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Estimation of Carbon Captured using the Walkey and Black Technique by Tillandsia Purpurea in the Amara loma Ocucaje- Perú

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Carbon capture helps regulate the environment's temperature and thereby mitigate the impact of global warming. For carbon capture, various techniques are employed, such as membrane separation and chemical absorption (Girimonte et al., 2024); however, tillandsias are capable of doing it naturally. The objective was to determine the amount of carbon and water in *Tillandsia purpurea* and to estimate the total carbon captured on the Amara loma. Forty 1 m² plots were sampled, and six individuals were collected from each to determine their wet and dry weight (the samples were dried at 105 °C for 48 hours); the difference between the two allowed for the estimation of the amount of water. To obtain the %H (amount of water stored in the biomass), moisture was subtracted, and the results were subsequently extrapolated for the entire hill. To obtain carbon, 300 g of *T. purpurea* and 200 g of soil were extracted and processed in the Soil, Plant, Water, and Fertilizers Analysis Laboratory (LASPAF-UNALM) using the Walkley and Black technique; then the total amount for the hill was estimated through Kriging modeling using ArcGIS. An average fresh biomass of 25.2 g and 72.5% humidity was recorded; regarding carbon capture, 35.4 Tn C/ha was estimated for aerial carbon, which is the biomass of the tillandsial, and 19.4 Tn C/ha for the soil. The sum of both was 54.8 Tn C/ha, which captures the tillandsial of the Amara loma with an area of 7,338.63 ha.

1. Introduction

Anthropogenic activities from the energy supply, transportation, and industrial sectors generate emissions such as CO_2, methane (CH_4), nitrous oxide (N_2O), and halocarbons, which produce environmental waste, increasing long-term temperature and climate effects (Diaz, 2012). Carbon sequestration is a natural process that helps regulate ambient temperature (Rojo et al., 2003). To capture CO_2, various techniques are used such as membrane separation and chemical absorption (Girimonte et al., 2024); however, air plants naturally contribute to this process.The coastal hills are ecosystems that extend along the western coast of South America, between Peru and Chile, in the foothills of the Andes mountain range, at an altitude of between 100 and 1,000 meters above sea level (Dillon y Haas, 2003).
The plant under study was *Tillandsia purpurea* “Achupalla,” which is distributed in the coastal hills of the Peruvian desert, scattered in small patches that connect fragile ecosystems (Aguilar y Turkowsky, 1977). Eleven (11) species of the genus Tillandsia have been identified in southern Peru, which together form the tillandsials (Whaley et al., 2019). This plant has the ability to capture carbon dioxide through photosynthesis and store it in the form of biomass in its tissues (Rojo-Martínez et al., 2003). Morphologically, it has hairs on its leaves called trichomes that replace roots by absorbing water, nutrients, and particles from the air (Benzing and Bennett,

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2000), they also maintain turgidity in the tissues of photosynthetically active leaves and stems (Schulte, 2009). Chemically, they have a crassulacean acid metabolism (CAM) that allows them to fix CO_2 at night and close their stomata during the day. These characteristics help regulate temperature and resistance to episodic droughts (Winter et al., 1983); as is the case with *Tillandsia utriculata* L, where the water potential after two months of drought decreased from −0.75 to −1.25 MPa (Stiles y Martin, 1996).
The objective of this research was to estimate the amount of water and carbon that *Tillandsia purpurea* can capture, as well as the total amount of water and carbon stored in the Amara loma. To do this, it is necessary to determine the organic carbon using the Walkley and Black technique. This involves oxidizing the organic carbon present in living matter (*Tillandsia*) (Eyherabide et al., 2014).
The importance of the study lies in the fact that coastal hills are fragile ecosystems (Law No. 27308 and Law No. 28611) and many of them are currently under anthropogenic pressure due to urban growth, which has led to a reduction in their geographical extent and even their disappearance. There is also a lack of information on the amount of carbon and water they capture, so the value obtained would provide an indication of their importance as air purifiers (Benzing, 2000) and the ecosystem service they provide. Therefore, these results will help to reevaluate the ecosystem services provided by tillandsiales and enable the National Forest and Wildlife Service (SERFOR) to take the necessary conservation measures.

2. Materials and methods

2.1. Area of study

The area is located at coordinates 14°44'55“ S and 75°40'9” W, at an altitude of 875 meters above sea level. It has steep hills and sandy, stony, and mixed soil. According to the Ecological Map of Peru (ONERN, 1976), it is located in the Dry Desert-Warm Temperate (dd-Tc) zone, which has sparse vegetation and winds of 21 to 36 km/h. Cloud cover is variable, with clear skies or up to 40% cloud cover (clear skies were observed during the evaluation days), and the average temperature ranges from 15°C to 18°C.

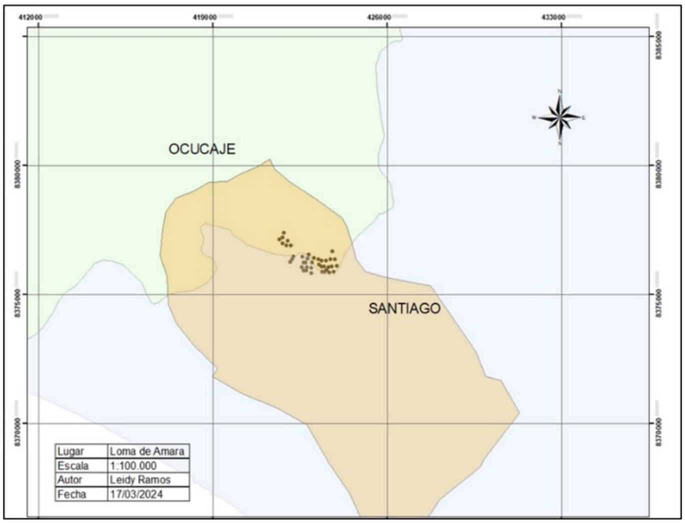

Figure 1. Study area, Loma de Amara and georeferenced points.

2.2. Establishment of plots

Forty 1 m^2 plots were established. Samples were taken at random from each of the quadrants, which were georeferenced using the Locus Map application. Six samples were taken from each quadrant: 300 g of *Tillandsia purpurea* and 200 g of soil sample at a depth of 10 cm.

2.3. Estimate fresh biomass - dry and humid

Fresh biomass was determined by weighing 240 individuals in total on the 40 plots, using a digital scale and dry biomass was obtained by placing samples in a 105°C oven for 48 hours and then weighing them. The difference between wet and dry weight allowed to know the humidity.

2.4. Determine the carbon capture in *Tillandsia purpurea* and soil

Forty samples of 300 g of *Tillandsia purpurea* and 200 g of soil were processed in the laboratory for Soil, Plant, Water and Fertilizer Analysis at the National Agricultural University La Molina (LASPAF-UNALM) using the Walkley and Black technique. This consists of oxidizing the organic carbon present in living matter (*Tillandsia*) by a solution of potassium dichromate and the reaction heat generated when it is mixed with sulphuric acid, obtaining a mixture to which phosphoric acid is added to avoid interference of Fe3+. Potassium dichromate is obtained as a residual product and is titrated with ferrous sulphate. Between 70 and 84% of the total organic carbon is detected with this procedure, so a correction factor must be introduced, which may vary per plant (Eyherabide et al., 2014). The reaction is expressed in the following equation:
$2Cr_2 0_7 = +3C^{\circ} + 16\ H + \rightarrow 4Cr_3 + 3Co_2\ + 8H_2O$; the oxidized C is quantified by titrating the excess $Cr+^6$; this obtained value is multiplied by the factor 1.3 to express the results in percent organic carbon (Walkey and Black, 1934 and Eyherabide et al., 2014).

2.5. Estimation of aboveground and soil carbon per plot

To know the amount of aboveground carbon per plot, the following equation was used: CAP=B x %CA, where B is equal to the dry plant biomass and %CA is the percentage of carbon in the biomass per plot. Regarding soil carbon, the formula CSP=%CS x S was applied; %CS: Percentage of carbon in the soil and S: Quantity of grams of soil (Arévalo y Aponte, 2020). The amount of soil gram was obtained by determining its bulk density. This density is determined by dividing the dry weight of the sample by the volume of the cylinder (Toledo, 2020). The soil samples were processed in the laboratory by placing them in an oven at 105 °C for 48 hours. Subsequently, they were sieved and dry weight data were taken.

2.6. Determination of total carbon in Amara loma by spatial modeling

The estimation of carbon in soil and tillandsia (aerial) using ArcGIS software. Interpolation techniques were used in geographic information systems. This process was carried out using ARC GIS (Version 10.8) and ArcMap 10.8 software. For the first model, a table with the coordinate information and aerial carbon data per quadrant was entered using the kriging tool; the method was ordinary. Then, the model optimization option was used so that the program itself could choose the most suitable model, but first, the data that met the normality criteria were validated. For the second model, the same procedure was performed with the soil carbon data per quadrant. (Porras, 2017). The amount of carbon in the study area (throughout the tillandsial) was obtained using the equation: $CT = CA + CS$; where:CT: Is the total carbon in Amara loma, CA: aboveground carbon and CS: soil carbon

3. Results and discussions

3.1. Estimation of fresh - dry biomass and humidity in the loma.

An average fresh biomass of 25.2 g and a dry weight of 7 g were recorded for the 40 plots (Figure 2a). The humidity in *Tillandsia purpurea* (Figure 2b) was 72.5% and 37.7%. This result differs from that obtained by Arévalo and Aponte (2020), who worked with *Tillandsia latifolia*, with an average humidity of 83.09%. Westbeld et al. (2009) mention that *Tillandsia landbeckii* captures between 2.5 and 3.7 l/m2/day; therefore, fog is the main source of water. These values are due to the fact that *Tillandsia latifolia* has a larger leaf surface area and, therefore, more hairs or trichomes that allow it to capture water from the fog. Likewise, water capture and storage is a peculiar characteristic of these species with CAM metabolism, so their stomata open at night, which reduces water loss through evaporation (Winter et al., 1983 and Arévalo and Aponte 2020).

Figure 2a. Tillandsial plot

Figure 2b. Tillandsia purpurea.

3.2. Determination of carbon in *Tillandsia purpurea* and soil

The amounts of carbon recorded in *Tillandsia purpurea* ranged from 16.84% to 51.16%. In soil, the minimum carbon percentage was 0.17%, and maximum 1.51% (Table 1). These results differ with that of Arévalo and Aponte (2020), where they mention that *Tillandsia werdermannii* registered 43.13% of organic carbon content in plant tissue and *Tillandsia landbeckii* 38.40% and *Tillandsia latifolia* 52.66%. Toledo (2020) estimated that *Tillandsia werdermannii* captured 39.79% followed by *Tillandsia purpurea* with 35.35%. This last figure gives us an idea of the different amounts of carbon that *Tillandsia purpurea* can sequester. The amount of carbon stored differs for each species according to the capacity of its vegetation cover, which maintains an amount of biomass per hectare that is a function of its heterogeneity, climate and soil type (Arévalo, Alegre, & Palm 2003).
The lower amount of carbon registered in comparison with the other tillandsias is due to the size of the plant, size of the leaf and the percentage of coverage of the plant on the soil. Regarding carbon sequestration in the soil is lower compared to the other studies, due to the fact that, the transfer of carbon from the plant biomass passes to the soil where it is stored (FAO,2017), however, this plant lacks a root that allows this transfer. Likewise, the type of soil (porosity) where some have the capacity to capture a greater amount of organic matter.

Table1. Percentage of carbon captured by Tillandsia latifolia and in the soil sample

Results	Máx.	Min.
Tillandsia purpurea	*51,16*	16,84
Soil sample	1,51	0,17

Regarding carbon storage in the soil, Arévalo and Aponte (2020) obtained a higher amount of carbon of 76.5 tons, while Arévalo Rivas in 2018 obtained 1.1 tons C/ha, which is lower than our 19.4 tons C/ha. The lower data is due to the low presence of dead biomass in the spring season. Hernández et al. (2014) mention that “dead plant matter on the soil is the main source of carbon.” In other words, where there is a higher density of living biomass, there will be greater mortality and, consequently, a greater amount of carbon stored in the soil.

3.3. Determination of total carbon in Amara loma by spatial modeling

Soil and tillandsial carbon sequestration data were modeled using Kriging geostatistical interpolation, resulting in a histogram with a Gaussian bell shape (Kurtosis of 2.37) and a normal distribution. The method used was the ordinary method in logarithmic function. The semiovariogram of the model applied in the kriging methodology for aerial carbon in the study area was determined by the linear equation of first degree obtaining the equation: 0.118722746308231 * x + 224.057987921692 and 118722746308231 * x + 224.057987921692 for soil carbon. With this equation it was possible to extrapolate the data. The amount of 35.4 Tn C/ha was estimated for the aerial carbon which is the biomass of the tillandsial (Figure 3b) and 19.4 Tn C/ha for the soil (Figure 3a). The sum of both was 54.8 Tn C/ha stored by the Amara loma with an area of 7,338.63 ha.
The value obtained in the study area (35.4 tC/ha) falls within the ranges of carbon stored in desert ecosystems around the world (0.15 and 45.55 tC/ha in African deserts, the Sahel transition zone, the Negev desert, some deserts in China, the Mojave, the La Paz basin, and Los Planes) Guerrero-Palomino., 2021.

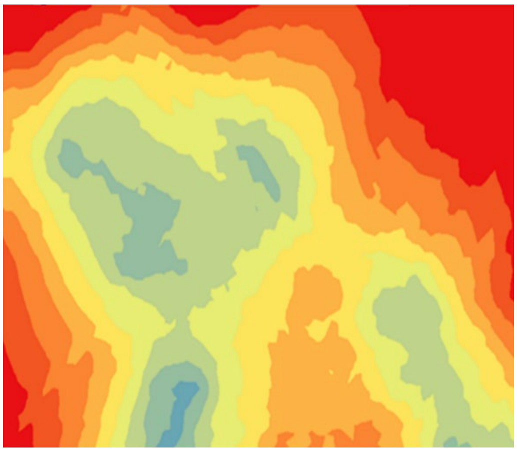

Figure 3a. Modeling of tillandsial carbon.

Figure 3b. Modeling Soil carbon

Some studies related to carbon sequestration include Cabrera (2016), who estimated 8.39 t/ha in tillandsial in the Quebrada Inocente Lomas de Ancón Reserved Zone, where necromass was the main carbon sink. Chino (2018) found 2.75 t C/ha of carbon stored in plant biomass in the Tillandsial del Cerro Intiorko - Tacna, and the total amount of carbon stored in the area was 61,250.21 t C. Arévalo and Aponte (2020) estimated 94.10 t for Cerro Piedra Campana (Lima/Peru). Toledo (2020) determined that in Lomas Arrojadero, in the districts of Inclán and Locumba - Tacna, Tillandsia werdermannii captured 1.78 t C/ha of carbon in plant biomass, while Tillandsia purpurea captured 1.66 t C/ha; the total amount of carbon stored in the living biomass and necromass of Tillandsia was 25.15 t C, representing an estimated capture of 92.30 tons of CO_2. Guerrero-Palomino et al., (2021) obtained a result of 39.29 tC/ha stored in Loma de Amancae for an area of 223.43 ha, and recorded a lower amount of carbon (1.44 tC/ha) in the above-ground biomass compared to the soil (37.85 tC/ha). The results of the other authors research differ from ours because the species are different (leaf size) even though they belong to the same family, and also because of the coverage and the size of the loma.
Ampuero, (2018) estimated the carbon stored in the community of the Junco (Schoenoplectus Americanus P.) under two growth scenarios in the coastal wetland wildlife refuge pantanos de Villa (Lima-Peru)" concludes that when performing the carbon analysis in the natural growth zone it can be observed that the total carbon deposits of the junco and in the natural growth zone were 305.37 tnC/ha, which is equivalent to 1120.70 tn CO_2/ha.
Other studies such as that of Ampuero, (2018) estimated the carbon stored in the community with the species Schoenoplectus Americanus (Junco) under a different scenario which was the coastal wetland wildlife refuge Villa swamps (Lima-Peru) ". This concludes that when carrying out the carbon analysis in the natural growth zone it can be observed that the carbon deposits of the rush totoral were 305.37 tnC/ha, likewise, Pumasupa (2018) quantified carbon capture in a forest species Haplorhus Peruviana Carzo as part of the Environmental Service of the Cinto Valley, Tacna. The estimated value was 4.5240 tnC/ha.
There is no other soil carbon sequestration study of tillandsiales, except for Arévalo and Aponte (2020), who obtained a carbon amount of 76.5 tn, which is different from our result (19.4 Tn C/ha).
This is due to the low presence of dead biomass in the spring season. Hernandez et al., (2014) mentions that "dead plant matter to the soil is the main source of carbon". That is, where there is a higher density of living biomass there will be greater mortality and consequently a greater amount of carbon stored in the soil.

4. Conclusions

An average fresh biomass of 25.2 g and 72.5 % of humidity was recorded; therefore, it is of great importance for the communities that inhabit this type of desert ecosystem. In reference to carbon sequestration, it was estimated 35.4 Tn C/ha for the aerial carbon which is the biomass of the tillandsial and 19.4 Tn C/ha for the soil. so the greatest capture occurred in the above-ground plant biomass. The sum of both was 54.8 Tn C/ha captured by the tillandsial of the Amara loma with an area of 7,338.63 ha, also, the value obtained in the study area falls within the ranges of carbon stored in desert ecosystems around the world (0.15 and 45.55 tC/ha) in African deserts, the Sahel transition zone, the Negev desert, some deserts in China.

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