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AGRICULTURAL SOIL ORGANIC CARBON BASELINE IN THE HIGHLANDS OF JALISCO

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Abstract: Among the global environmental problems on earth are global warming and climate change. These problems are caused by the greenhouse effect, a natural phenomenon occurring on earth, accentuated by gases present in the atmosphere called Greenhouse Gases (GHG). Carbon dioxide (CO_2) is one of these gases. Agriculture is an option as a solution to absorb and maintain this CO_2in the soil in order to reduce its concentration in the air. But first it is necessary to identify the current status of soil organic carbon (COS) in agricultural land, in order to develop and promote agronomic practices that reduce GHG emissions and retain COS. An initial action is to evaluate the COS content to determine its baseline and sequestration potential in agricultural lands in the Altos de Jalisco, which is the objective of this study. The soil database of the Productive Potential studies of the National Institute of Forestry, Agricultural and Livestock Research (Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias) was used. The vector map of agricultural use of Los Altos de Jalisco from INEGI was used. COS was estimated with the expression: $COS = \frac{MOS}{1.724} \cdot Da \cdot Pr$. For each variable, raster maps were generated and using map algebra procedures, COS was calculated for the agricultural lands in the area under study. It was found that the agricultural lands of the region under study have low and very low levels of COS, with less than 1.5% in more than 92% of the area. These results show a high capacity for COS sequestration, but they also show a high level of biological degradation of the agricultural lands of the Altos de Jalisco, with an important influence of rainfall.
Keywords: Soil organic matter, bulk density, agricultural land.

INTRODUCTION

The environmental problems present on earth originate in very localized areas, with local effects or in very distant areas and at a much later time than the site of origin, but which can compromise the global functioning of the planet, such as global warming and climate change (IPCC, 2023). Climate change is the result of global warming caused by the greenhouse effect, a natural phenomenon that occurs on Earth, with which the temperature of the planet is compatible with life. However, this phenomenon is accentuated when solar radiation reaches the surface of the planet, a part is absorbed by the surface and emitted in the form of heat radiation, where atmospheric gases allow the exit of a part of this energy out of the atmosphere, but another is returned to the surface in all directions causing the temperature to increase (INECC, 2018). The atmosphere is made up of various natural gases, but human activity has increased the concentration of some of these atmospheric components with man-made gases called Greenhouse Gases (GHGs), which amplify the greenhouse effect (IPCC, 2023). Carbon dioxide (CO_2) is one of these gases. In Mexico, GHG emissions are produced by the agricultural sector and in 2013 represented 12.0% of emissions on a national scale (INECC, 2018).

Faced with the current problem of climate change, the agricultural sector can preserve or even develop carbon sinks to absorb and maintain part of the CO_2in the soil of agricultural systems. This process involves removing it from the atmosphere, placing it in natural reservoirs, such as forests and/or agricultural land, with the possibility of reducing its concentration in the air (IPCC, 2023). In the case of forests, woodlands and agricultural lands, the process of atmospheric carbon sequestration is mainly mediated by plants through photosynthesis, with part of it stored as Soil Organic Carbon (COS) and part returning as

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oxygen and CO_2 to the atmosphere (Fynn et al., 2009). COS should remain sequestered in the soil through different management practices, but considering COS sequestered, the residence time in the soil should be 5 to 10 years (Jarecki and Lal, 2003). However, current land degradation not only decreases crop yields, but also reduces COS storage in agroecosystems. For this reason, it is important to identify the current status of COS in agricultural lands (FAO, 2022), in order to identify, develop and promote agronomic practices that reduce GHG emissions and retain COS, and improve farmers' livelihoods, with increased production and income for them (FAO, 2007).

In this context, a concern in developing COS sequestration in agriculture is whether there is a capacity in the soil to sequester organic carbon. This is one of the reasons why studies have been carried out to evaluate soil organic carbon. For this purpose, databases have been developed that include other soil properties, such as pH, total nitrogen, available potassium, phosphorus, calcium, magnesium, sodium, soil physical and chemical variables (Li et al., 2025; Paz-Pellat et al., 2016; Cruz-Cárdenas et al., 2014) and physiographic secondary variables (Ayala-Niño et al. 2020; Takata et al., 2007). A broad geospatial methodological approach has been used with models such as Kriging and variants (Li et al., 2025; Cruz-Cárdenas et al., 2014; Chaikaew et al., 2017; Mahinakbarzadeh et al., 1991), Bayesian techniques (Ngu et al., 2025; Mallik et al., 2022), weighted inverse distance (Mabit and Bernard, 2010), among others. The data used range from soil sampling with different objectives at various depths (Li et al., 2025; Chaikaew et al., 2017) combined with the use of drones (Zheng et al., 2024), remote sensing (Yu et al., 2022; Mallik et al., 2022; Sankar et al., 2019; Takata et al., 2007), land use and vegetation maps (Paz-Pellat et al., 2016), among others.

Los Altos de Jalisco is a Mexican region that produces more than 13.96% of Mexico's milk production, with family dairy production systems, using cattle fed with inputs from regional agricultural activity (SIAP-SADER, 2025), from other regions, or even from other countries (Coordinación General de Ganadería-SAGARPA, 2010). For this reason, corn forage for regional livestock has become a fundamental element for dairy cattle, especially during the dry season (Arias et al., 2012). However, this region is reported with soil degradation, with little emphasis on biological degradation (SEMARNAT, 2016), accentuated with the problem of climate change. Nevertheless, the agriculture in this region emerges as an option for COS sequestration. The objective of the present study was to evaluate the COS content to determine the baseline of carbon sequestration in agricultural lands of the Altos de Jalisco, Mexico.

MATERIALS AND METHODS

The study was conducted in lands with agricultural use in the Altos de Jalisco, as shown in Figure 1. The data collected from 2006 to 2021 from several localities of Jalisco, from soil analysis with Soil Organic Matter (SOM) and Apparent Density of Soil (Da), with soil samples taken at 30 cm depth in lands with agricultural use, were used. The laboratory chemical analysis for SOM was Walkley and Black (1947) and for Da the test tube method (Rosales, 2019). They were integrated into the database used in studies of productive potential carried out by INIFAP.

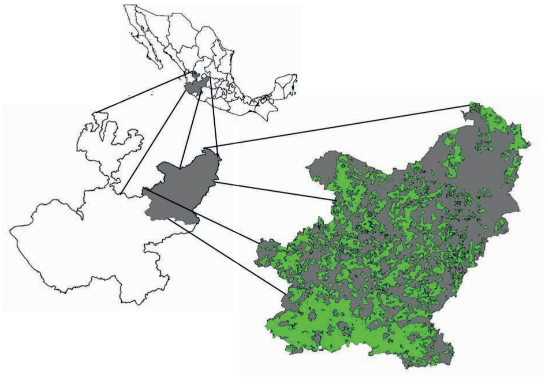


Figure 1. Geographic location of land with agricultural use in the Altos de Jalisco region, Mexico.

The procedure to quantify the amount of COS in the agricultural lands of Los Altos de Jalisco followed the procedure described below:

1. RASTER maps with the percentage of soil organic matter and bulk density with points every 90 m were generated by interpolation procedure using Inverse Distance Weighted Weighted (IDW) with pixels every 90 m in Idrisi Selva and Arcview GIS.
2. Agricultural land use for the Altos de Jalisco was defined with the Shapes of the vector data set of land use and vegetation published by INEGI, scale 1: 250,000 of the V series of the National set (INEGI, 2024).
3. The amount of COS was estimated by performing RASTER map algebra operations for the percentage of soil organic matter (MOS) and bulk density (Da), with 30 cm depth (Pr). The amount of COS was quantified with the following function: $COS = \frac{MOS}{1.724} \cdot Da \cdot Pr$, where COS represents the amount of organic carbon in the soil in t/ha, MOS is the percentage of organic matter in the soil, Da is the bulk density of the soil in g/cm^3 and Pr is the soil depth in cm (González et al., 2008).
4. The COS content obtained was reclassified according to Okalebo et al. (2002). Table 1 shows the COS and MOS levels, the equivalent in t/ha and their interpretation of COS content. Descriptive statistics were used for data analysis with the EXCEL program.

COS level (%)	SOM level (%) (%)	COS equivalent (t/ha)	Interpretation of COS COS content
< 0.5	< 0.86	< 19.5	very low
0.5 - 1.5	0.86 - 2.59	19.5 - 58.5	low
1.5 - 3.0	2.59 - 5.17	58.5 - 117.0	moderate
> 3.0	> 5.17	> 117.0	High

Table 1. Soil Organic Carbon Classification (Adapted from Okalebo et al., 2002).

RESULTS AND DISCUSSION

Figure 2 shows the percentage of Soil Organic Matter (SOM) for the study area. This figure shows that almost 65% of the region has a low level of SOM, more than 25% of the area has a medium level and 6.8% has a very low level. This result indicates that the highland region of Jalisco has a high soil capacity for carbon sequestration.

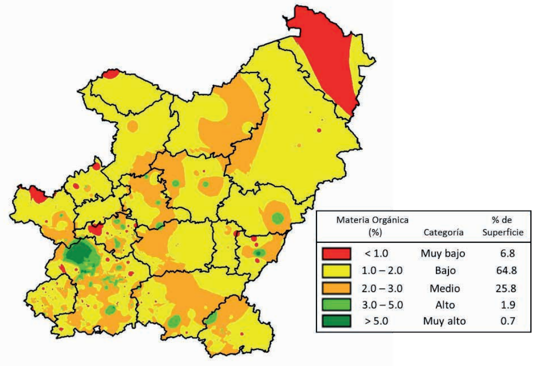


Figure 2. Map showing soil organic matter content (in percent) for the Altos de Jalisco, Mexico.

Figure 3 shows the bulk density (Da) of the soil for the study area and the area occupied by each category of Da. This figure shows that 20.6% of the region has less than 1.2 g/cm^{3}of Da, 8.6% has from 1.2 to 1.32 g/cm^{3}and 70.8% has more than 1.32 g/cm^3.

The first category of Da is associated with clayey material and SOM content, while the third category with sandy material (Porta et al., 2003). It is worth mentioning that soil texture and bulk density are connected through porosity; the higher the bulk density, the lower the porosity and vice versa. On the other hand, the soil texture with proportion of sand, silt and clay, affects the bulk density, by determining the available pore space.

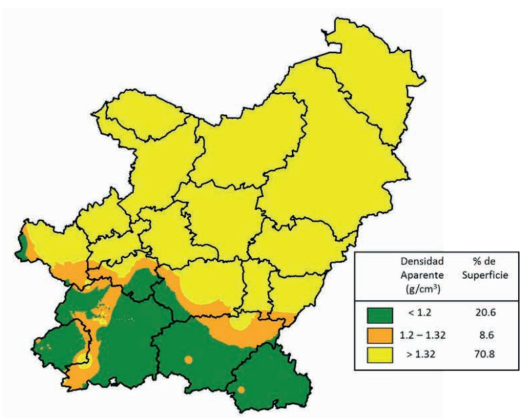
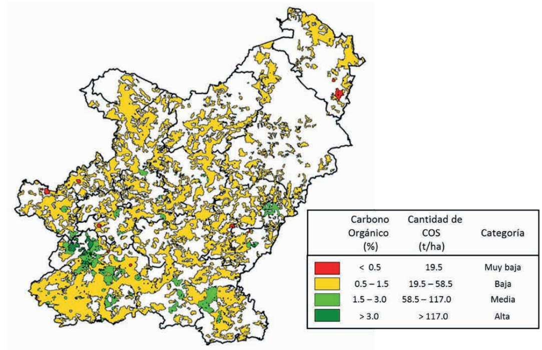


Figure 3. Map showing the bulk density distribution of soil in the Altos de Jalisco, Mexico.

Figure 4 shows the baseline COS for agricultural land under rainfed conditions for the Altos de Jalisco, Mexico. Table 2 shows the baseline (LB) COS categories, the percentage of COS and MOS per category, the COS content and area occupied by each COS category in the LB. The amount of baseline COS in the categories ranged from less than 0.5% (19.5 t/ha) to more than 3% (117.0 t/ha). The high percentage of the agricultural area in the low and moderate COS or SOM categories indicates the high capacity of Jalisco's alteño agricultural lands for COS capture and sequestration.



Baseline soil organic carbon (in percent) distribution for agricultural land under rainfed conditions in the Altos de Jalisco, Mexico.

The larger area in the low and moderate category of the COS LB is also indicative of the high degree of biological degradation of these lands (Steiner, 1996; Oldeman et al., 1991), attributed to the application of inadequate management practices and the soil exploitation characteristics of intensive production systems (Alam, 2014). It is indispensable to change soil management practices and a better use to natural resources (FAO, 2017), with which to increase COS through two paths: the first involves the restoration of degraded soils and/or the conversion of marginal soils to restored land use; the second path requires adopting recommended agronomic practices, such as conservation tillage, cover and intercropping crops, use of organic fertilizers with Integrated Nutrient Management, optimizing the irrigation system and the use of agroforestry systems (Lal, 2003).

A trend in COS was identified, defined by the amount of rainfall. The southern part of the region has a higher annual rainfall of 880.9 mm and towards the north it is reduced to 474.2 mm (Flores et al., 2012). The trend of the rainfall effect on COS availability has already been reported by other research (Márton, 2008; Hontoria et al., 1999).

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Baseline COS category	COS (%)	SOM (%)	Percentage of area in COS Baseline
very low	< 0.5	< 0.86	0.67
under	0.5 - 1.5	0.86 - 2.59	91.38
moderate	1.5 - 3.0	2.59 - 5.17	7.96
High	> 3.0	> 5.17	0.66

Table 2. Baseline categories of Soil Organic Carbon (COS), percentage of COS per category, percentage of Soil Organic Matter (SOM) and the percentage of the area occupied by each COS baseline category.

CONCLUSIONS

High potential for COS sequestration and its distribution was identified in the agricultural lands of the Altos de Jalisco. Agricultural lands have low and very low levels of COS, with less than 1.5% in more than 92% of the surface.

There is a tendency for the COS of agricultural lands to increase due to the amount of rainfall. The southern part of the region has higher annual rainfall and higher COS, while to the north rainfall is reduced with lower COS availability.

The results show the high degree of biological degradation of the agricultural lands of the Altos de Jalisco. The application of remediation actions to improve the soil quality of these lands is urgent.

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