

Determination of total carbon stored in reforestations established in the National Park Iztaccíhuatl Popocatepetl

Determinación del carbono total almacenado en reforestaciones establecidas en el Parque Nacional Iztaccíhuatl Popocatepetl

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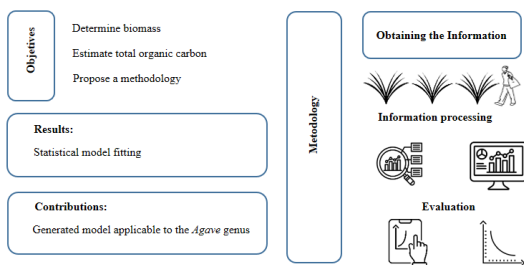


Abstract

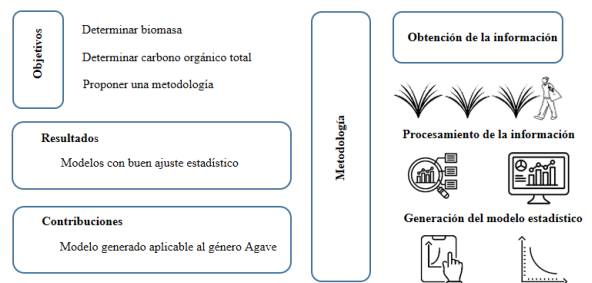
The Natural Protected Areas, are considered highly efficient, given their natural vocation and the objectives which are to keep their forests and meadows in perfect condition. The objective of this work was to generate allometric equations to estimate biomass and carbon from *Pinus hartwegii* and *Muhlenbergia macroura*, in addition to the carbon content in the soil, considered as carbon reservoirs. A destructive sampling of 94 trees from one to ten years old and 55 grass samples was carried out. The study was conducted in the Iztaccíhuatl-Popocatepetl National Park. Carbon from aerial biomass in reforestation and natural grassland was calculated using the generated equations and data obtained from 234 sampling sites. For the organic carbon determination in the soil, 35 samples were extracted at two depths (0-15 and 15-30 cm). The resulting equation for the estimation of the *Pinus hartwegii* biomass was $B=0.0092Db^{2.7303}$ and for *Muhlenbergia macroura* the equation were $B=0.075+0.00001393Db^2$ h. The average carbon content was 50.3 and 42.1% for trees and pastures, respectively. In order of magnitude the total carbon storage in the 750 hectares was 76,566.7 Mg of C in the soil, 2,249.50 Mg of C in pastures and 37.12 Mg of C in reforestation.

Resumen

Las Áreas Naturales Protegidas, se consideran altamente eficientes para secuestrar carbono porque fueron creados para mantener su vegetación en perfecto estado. El objetivo de este trabajo fue generar ecuaciones alométricas para estimar biomasa y carbono de *Pinus hartwegii*, *Muhlenbergia macroura* y en el suelo, para plantaciones de 750 ha del Parque Nacional Iztaccíhuatl-Popocatepetl. Se muestrearon 94 árboles de uno a diez años y 55 muestras de pasto. El carbono de la biomasa aérea en reforestaciones y pastizal natural se calculó mediante las ecuaciones generadas en este estudio y con datos obtenidos de 234 sitios de muestreo. Para la determinación de carbono orgánico en el suelo se extrajeron 35 muestras a dos profundidades (0-15 y 15-30 cm). La ecuación resultante para la estimación de la biomasa en arbolado menor a 7.5 cm de diámetro normal de *Pinus hartwegii* fue $B=0.0092Db^{2.7303}$ y para *Muhlenbergia macroura* fue: $B=0.075+0.00001393Db^2$ h. El contenido de carbono promedio fue de 50.3% para árboles y 42.1% para pastos. En orden de magnitud, el almacenamiento de carbono total en las 750 ha fue de 76,566.7 Mg de C en el suelo, 2,249.50 Mg de C en pastos y 37.12 Mg de C en reforestaciones de diez años.



Biomasa, Destructivo, Muestreo, Reforestación, Reservorio



Biomass, Destructive, Sampling, Reforestation, Reservoirs

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Introduction

One of the most important reservoirs of carbon (C) in the biosphere is found in terrestrial ecosystems, i.e. in living plant organic matter, necromass (dead plant matter) and soil organic matter (Ruíz *et al.*, 2014).

Forest ecosystems are particularly important as C reservoirs; they assimilate and store large amounts of carbon throughout their lifetime (De Jong *et al.* 2004).

According to Gargaglione *et al.* (2010), this capacity varies according to floristic composition, age and stocking density, information that coincides with that reported by Aalde *et al.* (2006) and Estrada (2007), who also highlight the participation of climate and forest management to which the ecosystem is subject, which indicates that secondary forests and young plantations fix a greater amount of carbon per unit of time (Estrada, 2007).

On the other hand, Barnes *et al.* 2024, found links between reforestation and surface and air temperature response in the eastern United States and found that forests cool the land surface by 1 to 2°C per year compared to nearby grasslands and croplands.

Trexler and Haugen (1995) state that Mexico's potential to store carbon through forest plantations is 30 to 85 x^{10⁶} Mg C, where vegetation cover plays an important role, showing that higher cover corresponds to higher carbon sequestration (Schneider *et al.* 2024).

According to SEMARNAT (2012) Mexico does not have a direct commitment to abate its CO₂ emissions to a specific level, but it does have the possibility of accessing carbon sequestration credits through the Clean Development Mechanisms (CDM) defined in the Kyoto Protocol.

It is for this reason that the quantification of carbon absorption by tree vegetation is more relevant, in this sense, biomass is the parameter at tree or forest level, which allows estimating carbon stores, understanding the term biomass as the amount of aerial organic matter present in the tree components: trunk, branches, leaves, fruits and roots.

The most commonly used methodologies in Mexico for estimating biomass and carbon in forest species are classified into indirect methods (generation of allometric equations, biomass or carbon expansion factors and using remote sensing images) and direct methods that consist of a destructive process to obtain samples of tree components (Díaz *et al.*, 2007).

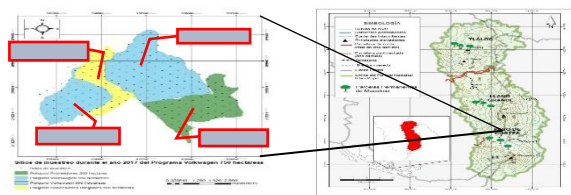
Therefore, the objective of the present work was to estimate the amount of biomass in young *Pinus hartwegii* Lindl. trees and in the *Muhlenbergia macroura* (Kunth) Hitchc. (*Muhlenbergia macroura*) (Kunth) Hitchc. and then measure the carbon in the above components and in the soil, in an area of 750 ha reforested in ten years by the Volkswagen de México company in four plots of the Iztaccíhuatl Popocatepetl National Park.

Materials and Methods

The study was carried out in an area of 750 ha, annexed to the programme on restoration, protection and conservation of natural resources of the Iztaccíhuatl Popocatepetl National Park (Izta-Popo NP). The area is made up of four properties located to the south of the Iztaccíhuatl volcano near the mountain pass called Paso de Cortés, with surfaces of 150, 100, 300 and 200 ha each (Figure 1), where ecological restoration work has been carried out since 2008, consisting of good soil management practices for water retention in ravines, barriers with dead plant material, infiltration pits and reforestation with the *Pinus hartwegii* species, in charge of the Volkswagen de México car company.

The area is located at the coordinates 21° 11' 58.00' North Latitude and 53° 60' 14.83' West Longitude. The predominant climate is cold and humid high mountain, with average annual temperatures between 5 and 12 °C (CONANP, 2013).

The soil units present are Lithosols now Leptosol, coarse-textured and medium-textured distric Regosol. Vegetation consists mainly of pine forest and zacatonal (CONANP, 2013). The area that includes the four properties is located in an altitudinal range from 3670 to 3885 m asl.

Box 1**Figure 1**

Location of the reforested properties studied, close to the Paso de Cortés valley in the Iztaccíhuatl-Popocatepetl National Park

To obtain information on the planted trees in terms of density (number of trees per unit area) and size (dimensions in basal diameter and height) of the four properties, systematic sampling was applied with a distance between rows and rows of 180 x 180 m due to the homogeneity of the properties in terms of type of vegetation and topography. In this way, 234 circular sites of 500m² were surveyed and the geographical coordinates were taken at each sampling point.

Determination of biomass in saplings

A methodology similar to that reported by Acosta *et al.* (2002), Avendaño *et al.* (2009) and Carrillo *et al.* (2016), used in different forest species in Mexico, was used to estimate the biomass in the saplings.

A representative sample of 94 *Pinus hartwegii* trees planted in the reforestations was taken, which showed no evidence of damage or phytosanitary problems and ranged in age from newly planted to 10 years old. Care was taken to include in the sample all sizes present by diameter category.

Prior to the extraction of the trees, the height at the first live branch (hL) and the total height (hT) were measured; useful data to generate the allometric model to estimate the biomass and carbon content.

Both variables were measured with a 3 m long 'ameritape' tape measure; the diameter of the base (Db) was also measured with a Surtek steel analogue vernier caliper, and when the base exceeded 20 cm in diameter, a 5 m long 'David Ominicus' tape measure was used.

In all cases, the centimetre was used as the unit of measurement. Using picks and shovels, the selected trees were extracted from the ground in their entirety, including their roots (thick, medium and thin); they were sectioned, labelled and transferred to be placed in a tunnel-type greenhouse to accelerate the loss of humidity, in order to finally obtain the dry weight of each of their components.

Before the material entered the greenhouse, the trees were separated into their root, stem, branches and foliage components, and their weight was constantly obtained until it was ensured that there was no longer any loss of moisture or until the constant weight of each component was obtained using a Mercurio digital scale with a capacity of 30 kg and 10 g of precision.

Components weighing less than 200 g were weighed on a Scout® Pro portable precision balance. Once moisture loss was no longer recorded in the greenhouse for all samples and all components, sub-samples were taken for complete drying and dry weight determination.

Once the parts of each tree were separated, a total of 376 subsamples were obtained, which were placed in paper envelopes and coded with the corresponding number of the tree and the part of the component to which they belonged (root, stem, branch or foliage).

Each subsample was weighed on a portable precision balance before being placed in a drying oven, so that information on the moisture content still contained in the subsamples could be obtained using the ratio: (initial weight-final weight/initial weight) and then this ratio of moisture loss could be applied to the greenhouse samples. Smaller subsamples were used in order to dry them completely and were placed in a Blue M Stabil-Therm drying oven at 75 °C for 72 hours until a constant weight was achieved, with the information on the moisture lost from the subsamples in the oven. This amount was applied to the total tree component that had been previously dried and weighed in the greenhouse, thus determining the dry weight or biomass of each component of all the trees sampled, and the sum of the biomass of the four components constituted the total biomass of each tree.

A potential model (Acosta *et al.*, 2002) was used to estimate total biomass as a function of Db, height at first branch (hL) or total height (hT). The fit parameters were obtained using the least squares statistical procedure using the SAS package (2011). The general form of the model is presented in equation 1 (Acosta *et al.*, 2002).

$$Y = bX^k \quad (1)$$

where Y is the tree-level biomass (kg), X is an easily measured tree variable (cm), in this case it could be hL, hT or Db; b and k are the model parameters.

Once the data on biomass content per tree (kg) were obtained, equation 1 was used to estimate it as a function of Db and the hL and hT variables for each tree were also tested with this model.

Determination of carbon in saplings

Of the 94 trees measured for biomass estimation, 13 trees were selected, covering all size ranges, used to determine the percentage of carbon per component.

It was decided to use only 13 trees since the variability of carbon content in the different components of a plant sample of the same species has been found to be low (Carrillo *et al.*, 2016), such content being reported to be approximately 50% (IPCC, 2003).

The subsamples were prepared and analysed in the laboratory, ground and sieved with a No.60 mesh. To obtain each subsample, we proceeded as follows: from each of the 13 trees we took a portion of material from each component (root, stem, branch or foliage) of approximately 5.0 g and placed it in a Blue M ov-490A-2 oven for two hours at 65 °C; then we took 30.0 to 30.9 mg and determined its carbon content by the dry combustion method in the Shimadzu TOC 5050-A carbon analyser.

Once the carbon content per component was determined, an average was obtained, which can be applied to the biomass content of each tree to determine the amount of carbon contained in each of the trees sampled. To obtain the carbon content of each component of the whole tree, the total biomass of each component was multiplied by the average of the fraction of carbon content obtained from the sub-samples.

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Determination of biomass and carbon in grasses

To measure the amount of biomass in *Muhlenbergia macroura*, 65 plants were selected to cover all sizes of grasses, prior to obtaining the samples in grasses, the following measurements were taken for each one: diameter at the base (Db) in cm with a 5 m diameter tape 'David Ominicus', the diameter measured included all the tillers at ground level; total height (H) in cm with a 3 m tape measure 'ameritape' and refers to the height at which the last leaf of the tiller is naturally located; The crown diameter (dc) in cm was also measured with the same tape used to measure 'H' and refers to the coverage of the leaves of all the naturally growing canes.

The inclusion of these three variables was intended to test one or more variables (combined variables) in the statistical model and determine which one(s) had the best fit. Subsequently, each specimen was extracted with all its roots, taking care not to lose leaves or roots. Each of the 65 plants were placed in paper bags and transported to a tunnel greenhouse to accelerate the loss of humidity.

Once in the greenhouse and once they were considered sufficiently dry, the aerial part and the roots were weighed separately on a Mercurio model digital scale with a capacity of 30 kg and 10 g of precision; this procedure was carried out until there was no longer any loss of moisture in the components of each plant or when their weight was constant.

Since the total dry weight of the components was not obtained in the greenhouse, aliquots of each component were taken to bring them to dry weight, before being placed in a Blue M ov-490A-2 drying oven in small envelopes, their weight was recorded on a Scout® Pro model portable precision balance as the initial weight and after 72 hours had passed and to ensure that there was no decrease in weight of each aliquot, their weight was recorded as the final weight to obtain the proportion of moisture loss using the ratio: initial weight-final weight/initial weight, which was applied to the material that remained in the greenhouse.

From the 65 plants, eight plants covering the whole size range were chosen to determine the percentage of carbon in each of their components (foliage and root), the eight plants were placed separately in a manila paper envelope and coded with the number of the specimen and the type of component. To determine carbon, the same procedure was used as for measuring carbon in trees.

The allometric model tested to determine the biomass and carbon in grasses was model 1: $Y=bX+a$
For both models the highest value of the coefficient of determination was considered as the best fit criterion.

Due to the high amount of grasses present in each sampling site, to define the amount of biomass per unit area expressed in $Mg\ ha^{-1}$ per grass concept, each site was divided into four sections and in each section the percentage covered by large grasses (> 10 cm diameter at the base) and small grasses (< 10 cm diameter at the base) was determined.

Measuring soil carbon

To measure soil carbon, out of the 234 sampling sites in the four farms, 35 were randomly selected in proportion to the size of the farm. At these, soil samples were obtained based on the methodology described in the National Forest and Soil Inventory (CONAFOR, 2011).

Soil samples were collected at two depths: 0-15 and 15-30 cm located in the centre of each plot, using two stainless steel augers with collection tubes of 4.1 and 2.17 cm in diameter, respectively. A total of 70 samples were obtained, labelled and placed in a tunnel greenhouse to accelerate drying.

After removing roots and stones, the soil samples were broken up with a hammer. Once homogenised, a subsample of approximately 5 g per sample was taken and dried in a Blue M ov-490A-2 oven at 105 °C for two hours, after which they were ground in a SPECK 8000 MIXER/MILL for three minutes (Acosta *et al.*, 2002); this ensures that at least 90% of the material passes through a 100 mesh mesh screen. After grinding, they were dried a second time at 105 °C for two hours; finally, to measure the organic carbon content, they were placed in a Shimadzu TOC 5000-A automatic total carbon analyser (Shimadzu TOC 5000-A).

To estimate the amount of carbon in the soil, an accurate measurement of the bulk density of the soil is required. Although the dry soil volume did not take into account the weight of stones and roots, it was corrected for the volume of stones, using the density value of $2.4\ g\ cm^{-3}$ calculated by Monreal *et al.* (2005).

On the other hand, the volume occupied by the roots in each soil sample was negligible, so it was not considered in the subsequent calculations. All results are presented in Mg (Megagrams, which is equivalent to tonnes).

Results and discussion

The distribution of biomass in planted trees and grasses was as follows: the highest accumulation in *Pinus hartwegii* was concentrated in the root with a mean of 37.36 %, followed by the foliage with 30.44 % of the total; the rest was contained in the stem and branches, with 24.06 and 8.14 %, respectively; these results are possibly due to the fact that the sampled plants were saplings of no more than 8 to 10 years of age and therefore, the highest biomass concentration was in the root and foliage.

Quite different from when measuring biomass concentration in adult trees, where the highest concentration is in the stem; for example, Carrillo *et al.* (2016) in a study for *Pinus hartwegii*, found that the biomass distribution was as follows: in the stem it varied from 45.5 to 84.6 % with an average of 65 %; in the branches, from 11.4 to 37.4, with an average of 23.8 % and in the foliage from 2.0 to 29.2, with an average of 10.9 %; for this study, the biomass content in the roots is not indicated because they were not included.

For the case of *Muhlenbergia macroura* the highest biomass concentration was in the aerial part, with an average of 78.34 % and the rest in the root (21.66 %).

This type of grass has a very shallow root, perhaps due to the moisture content and the type of soil that always prevails in the conditions where it grows and perhaps that is the reason for the distribution of carbon in these two components.

Biomass equations

Equation (1) to determine the total aboveground biomass of *Pinus hartwegii* as a function of diameter at base is as follows: $B=0.0092Db^{2.7303}$, where B is biomass in kg and Db is diameter at base in cm, with a coefficient of determination $R^2=0.9645$ and root mean square error=0.7696, considered acceptable (Figure 3a).

For *Muhlenbergia macroura*, although several mathematical models were tested to relate the amount of biomass as a function of Db, canopy height (H) and dc, the equation that provided the best fit was the linear equation relating the square of the diameter at base (Db) by height (H), the model is as follows: $B=0.00001393Db^2H+0.075$ where B is the biomass in kg, Db is the diameter at base in cm and H the height in cm, with $R^2=0.9402$ and root mean square error=0.3543 (Figure 3b).

Box 3

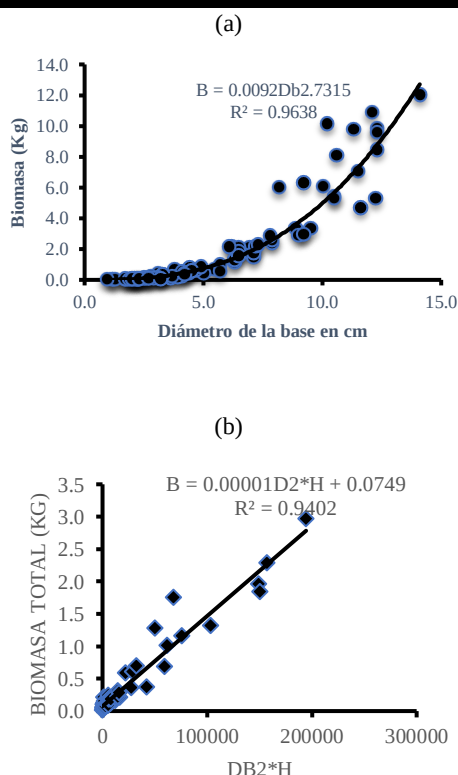


Figure 3

Dispersion of data and trend line of biomass values; a) *Pinus hartwegii*; b) *Muhlenbergia macroura*

The biomass values generated for the root, stem, branches and foliage of *Pinus hartwegii*, were within the range of percentages found for the same species in different sites (Ortíz-Rodríguez and Rodríguez-Trejo, 2008; Méndez et al., 2011; Cortés et al., 2019).

The values obtained indicate that at younger ages or in the smallest trees, the highest biomass concentration occurred in the root and foliage, in contrast to adult trees where it accumulates in the stem and branches (Carrillo et al., 2014; Carrillo et al., 2016; Ruíz et al., 2014). For Mexico, studies on the biomass storage potential of grass species are limited. However, foreign works, using more complex models, have limited this type of analysis (Burrell, et al.2024), finding that they have used species that are distributed in altitudinal gradients (3500-4000 masl) comparable to the species under study. The percentage of biomass of the aerial and root part of *Muhlenbergia macroura* determined were found to be within the ranges obtained for Peruvian zacatonal in the species *Calamagrostis vicunarum*, *Festuca dolichophylla* and *Muhlenbergia ligularis* (Quispe et al., 2015).

Carbon concentration

The carbon determined in the laboratory of the different components of the biomass of the *Pinus hartwegii* samples that were analysed was on average: 50.3 % in the root, 51.7 % in the stem, 50.7 % in the branches and 50.6 % in the foliage.

Therefore, in general, the average percentage of carbon with respect to the total biomass of each tree was 50.9 %, which is very similar to the percentage of carbon recommended for the biomass of different species (IPCC 1994).

For *Muhlenbergia macroura* the carbon was distributed in 42.0 % for the root and 42.2 % in the aerial part, with an overall average of 42.1 %, which differs considerably from the IPCC recommendation that 50 % of the biomass is carbon.

Carbon determination

To determine the carbon content for the *Pinus hartwegii* saplings, it is sufficient to apply the model to estimate the biomass and apply the percentage of carbon, which was 50.9, the average resulting from analysing the different components of the plant. There are studies that determine the biomass per plant component (Cortés et al. 2019), however, the objective in this study was to determine the total carbon store, both above and below ground, without considering the plant components.

Carrillo-Anzures, Fernando, Acosta-Mireles Miguel, Martínez-Ramírez Mayra and Flores-Ayala Eulogio. [2024]. Determination of total carbon stored in reforestations established in the National Park Iztaccíhuatl Popocatepetl. Journal Simulation and Laboratory. 11[30]1-10: e31130110. <https://doi.org/10.35429/JSL.2024.11.30.1.10>

For this study, the variable diameter at the base was used because the objective was to determine the amount of carbon present in the reforested trees and more than 90% of the sample used was trees smaller than 7.5 cm normal diameter, whereas for other studies, the most important thing is to measure the total carbon in the adult trees, without considering the carbon present in small trees or herbs and shrubs (Avendaño, et al., 2009, Acosta et al., 2002).

The equations are restricted to the range of variation in the dimensions of the sampled trees, whose diameter at the base ranged from 0.95 to 14.1 cm, which implies that they can be applied to the same species in different sites or regions, as long as they present similar environmental conditions and growth pattern.

In a plantation in China with *Pinus messoniana* , a result of 13.7 t ha⁻¹ of carbon was obtained at 10 years of age, and in plantations of 15, 20 and 25 years of age, maximum accumulated values of 50.14, 85.86 and 115.17 t ha⁻¹, respectively, were obtained (Bai & Ding, 2024), which were much higher than those obtained in the present study.

On the other hand, the determination of carbon in *Muhlenbergia macroura*, as for the reforestation trees, once the amount of biomass is determined, the average percentage of carbon obtained for this species is applied, which was 42 %.

Soil carbon

The content in the top layer (0-15 cm) was higher than that found in the second layer (15-30 cm) by approximately 15 %, only in the 200 ha plot, it was slightly higher in the depth of 15 to 30 cm; this result may be due to two factors; first, sampling was only carried out in four sites of the plot and this could generate uncertainty because a very low number of samples were used; the second factor that influenced and is considered the most reliable, is that the bulk density of the soil in the layer from 0 to 15 cm depth was 0.91 gr cm⁻³, while in the soil layer from 15.1 to 30 cm depth, the bulk density was 1.19 gr cm⁻³, however, the percentage of carbon in the shallowest layer was 4.07, while in the deepest layer it was 3.14, which confirms that the shallowest soil layer does contain a higher percentage of carbon.

The average organic carbon at the depth of 0 to 15 cm ranged from 48.29 to 67.06 Mg-ha⁻¹ and from 15 to 30 cm ranged from 38.23 to 57.8 Mg-ha⁻¹ (Table 1). Soil carbon values were found to be within the ranges (42.567-103.08 Mg ha⁻¹) cited by Madrigal et. al. (2019) for soils where *Pinus hartwegii* is distributed ; although they are low compared to pine forest, pine-oyamel and grassland soils (145.5 Mg ha⁻¹) (Vela et al., 2012) and lithosol soils (137.0 Mg ha⁻¹) (Food and Agriculture Organization of the United Nations [FAO] 2002).

Box 4
Table 1
Organic carbon stored in soil at two depths (0-15 y 15-30 cm) Mg·ha⁻¹.

Statistics	150 ha		100 ha		300 ha		200 ha	
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Minimum	35.	23.	47.	44.	39.	30.	45.	43.
Mean	35	06	62	82	80	41	31	82
	48.	38.	67.	57.	55.	40.	55.	56.
	29	23	06	80	38	51	66	01
Maximum	57.	48.	86.	73.	71.	57.	70.	89.
	99	93	62	59	68	29	80	44
Deviation	7.0	7.9	13.	11.	12.	8.1	11.	22.
			2	1	2		7	3

Carbon in reforestations and natural grasslands

The average carbon accumulated in *Pinus hartwegii* reforestations ranged from 0.026 to 0.74 Mg-ha⁻¹, a relatively low value compared to 19.68 Mg C ha⁻¹ for twelve-year-old mixed plantations of *Pinus devoniana* Lindl. and *P. pseudostrobus* Lindl. in Guanajuato Mexico (Méndez et al. 2011).

However, it is convenient to consider that the conditions where *Pinus hartwegii* develops with those of *Pinus devoniana* and *P. pseudostrobus* are different. The average carbon stock obtained for the eight grassland samples was 42.1 % with a standard deviation of 2.131 and varied from 2.85 to 3.04 Mg-ha⁻¹, which is well below the 21.4 Mg-ha⁻¹ reported by Segura et al. (2005) for grasslands in Mexico. The total carbon stored in the 750 ha was 78,853.39 Mg, of which 37.12 Mg corresponds to the *Pinus hartwegii* plantations, 2,249.50 Mg to natural *Muhlenbergia macroura* grass and 76,566.77 Mg in the mineral soil at a depth of 0 to 30 cm. Table 2 shows the distribution of carbon content by plot.

Box 5
Table 2

Total carbon stored in 750 ha of Iztaccíhuatl-Popocatepetl NP

Reservorio	Total carbon in Mg per site				Total
	150 ha	100 ha	300 ha	200 ha	
Reforestation	4.08	5.55	22.26	5.24	37.13
Natural grassland	446.76	285.33	913.67	603.74	2,249.50
0-15 cm	7,243.30	6,706.06	16,615.36	11,131.06	41,695.78
Soil 15-30 cm	5,735.15	5,780.26	12,154.12	11,201.47	34,870.99
Total	13,429.29	12,777.20	29,705.41	22,941.50	78,853.39

The carbon content in each plot studied will depend on the surface area of the plot, as well as the vegetation present at the time of the study.

Similar results regarding soil carbon content were found by Cruz *et al* (2019) in riparian soils of the Izta-popo National Park at a depth of 20 cm with a carbon content of 80.6 Mg C ^{ha-1}.

Gómez *et al* (2012) found that, in a low deciduous forest ecosystem, the amount of total soil organic carbon ranged from 78.12 to 93.68 Mg C ^{ha-1}, where the carbon included that of the forest floor, fine roots, coarse roots and medium roots, in addition to the soil organic C.

Conclusions

In this study it was possible to adjust two allometric equations, one of potential type to determine the biomass in trees smaller than 7.5 cm of normal diameter in *Pinus hartwegii*; the other is a linear equation to quantify the biomass in *Muhlenbergia macroura* by simply multiplying the square of its diameter at the base by the height.

At the same time, in the planted plots, carbon storage was determined at two depths of the mineral soil, and this showed the highest amounts (97.1%) of the total carbon stored in the four plots. Finally, it is concluded that there is a total of 78,853.39 Mg of carbon stored in the four plots of the ten-year old plantations established by Volkswagen de

México in the Paso de Cortés of the Iztaccíhuatl-Popocatepetl National Park.

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Authors' contribution

Carrillo-Anzures, Fernando: Project design, securing funding source

Acosta-Mireles, Miguel: Project design, obtaining source of funding, methodology design

Martínez-Ramírez, Mayra: Field data collection, sample analysis, data analysis, article writing.
Flores Ayala Eulogio: Data analysis, revision of the paper.

Availability of data and materials

Data from the present research are available upon request to the corresponding author.

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Abbreviations

CONANP	National Commission of Natural Protected Areas
CONAFOR	National Forestry Commission
Db	Diameter at base
Ht	Total height
hL	Height at first live branch
FAO	Food and Agriculture Organisation of the United Nations (FAO)
IPCC	Intergovernmental Panel on Climate Change
MDL	Clean Development Mechanisms

NP National Park
SEMARNAT Ministry of Environment
and Natural Resources

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