Scientific Paper

Organic carbon stocks in different types of land use

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Abstract

Objective: To evaluate the effect of different types of land use on organic carbon stocks in a typical dark red ferritic soil.

Materials and Methods: The research was developed in a permanent observation point, located in the Guaro locality, Mayarí municipality, Holguín province. Soil samples were taken at 0-20, 20-40 and 40-60 cm depth, in three types of land use: *Pinus cubensis* Griseb. forest, natural pasture (*Paspalum notatum* Alain ex Flügge) and *Saccharum* spp. to which total organic carbon was determined. In addition, undisturbed samples were taken to determine the bulk density.

Results: Significant differences in soil organic carbon stocks were found among the three types of land use, at a depth of 0-20 cm. The natural pasture had the highest stock. It was followed by *Saccharum* spp and *P. cubensis* forest. There was increase in the rate of edaphic carbon accumulation with depth in all types of land use. The highest values were found in the 0-20 cm depth, which decreased with profile. There were negative figures only in the *P. cubensis* forest, at 40-60 cm depth.

Conclusions: The highest carbon stocks were found in soils with *P. notatum*. This was followed by *Saccharum* spp. and *P. cubensis*. Land use types with less human activity showed the highest rates of carbon accumulation and better soil quality.

Keywords: soil density, fertility, depth

Introduction

Soil is the most important reservoir of carbon in the biosphere, containing three times more than vegetation and the atmosphere (Cerri *et al*., 2021).

More than 1,5 billion hectares of natural ecosystems have been converted to cropland, with only 25 % of the land area in its natural state, which contains more than half of the world's carbon stocks and is estimated to be reduced below 10 % by 2050 (Chang *et al*., 2012; Lorenz and Lal, 2018; FAO, 2022).

Soils in their natural state maintain native vegetation and physical characteristics suitable for the normal development of the plants that make up their ecosystem. When the type of use changes towards agricultural exploitation, this causes disruption of the balance, drastic modification of its properties and unfavorable alteration of plant growth (Ovalle-Molina, 2020).

Organic carbon accumulates in living biomass (stems, leaves, roots) and dead biomass (plant debris, leaf litter, soil organic matter). Any activity that affects the volume of biomass in vegetation and soil has the capacity to retain or release carbon from the atmosphere or into the atmosphere (Velásquez-Escobedo, 2019; Jiménez-Torres, 2021).

Due to the change of use from forests to agricultural crops in a wide variety of soils, losses of organic carbon stocks vary between 25 and 75 % of the proportions of organic carbon initially present and most of these losses occur in the first 20 years of land use change (Lal *et al*., 2007).

The carbon that remains in the soil is incorporated and stabilized in the different soil organic carbon pools (SOC), such as particulate or labile organic carbon, which can accumulate infinitely in the soil; but it mineralizes more rapidly (short residence time in the soil), thus contributing to nutrient cycling and sustaining biological activity, but is modified by agricultural management. In contrast, the fraction of organic carbon associated with minerals is subject to saturation, although it has greater stability and persistence in the soil and thus it is essential for soil structure and for sequestering carbon for a longer time. In order to sustain healthy soils, both fractions are important, as each performs specific functions (Hoffland *et al*., 2020; Lavallee *et al*., 2020).

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The objective of this work was to evaluate the effect of different types of land use (LUT) on the organic carbon stocks of a typical dark Red Ferritic soil.

Materials and Methods

Location. The work was carried out at the permanent observation point (POP), during 2010 in the Pinares de Mayarí locality, Mayarí municipality, Holguín province, located at 20º48'33" North latitude and 75º73'33" West longitude.

Soil characteristics. The soil was classified as typical dark Red Ferritic, according to Hernández-Jiménez *et al.* (2015) and was framed in three types of land use: pine forest (*Pinus cubensis* Griseb.), natural pasture (*Paspalum notatum* Alain ex Flügge) and sugarcane (*Saccharum* spp.).

Experimental procedure. Since 2010, stratified random soil sampling with three replicas was performed every year in June in each of the LUTs, at the depths of 0-20, 20-40 and 40-60 cm. The 2015 samples had their total organic carbon (TOC) determined by the Walkley-Black method (ININ and ONN, 1999). In addition, undisturbed samples were taken with cylinders of 105,35 cm^3 volume, and placed in filter weighers to determine bulk density (BD), by the ring method (ININ and ONN, 2003).

For the calculation of the soil organic carbon stock (SOCS) in undisturbed soils, the following equation was used (FAO, 2020):

$$SOCS = SOC \times BD \times p \times 104\ m^2\ ha^{-1},$$

SOCS - Carbon stock, mg ha^{-1}
SOC - Soil organic carbon as determined by data, %.
BD - Bulk density, mg m^{-3}
p - Considered thickness, m

In disturbed soils, it was calculated according to the methodology proposed by Solomon *et al.* (2002) for comparisons between equivalent soil masses. Corrections were made for equivalent depth.

$$SOCS = COS \times BD \times Zc \times 10$$

The thickness of the cultivated soils (Z) was corrected (Zc) by assuming that the bulk density and depth of cultivated soils were originally equal to those corresponding to natural soils:

$$Zc = (\text{BD of forest soil} / \text{BD of cultivated soil}) \times Z$$

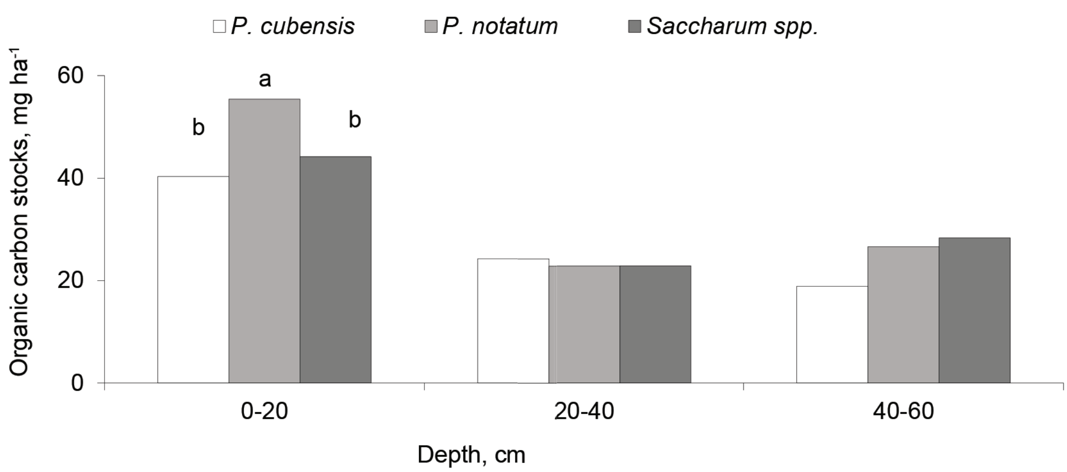
The calculation of the edaphic carbon accumulation rate (SOCAR) was determined according to Amado *et al.* (2006). It was obtained by the differences of SOCS between the original situation, the current situation and the years of LUTs.

$$SOCAR\ (mg\ C\ ha^{-1}year^{-1}) = (\text{current SOCS} - \text{original SOCS}) / \text{years}.$$

Statistical analysis. Normality was tested with the Shapiro-Wilk W test and homogeneity of variance, according to Bartlett. Duncan's multiple range mean comparison test was used to analyze the significant differences recorded during the analysis of variance. Statistical processing of the information was performed with Statistica v.8 and Microsoft Excel 2019.

Results and Discussion

Figure 1 shows the SOCS. In the different depths in each type of land use, significant differences ($p < 0,05$) were found in the 0-20 cm depth. In the other depths, there were no statistical differences among the LUTs. SOCS contents were higher at the 0-20 cm depth and the values decreased with



Different letters at each depth indicate significant differences ($p < 0,05$).

Figure 1. Organic carbon stocks (mg ha^{-1}) in the different land use types at different depths.

depth. These high contents are due to the fact that at this depth the organic remains of the crops are deposited, there is a higher concentration of plant roots and it is where all the transformation and decomposition processes by microorganisms occur (Allauca Ortega and Ayala Sánchez, 2021; Georgiou *et al*., 2022).

Maximum soil organic carbon storage capacity requires higher incorporation of plant biomass. In dynamic terms, at least 13 % of the total organic carbon is labile and will be lost when the soil reduces vegetation cover and changes in other factors (environmental, agricultural work, periodicity of inputs, physical, chemical and biological properties of the soil), which determine the margins to be stored by the soil, occur (Bell *et al*., 2021).

The highest soil organic carbon stocks, at the 0-20 cm depth, were recorded in the LUT *P. notatum*, where significant differences were found with increases of 15,09 and 11,21 mg ha^{-1} with regards to the LUTs *P. cubensis* and *Saccharum* spp., although there were no statistical differences between the last two. SOC contents in the LUT *Saccharum* spp. were higher (3,88 mg ha^{-1}) than in *P. cubensis*. This performance is ascribed to the quantity and quality of plant biomass accumulated on the soil surface, depending on the crop and the agricultural management of the LUTs.

The distribution of carbon stock accumulation in depth through the profile decreased up to 60 cm and reached 52 % in the LUTs *P. cubensis* and *P. notatum*. Meanwhile, in the LUT *Saccharum* spp. it was 36 %. This vertical distribution of carbon has a strong association with vegetation due to the amount of surface residues that each plant can generate and the size of its root system, mainly fine roots (< 2 mm). The presence of live and dead roots throughout the soil profile indicates constant cycling and transformation of organic matter.

Landriscini *et al*. (2020) proved the significant effect of cover crops on SOC. Its labile fraction was strongly related to the higher residue production and its quality in the topsoil.

Lopresti *et al*. (2020) add that the root system of grasses is very aggressive and is in constant renewal of roots, resulting in rhizodeposition. Rhizodeposits represent 50 % of the total biomass in perennial forages and 20 % in annual crops, making grasses a good option for increasing C sequestration in the tropics. A large part of the organic carbon in grasses is sequestered mainly through the roots, which gradually become part of the soil biomass (Rivera *et al*., 2021; Rojas-Solano *et al*., 2022).

The biomass contributed by *P. cubensis*, formed by needles, is quite resistant to decomposition. They are made up of 7 % of easily decomposable water-soluble compounds (soluble sugars and nitrogen compounds) plus lignin, which combines low and slow decomposition rates and releases organic acids that reduce biological activity, such as fungal and bacterial colonization (Cano-Flores *et al*., 2020).

Saccharum spp. is a crop that contributes a large amount of biomass according to the achieved yield. Rubio-González *et al*. (2019) report a contribution of 10-14 t ha^{-1} of biomass. Despite this, the values decrease, due to the agricultural activity developed in the LUT. This shows that continuously cultivated soils decrease SOCS in a few years, compared with those where agricultural activity is less or null.

After five years of study, the contribution of plant residues favored soil organic carbon stocks in the LUTs (figure 2). In all the LUTs there was an increase in SOCAR with depth. The highest values were found in the 0-20 cm depth, which decreased with profile. There were only negative values in *P. cubensis*, at the depth of 40-60 cm, because most of the roots are thick at that depth (> 2 mm).

Fine roots play a determining role in SOC, by annually transferring large amounts of carbon to the soil through the release of exudates and root necromass. Given their high turnover rate (Chang *et al*., 2012), they stimulate soil biological activity and the building of microbial carbon biomass (de-Oliveira-Pessoa-Paes *et al*., 2018); while the contribution to SOC from coarse roots, because of their slow decomposition rate, occurs over the long term (Robinson, 2007).

In *P. notatum* and *P. cubensis*, the highest accumulation rates were recorded, at the depth of 0-20 cm, with 4,94 and 4,19 mg ha^{-1} yr^{1}, which increased soil carbon stocks by 51,96 and 44,63 %, respectively; while *Saccharum* spp. increased them by 30,67 %, due to having lower accumulation rates. From the point of view of carbon sequestration, the LUTs with less anthropic activity were the most favored, which improves soil quality.

When SOC reserves increase, it means that the physical, chemical and biological properties of soils improve and, in parallel, CO_2 emissions to the atmosphere decrease (Barrezueta-Unda, 2021). This characteristic is particularly true for soils with low anthropogenic LUT (forests and natural pastures).

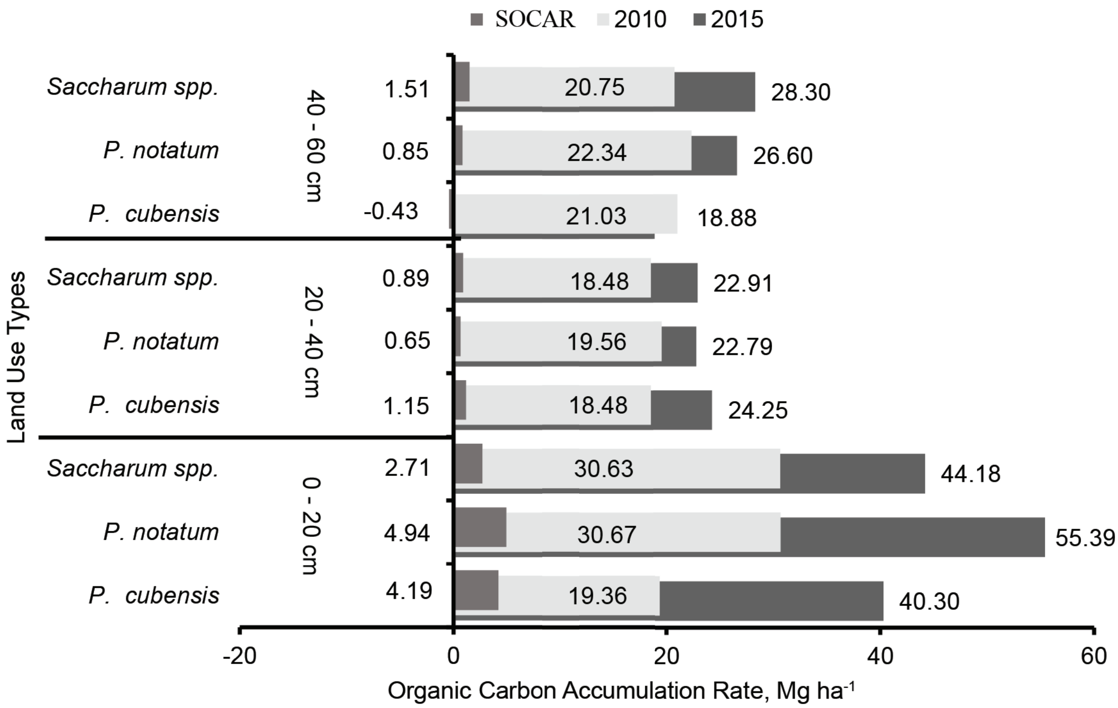


Figure 2. Rate of edaphic carbon accumulation (SOCAR) in different types of land use by depth.

In Brazil, Cerri *et al*. (1996) reported that two years after converting forest areas in the Amazon to pasture, losses in organic carbon stocks of 23,30 % were found at a depth of 20 cm, which was recovered after eight years by biomass inputs (96 t C ha^{-1}). When the change of the forest was to the use of *Saccharum* spp., OC was reduced by 47,2 % over a period of 50 years.

Conclusions

The highest carbon stocks were found in soils used with *P. notatum*. This was followed by *Saccharum* spp. and *P. cubensis*. Land use types with less human activity showed the highest rates of carbon accumulation and better soil quality.

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Conflict of interests

The authors declare that there is no conflict of interests among them.

Authors' contributions

- George Martín-Gutiérrez. Designed the research, directed and carried out the field sampling, performed the statistical analysis and interpretation of the results, and wrote the manuscript.
- Pablo Pablos-Reyes. Designed the research, participated in the analysis and interpretation of the results, and drafted the manuscript.
- Yakelin Cobo-Vidal. Collaborated in the analysis and interpretation of the results and in the drafting of the manuscript.
- Juan Alejandro Villazón-Gómez. Performed field sampling, collaborated in the analysis and interpretation of the results and in the writing of the manuscript.

Bibliographic references

Allauca Ortega, Lizbeth A. & Ayala Sánchez, Jennifer B. *Evaluación de carbono orgánico en diferentes fracciones compuestas del suelo de páramo, Chambo y Pungalá*. Trabajo de Integración Curricular. Proyecto de investigación presentado para optar al grado académico de Química. Riobamba, Ecuador: Facultad de Ciencias, Escuela Superior Politécnica de Chimborazo. http://dspace.espoch.edu.ec/handle/123456789/14802, 2021.

Amado, T. J. C.; Bayer, C.; Conceição, P. C.; Spagnollo, E.; Campos, B.-H. C. de & Veiga, M. da. Potential of carbon accumulation in no-till soils with intensive use and cover crops in southern. *Brazil J. Environ. Qual*. 35 (4):1599-1607, 2006. DOI: https://doi.org/10.2134/jeq2005.0233.

Barrezueta-Unda, S. Efecto de diversos atributos topográficos sobre el carbono orgánico en varios usos del suelo. *Ciencia UNEMI*. 14 (35):43-53. https://ojs.unemi.edu.ec/index.php/cienciaunemi/article/view/1214, 2021.

Bell, S. M.; Terrer, C.; Barriocanal, C.; Jackson, R. B. & Rosell-Melé, A. Soil organic carbon accumulation rates on Mediterranean abandoned agricultural lands. *Sci. Total Environ*. 759:143535, 2021. DOI: https://doi.org/10.1016/j.scitotenv.2020.143535.

Cano-Flores, O.; Vela-Correa, G.; Acevedo-Sandoval, O. A. & Valera-Pérez, M. Á. Organic carbon concentrations in the woodland and soils of the protected natural area "El Faro" in Tlalmanalco, Estado de Mexico. *Terra Latinoam*. 38 (4):895-905, 2020. DOI: https://doi.org/10.28940/terra.v38i4.757.

Cerri, C. C.; Bernoux, M. & Blair, G. J. Reservas y flujo de carbono en sistemas naturales y agrícolas del Brasil y las implicaciones para el balance global de CO_2. *Terra Latinoam*. 14 (1):1-12. https://www.terralatinoamericana.org.mx/index.php/terra/issue/view/103/48, 1996.

Cerri, C. E. P.; Cherubin, M. R.; Damian, J. M.; Mello, F. F. C. & Lal, R. *Secuestro de carbono en el suelo mediante la adopción de prácticas de manejo sostenible: potencial y oportunidad para los países de las América*. (F. Villarreal, coord). San José, Costa Rica: IICA. https://repositorio.iica.int/bitstream/handle/11324/19315/BVE21128138e.pdf?sequence=1&isAllowed=y, 2021.

Chang, R.; Fu, B.; Liu, Guohua; Yao, X. & Wang, S. Effects of soil physicochemical properties and stand age on fine root biomass and vertical distribution of plantation forests in the Loess Plateau of China. *Ecol. Res*. 27 (4):827-836, 2012. DOI: https://doi.org/10.1007/s11284-012-0958-0.

de-Oliveira-Pessoa-Paes, Leocimara S.; Lima, M. R. de; Kaschuk, Glaciela & Machado-Vezzani, Fabiane. Desarrollo de las raíces como indicador de la sustentabilidad del suelo de los sistemas de cultivo en el Bioma de la Mata Atlántica. *Cultivos Tropicales*. 39 (2):7-14. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0258-59362018000200001&lng=es&tlng=es, 2018.

FAO. *Día mundial del suelo 2022: la FAO publica el primer informe mundial sobre suelos negros*. Roma: FAO. https://www.fao.org/newsroom/detail/world-soil-day-2022-fao-global-report-black-soils/es, 2022.

FAO. *A protocol for measurement, monitoring, reporting and verification of soil organic carbon in agricultural landscapes*. Rome: FAO. https://www.fao.org/3/cb0509en/CB0509EN.pdf, 2020.

Georgiou, Katerina; Jackson, R. B.; Vindušková, Olga; Abramoff, Rose Z.; Ahlström, A.; Feng, Wenting *et al*. Global stocks and capacity of mineral-associated soil organic carbon. *Nat. Commun*. 13:3797, 2022. DOI: https://doi.org/10.1038/s41467-022-31540-9.

Hernández-Jiménez, A.; Pérez-Jiménez, J. M.; Bosch-Infante, D. & Castro-Speck, N. *Clasificación de los suelos de Cuba*. Mayabeque, Cuba: Instituto Nacional de Ciencias Agrícolas, Ediciones INCA, 2015.

Hoffland, Ellis; Kuyper, T. W.; Comans, R. N. J. & Creamer, Rachel E. Eco-functionality of organic matter in soils. *Plant Soil*. 455:1-22, 2020. DOI: https://doi.org/10.1007/s11104-020-04651-9.

ININ & ONN. *Calidad del suelo. Análisis físico. Determinación de la densidad aparente o peso volumétrico base suelo seco. NC 11272*. La Habana: Oficina Nacional de Normalización, Instituto de Investigaciones en Normalización, 2003.

ININ & ONN. *Calidad del suelo. Análisis químico. Determinación del porciento de materia orgánica. NC 51*. La Habana: Oficina Nacional de Normalización, Instituto de Investigaciones en Normalización. https://ftp.isdi.co.cu/biblioteca/BIBLIOTECA%20UNIVERSITARIA%20DEL%20ISDI/COLECCION%20DIGITAL%20DE%20NORMAS%20CUBANAS/1999/NC%2051.PDF, 1999.

Jiménez-Torres, Alexandra del C. La diversidad mejora el almacenamiento de carbono en los bosques tropicales. *RECIMUNDO*. 5 (3):316-323, 2021. DOI: https://doi.org/10.26820/recimundo/5.(3).sep.2021.316-323.

Lal, R.; Follett, R. F.; Stewart, B. A. & Kimble, J. M. Soil carbon sequestration to mitigate climate change and advance food security. *Soil Sci*. 172 (12):943-956, 2007. DOI: https://doi.org/10.1097/ss.0b013e31815cc498.

Landriscini, María R.; Duval, M. E.; Galantini, J. A.; Iglesias, J. O. & Cazorla, C. R. Changes in soil organic carbon fractions in a sequence with cover crops. *Spanish J. Soil Sci*. 10 (2):137-153. https://pdfs.semanticscholar.org/2cdc/88c7174f4b7eae4e9b3f997790431a139eb0.pdf, 2020.

Lavallee, Jocelyn M.; Soong, Jennifer L. & Cotrufo, M. Francesca. Conceptualizing soil organic matter into particulate and mineral-associated forms to address global change in the 21st century. *Glob. Chang. Biol*. 26 (1):261-273, 2020. DOI: https://doi.org/10.1111/gcb.14859.

Lopresti, M. F.; Milesi-Delaye, L. A. & Andriulo, A. E. *Partido de Pergamino: aumentó la superficie de maíz y trigo. ¿Aumentó el aporte de carbono al suelo? Informe técnico*. Pergamino, Argentina: EEA Pergamino, INTA. https://repositorio.inta.gob.ar/handle/20.500.12123/7047, 2020.

Lorenz, K. & Lal, R. Carbon sequestration in cropland soils. In: *Carbon sequestration in agricultural ecosystems*. Cham, Switzerland: Springer. p. 137-173, 2018.DOI: https://doi.org/10.1007/978-3-319-92318-5_3.

Ovalle-Molina, C., Ed. *Una Nama Agrícola para Chile mediante el secuestro de carbono orgánico en el suelo*. Serie Actas INIA No. 59. La Cruz, Chile: Instituto de Investigaciones Agropecuarias. https://biblioteca.inia.cl/bitstream/handle/20.500.14001/8703/Serie%20Acta%20INIA%20N%C2%B0%2059?sequence=1&isAllowed=y, 2020.

Rivera, J. E.; Colcombet, L.; Santos-Gally, Rocío; Murgueitio, E.; Díaz, Maura; Mauricio, R. M. *et al*., Eds. *Sistemas silvopastoriles: Ganadería sostenible con arraigo e innovación*. Cali, Colombia: CIPAV. https://www.afoa.org.ar/silvopastoril.pdf, 2021.

Robinson, D. Implications of a large global root biomass for carbon sink estimates and for soil carbon dynamics. *Proc. R. Soc. B*. 274 (1626):2753–2759, 2007. DOI: https://doi.org/10.1098/rspb.2007.1012.

Rojas-Solano, Jennifer; Brenes-Gamboa, S. & Abarca-Monge, S. Carbono en el suelo: comparación entre un área de pastos y un bosque. *InterSedes*. XXIII (47):184-205, 2022. DOI: https://doi.org/10.7440/res64.2018.03.

Rubio-González, A. M.; Galindo-Galindo, P.; Pérez-Egusquiza, F. J.; Ríos-Billini, P.; Perdomo-González, L.; Pérez-Castellanos, E. & Rubio-Rodríguez, M. A. *Estudio sobre el empleo de los residuos agrícolas cañeros como combustibles para la generación de electricidad en la industria azucarera cubana*. Santa Clara, Cuba: Editorial Feijóo, 2019.

Solomon, D.; Fritzsche, F.; Lehmann, J.; Tekalign, M. & Zech, W. Soil organic matter dynamics in the subhumid agroecosystems of the Ethiopian highlands. *Soil Sci. Soc. Am. J*. 66 (3):969-978, 2002. DOI: https://doi.org/10.2136/sssaj2002.9690.

Velásquez-Escobedo, J. V. *Captura y almacenamiento de carbono relacionado con la totora (Schoenoplectus californicus) del Área de Conservación Regional Albufera de Medio Mundo-Végueta 2017*. Tesis en opción al grado de Master en Ecología y Gestión Ambiental. Huacho, Perú: Escuela de Posgrado, Universidad Nacional José Faustino Sánchez Carrión.