Manglar

Manglar 21(3): 305-311 (2024)

Reservas de carbono en tres sistemas silvopastoriles de la Amazonía peruana

Carbon stocks in three silvopastoral systems in the Peruvian Amazon

María Elena Díaz Pablo[1*]; Julio Cesar Alegre Orihuela[2]; Carlos Alfredo Gómez Bravo[3]; Pedro Mendoza Tamani[4]; César O. Arévalo-Hernández[4,5]

1 Facultad de Zootecnia, Universidad Nacional de la Amazonía Peruana (UNAP). Yurimaguas, Perú.
2 Facultad de Agronomía, Universidad Nacional Agraria La Molina (UNALM). Lima, Perú.
3 Facultad de Zootecnia, Universidad Nacional Agraria La Molina (UNALM). Lima, Perú.
4 Facultad de Ingeniería, Universidad Nacional Autónoma de Alto Amazonas (UNAAA). Yurimaguas, Perú.
5 Departamento de Suelos, Instituto de Cultivos Tropicales (ICT). Tarapoto, Perú.

* Autor corresponsal: maria.diaz@unapiquitos.edu.pe (M. E. Díaz Pablo).

ORCID de los autores:

M. E. Díaz Pablo: https://orcid.org/0000-0002-2026-3559
J. C. Alegre Orihuela: https://orcid.org/0000-0002-7282-045X
C. A. Gómez Bravo: https://orcid.org/0000-0001-9021-5838
P. Mendoza Tamani: https://orcid.org/0000-0001-8798-3174
C. O. Arévalo-Hernández: https://orcid.org/0000-0002-1390-3503

RESUMEN

Los sistemas silvopastoriles (SS) combinan productividad con mitigación del cambio climático y mejoran las reservas de carbono (C). El objetivo de la investigación fue estimar las existencias de C en tres sistemas silvopastoriles de la selva alta. Para el estudio se seleccionaron tres sistemas silvopastoriles: Cedrelinga cateniformis (Tornillo), Eucalyptus spp. (Eucalipto) e Inga edulis (Inga). Se recolectaron y analizaron muestras de suelo de 0-15 cm y 15-30 cm para determinar sus características físicas y químicas. La estimación de las reservas de C se realizó a partir de biomasa con ecuaciones alométricas. El análisis estadístico se realizó mediante análisis descriptivo (medias y desviación estándar) y ANOVA y uso de la prueba de Scott Knott. Las propiedades del suelo no mostraron diferencias significativas entre SS, a excepción de P, Al y CIC. Las reservas de carbono fueron mayores en el sistema tornillo. En general, las reservas de C en el SS fueron mayores en el suelo y representaron la principal reserva de C, superando a la vegetación. Los resultados resaltan la importancia del suelo como sumidero de carbono y su papel en la mitigación del cambio climático.

Palabras clave: Sistema agroforestal silvopastoril; árboles forestales; pastos; carbono del suelo; hojarasca.

ABSTRACT

Silvopastoral systems (SS) combine productivity with climate change mitigation and improve carbon (C) stocks. The objective of the research was to estimate C stocks in three silvopastoral systems of the high jungle. Three silvopastoral systems were selected for the study: Cedrelinga cateniformis (Tornillo), Eucalyptus spp. (Eucalyptus) and Inga edulis (Inga). Soil samples of 0-15 cm and 15-30 cm were collected and analyzed to determine their physical and chemical characteristics. The estimation of C reserves was carried out from biomass with allometric equations. Statistical analysis was performed using descriptive analysis (means and standard deviation) and ANOVA and use of the Scott Knott test. Soil properties did not show significant differences between SS, except for P, Al and CEC. Carbon reserves were higher in the screw system and lower in the inga system. In general, C reserves in the SS were greater in the soil and represented the main C reserve, surpassing the vegetation. The results highlight the importance of soil as a carbon sink and its role in mitigating climate change.

Keywords: Silvopastoral agroforestry system; forest trees; pasture; soil carbon; litter.

Recibido: 27-05-2024.
Aceptado: 12-08-2024.

DOI: http://doi.org/10.57188/manglar.2024.033

INTRODUCCIÓN

The Amazon, considered the lungs of the world, is a vast and biodiverse ecosystem that supports a great variety of flora and fauna species (Walker et al., 2020), as well as being one of the world's largest carbon reservoirs due to its extensive forest biomass. Amazonian trees play a fundamental role in climate change mitigation by capturing and fixing atmospheric carbon dioxide (Sharrow and Ismail, 2004; Wright et al., 2001). However, in recent decades, various human activities such as indiscriminate logging, illegal mining, human settlements and natural resource exploitation have led to the deforestation of extensive areas of virgin forests in this region (Assunção et al., 2017; Coomes et al., 2021; Dávalos et al., 2011; Garate-Quispe et al., 2021). While these activities are widely known, it is crucial to highlight the role that extensive cattle ranching and shifting agriculture have played in contributing to the massive deforestation of vast forested areas in the Latin American Amazon, causing the loss of biodiversity-rich ecosystems, the extinction of species and contributing to the increase of greenhouse gas emissions, carbon to the atmosphere, as forests capture about 30% of annual anthropogenic emissions (Gallo Aponte & Sanabria Rodelo, 2019; Kaimowitz & Angelsen, 2008; Le Quéré et al., 2015).

In the Peruvian Amazon, both activities have caused the disappearance of large areas of tropical forests, perpetuating a cycle of environmental degradation where areas deforested by shifting agriculture are subsequently used for extensive grazing, impeding forest regeneration (Dourojeanni, 1987; Velarde et al., 2010). Shifting agriculture, practiced by resource-poor farmers, consists of cultivating forest soils for 2 to 3 years until their fertility is exhausted and then leaving them fallow for periods of 5 to 20 years, driving the constant search for new land due to severe Amazonian soil limitations (Dourojeanni, 1987).

Although extensive livestock farming accounts for 40% of the gross value of national agricultural production (MINAGRI, 2017), its negative impacts are undeniable. Deforestation and land use change are responsible for 47% of greenhouse gas emissions in Peru (MINAM, 2009). In addition, these systems imply low efficiency in land use, erosion, loss of biodiversity and social inequality, factors that have caused cattle ranching to be seen as a productive sector that threatens ecological sustainability (Mahecha, 2003). It is therefore urgent to implement sustainable livestock production systems that reconcile economic, sociocultural and ecological needs and contribute to climate change mitigation.

In this context, silvopastoral systems (SS) have emerged as a promising sustainable alternative. These agroforestry systems integrate trees, shrubs and grasses for the production of livestock, timber, fruits and other goods, increasing pasture quality, improving animal productivity, providing shade for livestock, restoring degraded soils, sequestering carbon, conserving biodiversity and mitigating adverse environmental impacts of conventional livestock systems (Broom, 2017; Buitrago, et al., 2018; Montagnini et al., 2013; Murgueitio et al., 2015); Although there are various SS modalities adapted to different purposes, in the Peruvian Amazon their full adoption has been limited due to the socioeconomic situation of agricultural producers, opting for local adaptations such as pastures with scattered trees and basic management of improved pastures in extensive breeding systems, with some exceptions in dairy production systems (Ríos et al., 2002; Robiglio et al., 2015). However, in some towns in the San Martin region, at the beginning of the 21st century, producers installed improved pastures and adopted pasture management practices, allowing to increase the stocking rate to 3-4 animals per hectare (Ríos et al., 2001). Past research has shown that improved pasture, tree and SS are land uses with high carbon sequestration potential are sustainable for farmers (Anguiano et al., 2013; Ibrahim et al., 2007; McGroddy et al., 2015; Oliva et al., 2017) and may be a climate change mitigation strategy and the sustainable use of Amazonian territory.

Given the evidence of the high carbon sequestration potential of SS and their role as sustainable livestock production systems, the present study aimed to estimate carbon stocks in three SS of the Selva Alta Peruana, in the district of Soritor, province of Moyobamba.

METODOLOGÍA

Location

The study was carried out in Soritor, province of Moyobamba, San Martin, northeast of the Sub-Andean Belt of the Andes, in the area known as Alto Mayo. The urban-district is located 883 m above sea level (m.a.s.l.), while the highest mountains are near 3,000 m.a.s.l. Geographically, it is located between the coordinates: 6°8'21.2” S latitude and 77°6'7.8 W longitude. The average annual precipitation is 52.7 mm, and the average temperature is 26 °C (WeatherSpark, 2022) (Figure 1).

Selection of silvopastoral systems

Three SS arrangements were selected: SS with Inga (Inga edulis) dispersed in pastures, SS with eucalyptus (*Eucalyptus torrelliana*) in live fence and SS with tornillo (*Cedrelinga cateniformis*) dispersed in pastures. Each arrangement had 3 replications (Table 1). These systems were taken as if it were a completely randomized Block Design, being the blocks the sites where the SS plots were located for each repetition and the treatments were the 3 SS.

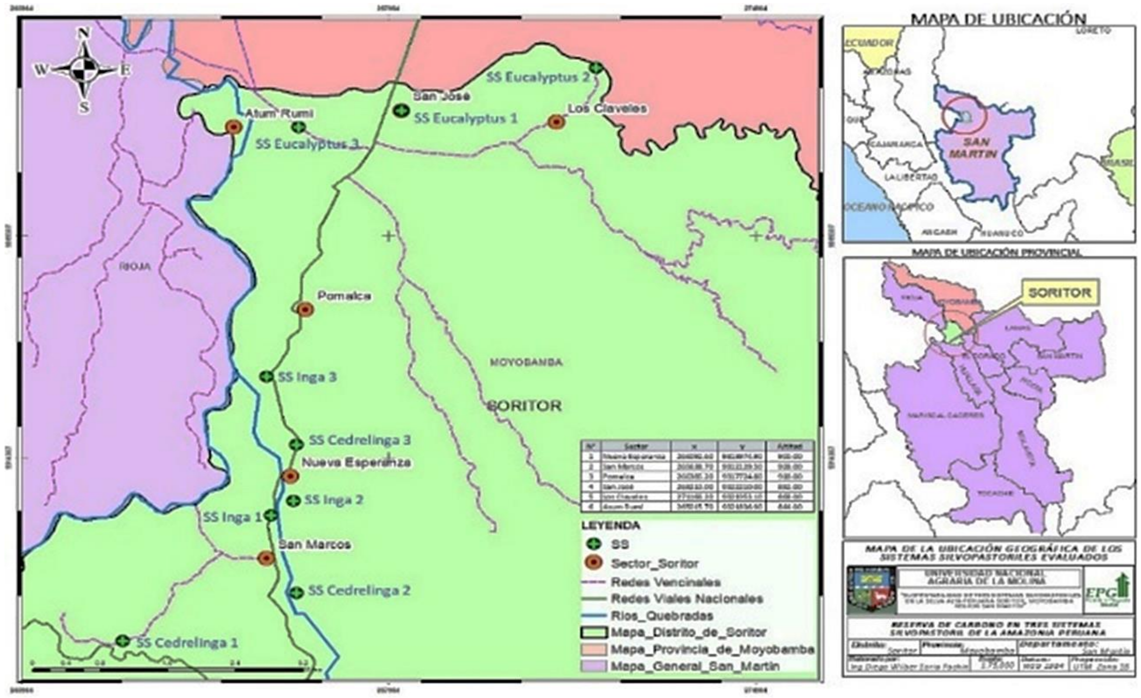

Figure 1. Geographical location of the sectors of influence for the sampling of three SS in the Peruvian Amazon.

Table 1
Location of the plots selected for the sampling of three SSPs in the Peruvian Amazon

SS	Species	Arrangement	Predominant pasture	Location of the plot
1	Inga (*Inga edulis*)	Dispersed in pastures	Brachiaria decumbens	1. Nueva Esperanza 2. Nueva Esperanza 3. Pomalca
2	Eucalyptus (*Eucalyptus torrelliana)*	Life fences	Brachiaria decumbens	1. San José 2. Los claveles 3. Atun Rumi
3	Tornillo (*Cedrelinga catenaeformis* Ducke)	Dispersed in pastures	Brachiaria decumbens	1. San Marcos 2. San Marcos 3. Nueva Esperanza

Soil sampling and analysis

For soil sampling, 5 pits were made for each experimental plot and soil samples were collected at 2 different depths: 0-15 cm and 15-30 cm. The soil was air-dried and taken to the laboratory for grinding, sieved at 2 mm and stored for subsequent physical and chemical analysis.

The analyses performed on the soil samples followed the procedures of Anderson and Ingram (1992) and Arévalo-Hernández et al. (2021), where soil texture (Bouyucos), soil bulk density (cylinder method), pH (1:2. 5 in water), organic matter (Walkey and Black, 1934), CEC (1M ammonium acetate, pH 7.0), P (Olsen), Ca, Mg, K (1 M ammonium acetate, pH 7.0) and Al (1 M KCl).

Evaluation of fresh aerial biomass of silvopastoral systems

For tree biomass, a 50 x 50 m plot was established and the trees within this area were evaluated and geo-referenced with a GPS navigator. Tree height measurements were taken with a Leica Geosystems laser distance meter. Diameter at breast height (DBH) was measured at 1.30 cm with a tape measure. The diameter of the tree crown was measured in three repetitions with a meter to finally obtain an average, then the vertical projection of the crown to the ground was estimated, after which calculations were made to obtain the radius of the tree. The tree and pasture litter were evaluated in a 0.50 x 0.50 m wooden quadrat at the base of the tree. Fresh litter samples were collected inside the quadrat and weighed. This procedure was repeated 5 times. Subsequently, all the material collected by each SS was sent to the laboratory to determine the dry matter content. For the live biomass of the pastures, seven replicates were randomly cut in a wooden quadrat of 0.50 x 0.50 m in a zigzag pattern along the entire area of the SS. These fresh samples after weighing were taken to the laboratory for dry matter analysis.

Determination of the dry weight of samples

From all samples collected for biomass determination, 100 g of material (leaf and grass) were dried at 105 °C in a circulating air oven and, after 24 hours, the dry weight of the samples was determined.

Then, based on the area harvested and the percentage of dry weight obtained, the biomass in t ha-1 was calculated with the following formula:

$$Dry\ weight\ \left(\frac{t}{ha}\right) = Fresh\ wight\ (g) * \frac{Dry\ weight\ \%}{100} * 0.04$$

Estimation of tree biomass

For biomass estimation, the following formulas were used for each tree species:

For Inga edulis (Terán-Ramírez et al., 2018):

$$\ln B\ \left(\frac{kg}{tree}\right) = (-1.289\ +\ 0.032\ \mathrm{X}\ \mathrm{DBH}^2 - \ 0.002\ \mathrm{X}\ \mathrm{DBH}^3\ +\ 1.131\ \ln \mathrm{DBH})$$

For Eucalyptus sp (Arévalo et al., 2003) :

$$B\ \left(\frac{kg}{arbol}\right) = 0.1184\ \mathrm{X}\ \mathrm{DBH}^{2.53}$$

For Cedrelinga cateniformis (Núñez Silvestre, 2018) :

$$\ln B\ \left(\frac{kg}{arbol}\right) = -2.96 + 2.66\ \mathrm{X}\ \ln \mathrm{DBH}$$

B: Total biomass (t ha^{-1})

DBH: Diameter at breast height (1.3 m).

Finally, the results were transformed into t ha^{-1}, considering the measured plot (2500 m^2) and the transformation from kg to tons.

Estimation of C in vegetation and soil

To estimate C, the conversion factor of 0.45 in plant species was used, following the formula below:

$$Cveg\ stock\ \left(\frac{t}{ha}\right) = Dry\ weight\ (\frac{t}{ha}) * 0.45$$

The following formula was used to calculate soil carbon stocks

$$Csoil\ stock\ \left(\frac{t}{ha}\right) = OC * BD * Depth * 100$$

OC= Organic carbón in %

BD = Bulk density in t/m^3

Depth = Soil Depth in m.

Finally, vegetation C and soil C were added together to calculate total carbon.

Statistical analysis

All statistical analyses were performed in the R statistical package. Descriptive statistics of mean and standard deviation were performed, and analysis of variance -ANOVA at a significance level of 0.05 was also performed. In case of significant differences, the Scott-Knott mean comparison test was performed at 0.05%.

RESULTADOS Y DISCUSIÓN

Soil attributes

The results of the soil analysis at 0-15 cm depth in the silvopastoral systems (SS) studied are presented in Table 2 and were only presented at the 0-15 cm depth, since from 15-30 cm it was not significantly different. In general, there were no significant differences ($p > 0.05$) between the physical properties of the soil, being all of them clay loam, likewise, it was decided to present only the bulk density (DA) of the soil, since it is used in the carbon calculations presented later.

However, for chemical properties, significant differences ($p \leq 0.05$) were observed in P, CIC, Ca^{+2}, Mg^{+2} and Al^{+3}. The SS with inga obtained the lowest values of P, but the highest average values of CIC and Al^{3+}. The high CEC may be associated with the presence of 2:1 phyllosilicates and kaolinite clays type 1.1, which leads to high exchangeable Al values and at the same time is conditioned by the lower value of available P in the SS. However, the p values obtained in all systems are considered very low (< 4 mg/kg) since it is the most limiting element in all acid soils of the Peruvian Amazon.

In the case of Ca and Mg, these values were similar in both the system with Eucalyptus and Inga, being the system with Cedrelinga the one that presented the lowest concentrations of these elements. This could be related to the high nutritional requirements of this species compared to the others (Alvarado, 2015).

Traditional pasture management with excessive animal stocking produces overgrazing and degradation in the physical quality of the soil with increases in the BD on the soil surface and increased mechanical resistance, which hinders root penetration, affecting pore distribution and soil structural stability (Salazar et al. 2024), on the other hand, SS recover the physical properties of the soil improving structural stability by increasing the C content in the soil, since with SS there is a diversified production with higher aerial biomass content and higher levels of soil organic matter as well as better animal/pasture management (Polanía-Hincapié et al. 2021). However, in the present study no such significant changes ($p > 0.05$) in the 'physical properties' were evidenced. Regarding soil chemical properties, Rodriguez et al. (2018), in their research observed that phosphorus levels increased after the establishment of a SS of *Tithonia diversifolia* (Hemsl.) A. Grey (Boton de oro) and associated grasses in areas dedicated to cattle ranching. However, they appreciated that in areas where the SS had been established for three years, the level of available P in the soil was the same as before the establishment of the SS. Agboola & Joseph (2014) also obtained an increase in soil P in degraded areas invaded by boton de oro.

Table 2

Soil physical and chemical attributes at 0-15 cm depth, in Cedrelinga, Eucalyptus and Inga silvopastoral systems studied in the Peruvian amazon

Silvopastoral	**BD***	**pH**	**OM**	**P**	**CEC**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Al^{3+}**
Systems	**g cm^{-3}**	**--**	**%**	**mg kg^{-1}**	**cmol+ kg^{-1}**				
Cedrelinga	1.33±0.18	4.24±0.50	3.12±0.18	3.43±0.21A	9.07±0.56B	0.36±0.18C	0.25±0.03B	0.14±0.02	0.83±0.40B
Eucalyiptus	1.38±0.04	4.85±0.10	3.76±0.26	3.20±0.95A	9.01±5.05B	7.61±4.01B	1.81±0.97ª	0.35±0.35	0.00±0,00B
Inga	1.22±0.10	4.99±0.13	2.88±0.85	0.93±0.25B	25.49±3.05A	4.67±2.18A	1.77±0.62A	0.64±0.54	6.87±3.87A
PV	0.3205	0.0581	0.1622	<0,01	<0,01	0.0496	0.02874	0.1822	<0.01

*BD= Soil bulk density, OM= Organic matter, CIC= Cation Exchange Capacity.

Different letters in the columns mean significant differences between SS at 0.05 according to the Scott-Knott test.

Aboveground biomass

The results of biomass (dry weight) for each plant fraction (trees, grasses and litter) are presented in Figure 2. The biomass produced was in the order (mean ± standard deviation) of 6.64 ± 0.97 t ha^{-1} (trees), 1.01 ± 0.31 t ha^{-1} (grass) and 3.14 ± 0.73 t ha^{-1} (litter) for the system with Cedrelinga. Meanwhile, the system with Eucalyptus achieved 0.94 ± 0.94 t ha^{-1} (trees), 0.59 ± 0.20 t ha^{-1} (pasture) and 5.06 ± 1.89 t ha^{-1} (litter). Finally, the system with Inga obtained: 0.81 ± 0.71 t ha^{-1} (trees), 0.69 ± 0.07 t ha^{-1} (pasture) and 2.83 ± 0.79 t ha^{-1} (litter).

It can be observed that both the biomass produced by trees (Figure 2A) and grasses (Figure 2B) were significantly ($p < 0.05$) higher in the system with Cedrelinga. However, in the case of litter production (Figure 2C), production was higher in the system with Eucalyptus.

In the case of overall biomass production (Figure 2D), in all cases the litterfall was higher except for the Cedrelinga system, where the biomass produced by the trees was higher than the dry mass produced by the litterfall.

Oliva et al. (2017) found that in a silvopastoral system with *Pinus patula* contents of 19.37 t ha^{-1} of aerial biomass, and which were higher than those found in the present research; the biomass of herbaceous shrubs (3.50 t ha^{-1}) was also higher; As for litter biomass, the values were similar to those of the system with Cedrelinga and the system with Inga edulis, except with that of the system with Eucalyptus which was higher (Figure 2D). Likewise, Zavala Solórzano et al. (2018) found higher values in terms of total biomass in an agroforestry system with coffee associated with Inga edulis and other species.

The results of carbon stocks for each fraction (vegetation and soil) are presented in Figure 3. The carbon stocks produced in both aboveground vegetation and soil were of the order (mean ± standard deviation) of 10.8 ± 1.6 t ha^{-1} (vegetation) and 66.0 ± 10.9 t ha^{-1} (soil) for the system with tornillo, while the Eucalyptus system achieved 6.6 ± 1.9 t ha^{-1} (vegetation) and 62.9 ± 15.4 t ha^{-1} (soil). Finally, in the system with inga, 4.3 ± 0.1 t ha^{-1} (vegetation) and 61.7 ± 42.4 t ha^{-1} (soil) were obtained. It was observed that soil carbon stocks were relatively uniform in the three SS, with the highest average accumulated value in the SS with Cedrelinga and the SS with Inga the one that stored the least carbon, probably due to the age of the trees.

In the overall carbon production, in all cases the soil stored most of the carbon in the SS, much more than in the aerial vegetation. These results highlight the importance of soil for carbon storage and its role in climate change mitigation by reducing CO_2 concentrations in the environment.

In the research of Oliva et al. (2017), it was found that in a SS composed of Pinus patula and native herbaceous plants there were 10.9 t ha^{-1} in aboveground biomass and 81.2 t ha^{-1} in the top 30 centimeters of soil, values higher than those reported here.

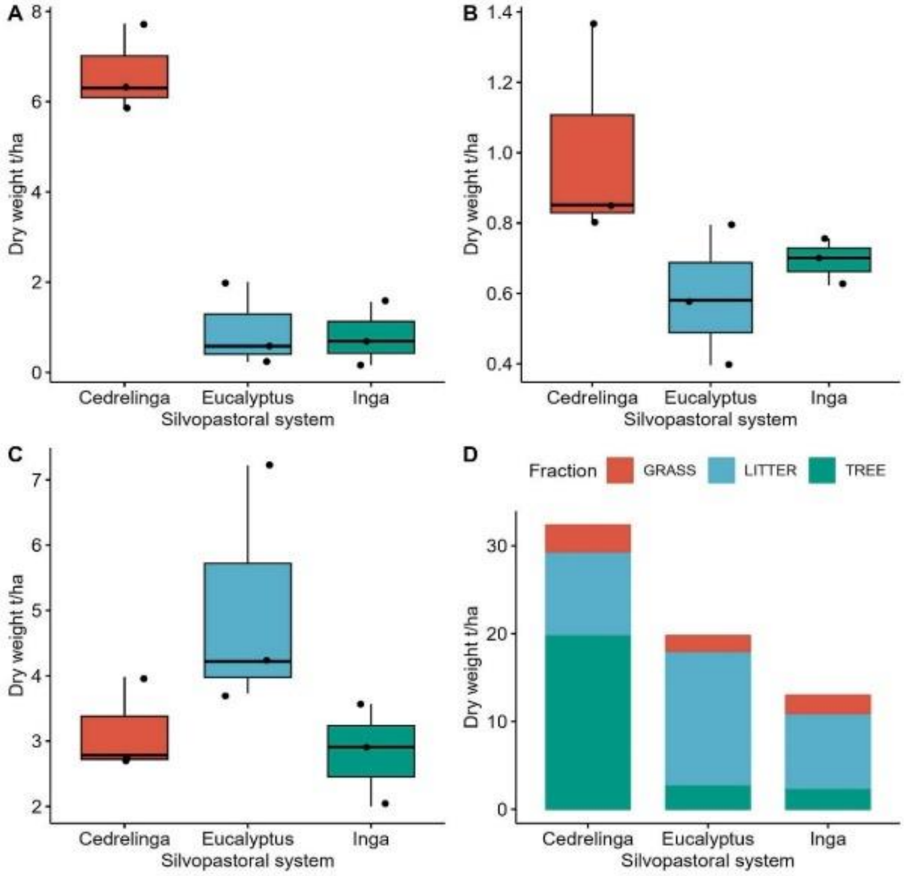

Figure 2. Biomass production (dry weight) in t ha-1 in three SS of the Peruvian Amazon. A: Tree biomass production, B: Grass biomass production, C: Litter production and D: Bar graph of proportion for each biomass fraction in the studied systems.

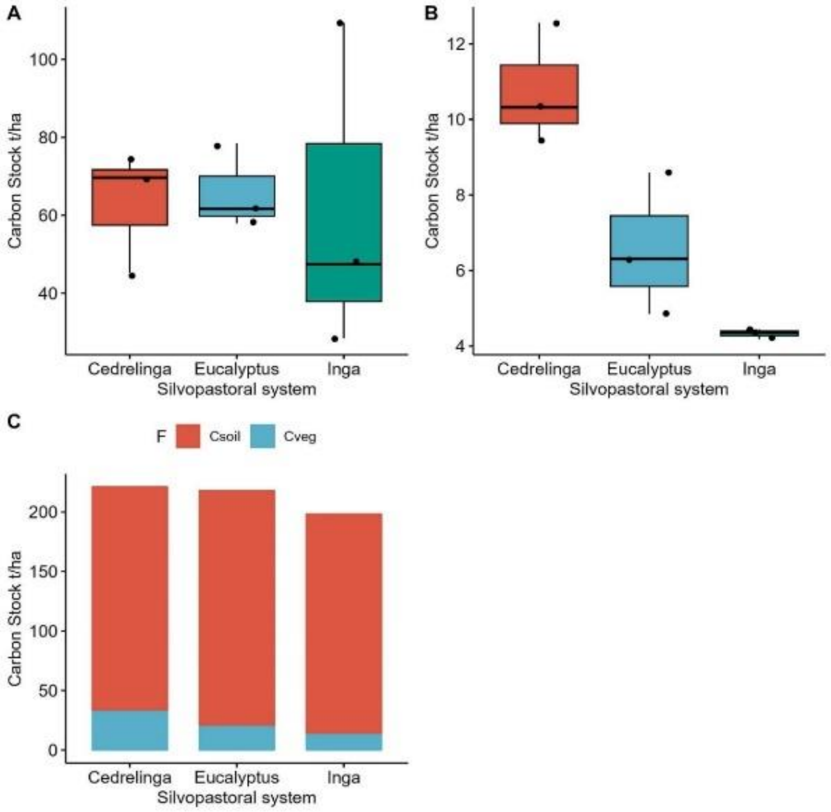

Figure 3. Carbon stocks in t ha^{-1} in three silvopastoral systems in the Peruvian Amazon. A: Soil organic carbon stocks, B: Vegetation carbon stocks, C: Bar graph of proportion for each carbon fraction in the systems studied.

Anguiano et al. (2013) reported values between 101.2 and 128.6 t ha^{-1} in the aboveground biomass of SS composed of various densities of coconut (*Cocos nucifera*), *Leucaena leucocephala* Var. Cunningham and Pennisetum purpureum Cuba CT-115. In turn, Ibrahim et al. (2007) reported that total C stocks in improved pastures with low tree density were 119.1, and 102.9 to 128.6 t ha^{-1} in Costa Rica and Nicaragua, respectively. Variations in C stocks in different SS are due to tree species, tree density and soil and climatic conditions.

CONCLUSIONES

Agroforestry systems are sustainable agronomic ecosystems that combine productivity with climate change mitigation while improving C stocks.

In soil physical and chemical properties, no significant differences were found between systems with the exception of P, Al and CEC. In terms of vegetation C stocks, the system with Cedrelinga cateniformis was the most productive while Inga edulis had the lowest C accumulation. Soil carbon stocks remained relatively uniform among the three systems, being slightly higher in the system with Cedrelinga. In general, soil represented the main carbon stock in the silvopastoral systems studied, surpassing vegetation.

The results highlight the importance of soil as a carbon sink and its role in mitigating climate change by reducing CO_2 concentrations in the atmosphere.

REFERENCIAS BIBLIOGRÁFICAS

Agboola, O., & Joseph, I. M., (2014). Impact of *Tithonia diversifolia* (Hemsly) A. Gray on the soil, species diversity and composition of vegetation in Ile-Ife (Southwestern Nigeria), Nigeria. *Int. J. Biodiversity and Conservation, 6*, 555–562. https://doi.org/10.5897/IJBC2013.0634

Alvarado, A. (2015). Plant Nutrition in Tropical Forestry. In: Pancel, L., Köhl, M. (eds) Tropical Forestry Handbook. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-41554-8_105-2

Anderson, J. M., & Ingram, J. S. I. (1993). Tropical Soil Biology and Fertility: A Handbook of Methods. *The Journal of Ecology, 78*, 2, 547-548. https://doi.org/10.2307/2261129

Anguiano, J. M., Aguirre, J., & Palma, J. M. (2013). Secuestro de carbono en la biomasa aérea de un sistema agrosilvopastoril de *Cocos nucifera*, *Leucaena leucocephala* Var. Cunningham y *Pennisetum purpureum* Cuba CT-115. *Avances en la investigación agrícola, 17*, 149–160.

Arévalo-Hernández, C. O., Arévalo-Gardini, E., Farfan, A., Amaringo-Gomez, M., Daymond, A., Zhang, D., & Baligar, V. C. (2022). Growth and nutritional responses of juvenile wild and domesticated cacao genotypes to soil acidity. *Agronomy, 12*, 3124. https://doi.org/10.3390/AGRONOMY12123124

Arévalo, L., Alegre, J., & Palm, C. H. (2003). Manual de reservas totales de carbono en los diferentes sistemas de uso de la tierra en el Perú. Publicación de STC/CGIAR/Ministerio de Agricultura, Lima, Perú.

Assunção, J., Gandour, C., Pessoa, P., & Rocha, R. (2017). Property-level assessment of change in forest clearing patterns: The need for tailoring policy in the Amazon. *Land Use Policy, 66*, 18-27. https://doi.org/10.1016/j.landusepol.2017.04.022

Broom, D. M. (2017). Components of sustainable animal production and the use of silvopastoral systems. *R. Bras. Zootec. 46*, 683–688. https://doi.org/10.1590/s1806-92902017000800009

Buitrago, M. E., Ospina, L. A., & Narváez, W. (2018). Sistemas silvopastoriles: alternativa en la mitigación y adaptación de la producción bovina al cambio climático. *Boletín Científico Centro de Museos Museo de Historia Natural, 22*, 31–42. https://doi.org/10.17151/bccm.2018.22.1.2

Coomes, O. T., Cheng, Y., Takasaki, Y., & Abizaid, C. (2021). What drives clearing of old-growth forest over secondary forests in tropical shifting cultivation systems? Evidence from the Peruvian Amazon. *Ecological Economics, 189*, 107170. https://doi.org/10.1016/j.ecolecon.2021.107170

Dávalos, L. M., Bejarano, A. C., Hall, M. A., Correa, H. L., Corthals, A., & Espejo, O. J. (2011). Forests and Drugs: Coca-Driven Deforestation in Tropical Biodiversity Hotspots. *Environmental Science & Technology, 45*, 1219-1227. https://doi.org/10.1021/es102373d

Dourojeanni, M. D. (1987). Aprovechamiento del barbecho forestal en áreas de agricultura migratoria en la Amazonía peruana. *Revista Forestal del Perú, 14*(2), 1-33.

FAO (Organización de las Naciones Unidas para Agricultura y Alimentación) (2015). World reference base for soil resources 2014, update 2015.World Soil Resources Reports No. 106. Rome, Italy: FAO

Gallo Aponte, W. I., & Sanabria Rodelo, A. (2019). Evaluación de impacto ambiental y ganadería extensiva en Colombia, en: Lecturas sobre Derecho de Tierras. Volumen III. Bogotá: Universidad Externado de Colombia, 2019. pp32.

Garate-Quispe, J. S., Canahuire-Robles, R., Surco-Huacachi, O., & Alarcón-Aguirre, G. (2021). Desarrollo estructural y composición florística arbórea en áreas afectadas por la minería aurífera en la Amazonía peruana: 20 años después de su repoblación forestal. *Rev. Mex. Biodiv., 92*, 923437. https://doi.org/10.22201/ib.20078706e.2021.92.3437

Ibrahim, M. A., Chacón, M., Cuartas, C., Naranjo, J., Ponce, G., Vega, P., Casasola Coto, F., & Rojas, J. (2007). Almacenamiento de carbono en el suelo y biomasa arbórea en Sistemas de uso de la tierra en paisajes ganaderos de Colombia, Costa Rica y Nicaragua. Agroforestería en las Américas, 45.

Kaimowitz, D., & Angelsen, A. (2008). Will Livestock Intensification Help Save Latin America's Tropical Forests? *Journal of Sustainable Forestry, 27*, 6–24. https://doi.org/10.1080/10549810802225168

Le Quéré, C., Moriarty, R., Andrew, R. M., Canadell, J. G., Sitch, S., Korsbakken, J. I., Friedlingstein, P., Peters, G. P., et al. (2015). Global Carbon Budget 2015. *Earth Syst. Sci. Data, 7*, 349–396. https://doi.org/10.5194/essd-7-349-2015

Mahecha, L. (2003). Importancia de los sistemas silvopastoriles y principales limitaciones para su implementación en la ganadería colombiana. *Revista Colombiana de Ciencias Pecuarias, 16*, 11–18.

McGroddy, M. E., Lerner, A. M., Burbano, D. V., Schneider, L. C., & Rudel, T. K. (2015). Carbon Stocks in Silvopastoral Systems: A Study from Four Communities in Southeastern Ecuador. *Biotrópica, 47*, 407–415. https://doi.org/10.1111/btp.12225

MINAGRI. (2017). Diagnóstico genético - Plan Ganadero - Priorizado para 2017-2021. Ministerio de Agricultura y Riego 69. Ministerio de Agricultura y Riego. Lima, Perú. Pp. 69.

MINAM. (2009). Causas y medidas de mitigación de la deforestación en zonas críticas de la Amazonía peruana y la emisión de gases de efecto invernadero. Ministerio del Medio Ambiente, Lima, Perú.

Montagnini, F., Ibrahim, M., & Murgueitio Restrepo, E. (2013). Systèmes silvopastoraux et atténuation du changement climatique en Amérique latine. *Bois & Forets Des Tropiques, 316*, 3-16. https://doi.org/10.19182/bft2013.316.a20528

Murgueitio, E., Barahona, R., Chará, J., Flores, M., Mauricio, R., & Molina, J. (2015). Los sistemas silvopastoriles intensivos en América Latina son una alternativa sostenible para enfrentar el cambio climático en la ganadería. *Revista Cubana de Ciencias Agrícolas, 49*.

Núñez Silvestre, A. D. (2018). Estimación de biomasa aérea de *Cedrelinga cateniformis* Ducke en Alto Mayo, San Martín (tesis pregrado). Universidad Nacional Agraria La Molina. 83 p.

Oliva, M., Culqui Mirano, L., Leiva, S., Collazos, R., Salas, R., Vásquez, H., & Maicelo Quintana, J. L. (2017). Reserva de carbono en un sistema silvopastoril compuesto por Pinus patula y especies nativas plantas herbáceas. *Scientia Agropecuaria, 8*, 149-157. https://doi.org/10.17268/sci.agropecu.2017.02.07

Polanía-Hincapié, K. L., Olaya-Montes, A., Cherubin, M. R., Herrera-Valencia, W., Ortiz-Morea, F. A., Silva-Olaya, A. M. (2021). Soil physical quality responses to silvopastoral implementation in Colombian Amazon. *Geoderma, 386*, 114900. https://doi.org/10.1016/j.geoderma.2020.114900

Ríos, J., Valencia, F., & Muñoz, M. (2001). Informe de actividades de investigación en la Amazonía peruana. Tingo María, Perú.

Ríos, J., Valencia, F., Valencia, T., Tourrand, J.-F., Grijalva, J., da Veiga, J., Poccard-Chapuis, R., Alves, A., Piketty, M. -G., & Thales, M. (2002). Sistemas de producción agrícola familiar como alternativa a la producción de coca en la Amazonía peruana. In: Simpósio Latino-americano sobre investigação e extensão em pesquisa agropecuária, 5.; Encontro da Sociedade Brasileira de Sistemas de Produção, 5. Florianópolis. Anais. Florianópolis: SBSP.

Robiglio, V., Reyes, M., & Castro, E. (2015). Diagnóstico de productores familiares en la Amazonía peruana. Oficina Regional del ICRAF para América Latina, encargado por GGGI & DIE: Lima, Perú.

Rodriguez, I., Crespo, G., Herrera, M., & Medina, Y. (2018). Comportamiento del pH, P asimilable y Ca y Mg cambiables en un suelo ferralítico ocupado por un sistema silvopastoril de *Tithonia diversifolia* (Hemsl.) Gray y gramíneas asociadas. *Desarrollo, 30*, 9.

Rudel, T. A. (2005). Tropical Forests: Regional Paths of Destruction and Regeneration in the Late Twentieth Century. Publisher: Columbia University Press: 256 p. https://doi.org/10.7312/rude13194

Salazar, R., Alegre, J., Pizarro, D., Duff, A. J., García, C., & Gómez, C. (2024). Soil carbon stock potential in pastoral and silvopastoral systems in the Peruvian Amazon. Agroforestry Systems, 1-11.

Sharrow, S. H., & Ismail, S. (2004). Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. *Agroforestry Systems, 60*, 123–130. https://doi.org/10.1023/B:AGFO.0000013267.87896.41

Terán-Ramírez, M. A., Rodríguez-Ortiz, G., Enríquez-del Valle, J. R., & Velasco-Velasco, V. A. (2018). Biomasa aérea y ecuaciones alométricas en un cafetal en la Sierra Norte de Oaxaca. *Ecosistemas y recursos agropecuarios, 5*(14), 217-226.

Velarde, S., Ugarte-Guerra, J., Tito, M., Capella, J., Sandoval, M., Hyman, G., Castro, A., Marín, J., & Barona, E. (2010). Reducir emisiones de todos los usos del suelo. Informe para Proyecto REALU-Perú. Reducir las emisiones de todos los usos del suelo. Informe para Proyecto REALU-Perú.

Walker, W. S., Gorelik, S. R., Baccini, A., Aragon-Osejo, J. L., Josse, C., Meyer, C., Macedo, M. N., Augusto, C., Rios, S., Katan, T., De Souza, A. A., Cuellar, S., Llanos, A., Zager, I., Mirabal, G. D., Solvik, K. K., Farina, M. K., Moutinho, P., & Schwartzman, S. (2020). The role of forest conversion, degradation, and disturbance in the carbon dynamics of Amazon indigenous territories and protected areas. *PNAS, 117*, 3015–3025. https://doi.org/10.1073/pnas.1913321117

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science, 37*, 29–38.

WeatherSpark, (2022). Clima y tiempo medio durante todo el año en Soritor. URL https://es.weatherspark.com/

Wright, D. G., Mullen, R. W., Thomason, W. E., & Raun, W. R. (2001). Estimated land area increase of agricultural ecosystems to sequester excess atmospheric carbon dioxide. *Communications in Soil Science and Plant Analysis, 32*, 1803–1812. https://doi.org/10.1081/CSS-120000251

Zavala Solórzano, J. W., Zavala Guerrerp, S. L., Mansilla Minaya, L. G. (2018). Estimación de biomasa y carbono almacenado en un sistema agroforestal del cafetal de la Universidad Nacional Agraria de La Selva. *Investigación y Amazonia, 8*, 1–8.