
| Mann-Whitney U | 101674 |
| Asymptotic sig. | 0.00 |

Esparza & Martínez (2018) found a greater amount of carbon stored in trees with a diameter greater than 31.5 cm. In the same context, Santamaria et al. (2014) and Berenguer et al. (2014) found greater carbon stored in intermediate diameters of 10 - 20 cm and greater than 20 cm. This coincides that the high hill forest's total diameter was 12 806.05 cm compared to the low hill forest's 10 560.29 cm. The high hill forest's carbon stock was also higher at 17.07 $t.ha^{-1}$. As indicated by Sione et al. (2019) and Naji et al. (2013), the larger the diameter of the tree, the greater the amount of carbon stored. This is because the larger the diameter, the greater the availability of water and nutrients for optimal development.

Similarly, trees with greater height have a greater amount of stored carbon (Quiceno et al. 2016). This is reflected in the sum of the heights in high hill forests with 11 222 54.15 cm and stored carbon of 17.07 $t.ha^{-1}$, unlike the low hill forest (936 351.50 cm), which was 6.65 $t.ha^{-1}$. As mentioned by Mendoza-Hernández (2015) and Granado-Victorino et al. (2017), the growth rate in height and diameter of trees is related to the increase in aerial biomass.

On the other hand, the high content of carbon stored in the high-hill forest may be because it has a greater basal area than the low-hill forest. As indicated by Jadan et al. (2017) and Cueva et al. (2019), the geographic altitude increases the density and basal area in the forest. As a result, the aerial biomass increases. Additionally, the difference in carbon stocks among forest species is related to tree diameter, age, wood density, and forest type, among others (Chave et al. 2006, Brown 1997).

Rojas et al. (2019) stated that carbon sequestration in ecosystems is related to the wood's floristic composition, age, and density. On the other hand, Paredes (2018) indicated that the greater the volume and density of wood, the greater the amount of carbon stored in the parts of the trees. The mentioned is related to the sum of the density of wood (304.175 $g.cm^{-3}$) in high hill forests, where it was found greater carbon stored.

The organic carbon in the soil has a proportional relationship with the carbon stored, Leuschner et al. (2013), Mogollón et al. (2015), Echeverria (2017), and Huamán-Carrión et al. (2021) indicated that as the geographical altitude rises, the organic carbon in the soil will increase. This is because there is an increase in precipitation (Díaz 2017) which is essential for developing a forest.

The high-hill forest has had a higher carbon stock, which could be due to its greater abundance and dominance than the low-hill forest (Camones 2014). The results obtained coincide with Sosa (2016), where he obtained a higher carbon stock in high hill forest with 142.50 $t.ha^{-1}$ and lower stock in low hill forest with 127.62 $t.ha^{-1}$.

Finally, it is necessary to determine the amount of biomass that exists in the tree species, since from these it is possible to calculate the carbon concentration of a forest and thus contribute to the management of natural resources towards sustainable development (Avendaño et al. 2007).

## CONCLUSION

Geographical altitude has an effect on the carbon stock in low and high hills, since the Mann-Whitney U test gave a value of $p = 0.00 < p = 0.05$, which could be due to differences in meteorological variables such as precipitation, temperature, humidity, added to this, the different species that inhabit different areas influencing the density of wood, diameter and height of the tree.

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