GLOBAL SYMPOSIUM ON SOIL ORGANIC CARBON, Rome, Italy, 21-23 March 2017

National Map of Organic Carbon in the Soils and Mantle of Mexico (SOCM, 2017)

Cruz-Gaistardo, C.[1,4]; Etchevers-Barra, J.[4,5]; Leyva-Reyes, J.[2]; García-Carreón, S.[2]; Guevara-Santamaría M.[8]; Vargas, R.[8]; Báez-Pérez, A.[3,4]; Cueto-Wong, J.[3,4]; González-Acuña, I.[3,4]; Cuevas-Corona, R.[4]; Saynes-Santillán, V.[4,5]; Guerrero-Peña, A.[4,5]; Hidalgo-Moreno, C.[4,5]; ; Padilla-Cuevas, J.[4,5]; Jarquín-Sánchez, A.[4,6]; López-Anaya, M.[4,6]; Vargas-Rojas, R.[7], González-Murguía, R[7]; Morfín-Ríos, J[9]; Martínez-Vargas, M.[1,4]; Sosa I.[4]*

[1]Instituto Nacional de Estadística y Geografía, INEGI. omar.cruz@inegi.org.mx
[2]Comisión Nacional Forestal, CONAFOR.
[3]Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias. INIFAP.
[4]Red Temática Nacional de Laboratorios para el Análisis, Uso, Conservación y Manejo del Suelo. REDLABs.
[5]Colegio de Postgraduados, COLPOS.
[6]Colegio de la Frontera Sur, ECOSUR.
[7]Organización de las Naciones Unidas para la Agricultura y la Alimentación. FAO.
[8]Universidad de Delaware. UDEL.
[9]Programa de las Naciones Unidas para el Desarrollo. PNUD.

Introduction, scope and main objectives

At the global scale there is high uncertainty in soil organic carbon (SOC) data. This is mainly due to: (1) the difference between the volume of the analyzed sample and the total volume of the sample; (2) the heterogeneity of soil survey protocols and analyzes; and (3) the simplistic mechanisms used so far in Mexico for the propagation and spatial prediction of SOC information. In Mexico, SOC analysis were performed on 36,015 soil samples between 1968 and 2016, from five independent soil inventories with asymmetric sampling designs [/1,2]. Four INEGI inventories were mainly directed to grasslands, agricultural lands and areas of extreme erosion, and one inventory of CONAFOR was oriented to forested lands. Since 2003, several institutions such as COLPOS and the Mexican Carbon Program (PMC) have made important efforts in harmonizing SOC data at the national level. In 2013, the Joint Research Center (JRC) of the European Commission supported the presentation of the first SOC map of Mexico with a first national SOC stock estimate of 8.17 Gt [/3]. In 2014, PNUD estimated an average uncertainty of 68.2% of greenhouse gas (GHG) emissions derived from estimates and available data at the country level, and higher uncertainty was found in in areas with the highest land use change rates [/4]. Currently the REDLAB has generated a set of common protocols and proficiency tests among soil laboratories with large national experience in order to reduce the current uncertainty of SOC estimates. The conceptual framework used for the data acquisition process is fully compatible between the national REDLAB protocols of Mexico and its interinstitutional consortium. The objective of this work was to show the results achieved from the analyzes and spatial propagation of SOC and mantle OC data (SOCM) obtained from national soil surveys of INEGI (1968-2016) and CONAFOR (2015-2016), for its integtation in the Global Map of Organic Carbon (GSOC, 2017), with the ultimate goal of satisfying the current demand of SOC information in the United Nations Statistics Commission (UN), the Science Policy Interface (SPI) of the UNCCD, of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and the Intergovernmental Panel on Climate Change (IPCC).

Methodology

The SOCM calculation (2017) is the result of a series of concatenated processes that include sample design and analysis, field and laboratory methods, quality control and spatial data propagation techniques, as well as an iterative process to assess and reduce uncertainties.

Design and analysis of SOCM sampling

Four comparable types of SOCM sampling designs which consider leaf litter (sapric-hemic layer), fermentation (fibric-hemic layer) and mineral soil were applied. The first type of sampling is systematic. In the center of each study site a main sample is obtained using a cylinder (of 10 cm wide by 30 cm deep). Eight additional replicates using 2.54 cm wide auger holes in two study transects (NS, EO). The distances are 4 and 11 meters from the center to each replicate within an area of 400 m^2. Leaf litter or fermentation samples are taken on an area of 0.09 m^2. Mineral soil samples are collected from 0 to -30 and -30 to -60 cm deep [/5]. The second type of sampling is a vertical cut with standardized sampling depths and located 12 m north of the center of the site [/5]. The third sample design is directed to the most representative site of the geomorphological landscape and the samples are obtained in each genetic subhorizon. This sampling is performed under the diagnostic criteria of the World Reference Base (WRB 2015). Its objectives are to improve the representativeness of national sampling and to calibrate the error of systematicity. The maximum depth in this sampling is 100 cm [/6,7]. The fourth type of sampling is in experimental phase and consists of a network of semiquantitative points of rapid data acquisition with the objective to densify the most important variables related to carbon up to 30 cm.

Field observations

The sampling volume and the weight in the natural state are taken in the field to obtain the precise calculation of the SOCM in the laboratory. Also, CONAFOR performs other measurements that support quality control such as the total number of living trees, tree height (m), normal and basal diameter of trees (cm), crown width (m), woody material fallen by class, size and level of putrefaction (Mg ha^{-1}), canopy cover in two transects (%) and degree of erosion with supporting photographic evidence. In the national survey performed independently by INEGI, 28 soil specialists collect soil genetic subhorizon samples with a field description for 48 study variables, including direct SOC covariates such as spoil structure, soil field color, hand-soil texture, stoniness and coarse fragments, concretions and soil compaction[/6].

Operation of laboratory processes.

The laboratory analysis are based on 14 protocols which include the fields of application, principles of operation, common materials and reagents, as well as approved and standarized methods and controls. The carbon concentration in the soil (SOCconc) is calculated uniformly by the REDLABs using a total carbon analyzer, in percentage units, however, other forms of calculation have also been adopted to gradually improve SOCconc estimates; for example the regional chemometric models based on NIR technology. Carbon stocks (SOCstock) are calculated by the product of carbon concentration (SOCconc), the actual depth of sampling (for map effects is used from 0 to -30 cm) and the bulk density in the stoniness-free fine fraction of the soil (ton ha^{-1}).

Spatial integration of the new SOC values.

To spatially represent SOC information we use regionalization models that represent changes in average SOC values as a function of changes in factors of soil formation (or loss); such as gravity, climate, vegetation, land use, water erosion, deforestation, degradation and recovery. Each logical relationship has both exception rules and quantitative trend graphs for the continuous range of carbon values which is established from the available cartographic information[/8,9,10]. Digital soil mapping techniques are also used to build statistical models and spatial predictions of SOC and depth[/11]. The on-going development and the implementation of a national soil spatial inference engine assisted with high performance computing techniques will allow to periodically provide wall-to-wall SOC estimates at relevant scales for natural resources management.

Updating of uncertainties.

The estimation of uncertainties follows the good practices suggestions from the IPCC (2003) through the use of the following equations:

$$Uj = [(ICj /2) / Xj'] * 100 \quad \text{(Eq. 1)}$$
$$Xj' - 1.96 [V (Xj')]1/2 < = Xj' < = Xj' + 1.96 [V (Xj')]1/2 \quad \text{(Eq. 2)}$$
$$V(Xj')] = 1/w [1 + 4/w2 \Sigma (1/ni) (wi \{w – wi\})] \quad \text{(Eq. 3)}$$

Where Uj is the uncertainty of the SOC average of the soil in the subcategory j (inventory, climatic group, vegetation type or carbon interval), Xj' is the SOC average of the soil or subsoil of subcategory j. The variance V (Xj ') is defined in turn by Eq. 3, which is the variance of the estimated weighted average for subcategory j.

Results

A total of 36,015 SOCconc analyzes were performed and concentration values varied from 0.1 to 89.3% for the four sampling designs. The results of soil analysis obtained by REDLABs in 2015 show the following average percentages of SOC according to the type of analyzed sample: leaf litter (41.1%), fermentation layer (26.2%) and mineral soil (5.7% for the first 30 cm of soil depth and 3.3% for the 30 to 60 cm interval of soil thickness). The soils of Mexico have an average depth of 34.2 +/- 3.7 cm, based on a study with maximum excavation depth of 60 cm. Regarding stoniness, the average value found was 21.5% compared to the samples obtained in the INFyS 2015-2016 and 24.8% for the samples obtained in the INEGI Inventory 1968-2016. The total SOC stock in Mexico is 7.12 Pg (Uj = 53.6%) if we consider detailed physiography and vegetation polygon type maps as a baseline for regionalization purposes [/ 8,9]. The average national SOC stock is 36.4 Mg ha^{-1}. (Figure 1). The total national organic carbon stock of the mulch is 0.61 Pg for the litter layer and 0.35 Pg for the fermentation layer. (Figure 2).

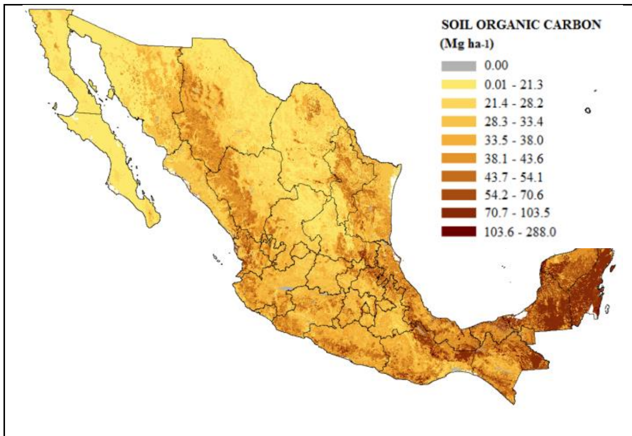

Figure 1. National Map of Organic Soil Carbon (2017).

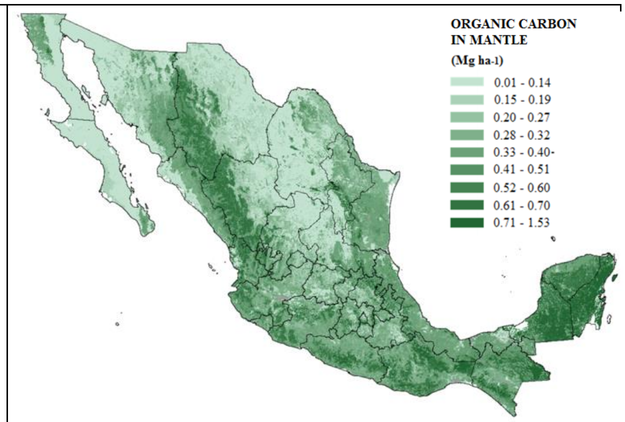

Figure 2. National Map of Organic Carbon of the Mantle (2017).

Discussion

We show a first effort towards an official SOC of Mexico. The SOC values are best related to the fermentation layer ($R^2 = 0.97$), the correlation with the litter layer was also significant ($R^2 = 0.78$). The most significant source of uncertainty is the value of internal stoniness. Total uncertainty of SOC reservoirs will increase significantly when considering environmental complexity, the effect of seasonality, and extreme events such as fires, floods, landslides, or prolonged droughts.

Conclusions

The data obtained during the soil survey by INEGI and CONAFOR in 2015-2016 reduce the general uncertainty for the current estimates of SOC reserves and concentrations by 3.9% and improves the characterization of the carbon dynamics by changes in land use, especially on areas with less than one hectare of soil surface.

References

1. Continuo Nacional de Perfiles de Suelos basado en World Reference Base. INEGI, 2015.
2. Base de datos geoespacial del Inventario Nacional Forestal y de Suelos. REDLABs, 2016.
3. Soil Organic Carbon Map of Mexico. Conference of Soil Carbon Sequestration, for climate, food security and ecosystem services. INEGI. Iceland, 2013.
4. Estimaciones de carbono en suelos en México para el sector de uso de suelo, cambio de uso del suelo y silvicultura. PNUD, México, 2015.
5. Procedimientos de muestreo del Inventario Nacional Forestal y de Suelos. Versión 15.8. México: CONAFOR, 2015.
6. Diccionario del Continuo de Datos Edafológico serie III, INEGI, 2015.
7. Base Mundial Referencial de Suelos. FAO-IUSS, 2015.
8. Continuo Nacional Fisiográfico, escala 1:250,000. INEGI, 2015.
9. Continuo Nacional de Uso de Suelo y Vegetación Serie 6, escala 1:250,000. INEGI, 2017.
10. Mapa de cambios de cobertura del suelo por desforestación, degradación y recuperación, escala 1:20,000. PNUD, 2014.
11. Guevara Mario; Vargas Rodrigo; Arroyo Carlos; Equihua Julian; Cruz Carlos; Etchevers Jorge; Paz Fernando; Brunsell Nathaniel, Hayes Daniel and de Jong Ben. Inferencia espacial de la concentración de carbono orgánico en los suelos de México. En “Estado Actual del Conocimiento del Ciclo Carbono y sus Interacciones en México: Síntesis a 2016”, Memorias del Simposio Internacional del Carbono en Mexico. Texcoco, Estado de México, Septiembre de 2016.