Essay

Scientific research in Mexico: sequestration of organic carbon in agricultural and grazing land

Bertha P. Zamora-Morales[1§]
Mayra Mendoza-Cariño[2]
Dora Ma. Sangerman-Jarquín[3]
Abel Quevedo Nolasco[4]
Agustín Navarro Bravo[3]

[1]INIFAP. Av. Progress num. 5, Barrio de Santa Catarina, Del. Coyoacán, Mexico City. CP. 04010. [2]Faculty of Higher Studies Zaragoza-UNAM. Battle May 5 s/n, corner Fuerte de Loreto, Col. Ejército de Oriente, Iztapalapa, Mexico City. CP. 09230. [3]Valley of Mexico Experimental Field-INIFAP. Highway Los Reyes-Texcoco km 13.5, Coatlinchan, Texcoco, State of Mexico. CP. 56250. (sangerman.dora@inifap.gob.mx; navarro468@yahoo.com.mx). [4]Postgraduate School-*Campus* Montecillo. Mexico-Texcoco Highway km 36.5, Montecillo, Texcoco, State of Mexico. CP. 56230.

[§]Corresponding author: zamora.patricia@inifap.gob.mx.

Abstract

Organic carbon (CO) is related to the sustainability of agricultural systems, whose activities under inadequate practices degrade soils. This work had the following objectives: to know the trend of scientific research in Mexico, related to the capture of CO in agricultural and grazing lands; and propose lines of study that respond to current knowledge needs. A systematic review was made in online databases and in the physical and digital collection of institutions that study the subject, period 1990-2016. The 79 publications were compiled, mainly scientific articles (64.6%) and theses (29.1%), with a notable increase towards the last decade. The CO was estimated basically with analytical techniques, computational models and mathematical methods. The studies included several approaches: warehouse estimation; fertility; carbon dynamics; impacts of soil conservation practices and changes in use. The Postgraduate School stood out among the institutions that study the subject, for its number of investigations. Also, the state of Mexico and Tabasco for the studies carried out in their territories. The research was disseminated in national (59.6%) and international (40.4%) media. The National Council of Science and Technology and the Mexican Carbon Program, as well as the international commitments that Mexico has acquired in the area of climate change, have supported and reoriented research on the subject that it occupies. Study lines were proposed, among them: the standardization of analytical methodologies, indicators of CO capture and CO_2 emissions.

Keywords: carbon stores, climate change, pasture, scrubland, soil management practices.

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The organic carbon of the soil (COS) is related to the sustainability of agricultural systems, since it influences most of the chemical, physical and biological properties of the soil, which define its fertility and productive capacity (Sánchez *et al*., 2004). However, traditional agronomic practices and mismanagement of animal-carrying capacity in the livestock sector generate carbon erosion and negative impacts on soil fertility (Mchunu and Chaplot, 2012). Thus, conventional agriculture has caused the loss of 20 to 80 Mg C ha^{-1} in tropical agricultural areas, which together with land use changes of the last 200 years, generated reductions of 78 ±12 Pg of carbon (Lal, 2004).

On a global scale, agricultural soils occupy about 38% of the earth's surface (12% crops and 26% induced pasture), which implies the use of the most widespread land on the planet (FAO, 2014). These soils contain 10% of the total CO storage (Paustian *et al*., 1997). Mexico has an area of 198 million hectares, 15% are used for agricultural crops and 58% for various forms of grassland (SAGARPA, 2013). In the arid and semi-arid northern part of the country, pastoral use is widespread, where grasslands and thickets are the basis of extensive livestock farming (Jurado-Guerra *et al*., 2013).

The development of agricultural activities under inadequate practices has led to Mexican soils, to varying degrees of deterioration. Among them, the reduction of productive potential and emissions of soil carbon into the atmosphere, in the form of CO_2. The above concerns the scientific community and society in general, due to its repercussions in the areas of agri-food productivity and climate change (CC).

For these reasons, the issue of carbon sequestration in the soil has gained interest in Mexico in recent years. That is why the objectives of this work were: i) to know the trend of scientific research of the last 26 years, related to the capture of CO in Mexican agricultural soils, to identify gaps in information; and ii) to propose lines of study that allow satisfying current knowledge needs and a greater understanding of the subject.

In different online databases, a systematic review was made: ISI Web of Knowledge, Google Scholar, Mexican Carbon Program (PMC), ProQuest Natural Science collection and Science direct, included the registration of the physical and digital heritage of the main research and academic institutions of the country, whose study topics are associated with the capture of the COS. In particular, Postgraduate School (COLPOS), Autonomous University Chapingo (UACH), Autonomous Metropolitan University (UAM), National Autonomous University of Mexico (UNAM) and Autonomous University of the State of Mexico (UAEM).

The documentary search comprised the period 1990 to 2016: scientific articles, theses, technical and governmental reports, books and memories of congresses and symposiums were compiled, in which duplication of content was avoided. The publications were organized and analyzed in a database in Excel, where various fields were filled, including: author, year, title, journal or editorial, federative entity where the research was carried out and participating institutions and other study units related to: the objectives, methodologies to evaluate the COS, physical, chemical and biological parameters.

During the review, 79 publications were gathered: scientific articles (64.6%), thesis of degree (15.2%), master's degree (10.1%) and doctorate (3.8%); books (2.5), memories of congresses and symposiums (3.8%). The documentary search was carried out mainly in online databases. Although the physical collections of the dependencies mentioned above were consulted the results obtained could be improved; through, of the exhaustive scrutiny of the gray literature that houses other institutions, where the knowledge remains hidden for lack of diffusion.

The period of interest started from 1990, but the longest publication corresponds to 1997. The record of these was obtained in the following years: 1997-2001, 5.1%, 2002-2006, 8.9%, 2007-2011, 22.8% and 2012-2016, 63.3%. The above, showed a growing trend in the development of research on carbon sequestration in soil in Mexico, with a notable increase in the last decade.

Publications according to the subject of study

The research of the first five years associated the capture of the COS with the type of tillage and with analytical techniques. As of 2002, studies were related to new approaches: estimation of edaphic reserves according to soil type (19.4%), fertility (18.1%), soil conservation practices (16.7%), changes in use (13.9) %), soil quality (8.3%), effects of extensive grazing (8.3%), methodologies and laboratory techniques (8.3%), carbon dynamics (5.6%) and agricultural crops (5.6%).

The study of the crops was distributed as follows: corn (36.7%), beans (15.2%), squash and wheat (6.3% each one), coffee and pastures (5.1% each one), alfalfa and barley (3.8% each one), canola, various fruits and potatoes (2.5% each one), oats, castor beans, sorghum, veza (1.3% each one).

The investigations considered the following units of study: soil type (11.9%), conventional (7.7%) and reduced (8.4%), waste (7.7%), organic (7%) and inorganic (7.7%), agricultural systems defined by monocultures (7.7%), crop rotation (7%), intercropping (5.6%) and cover crops (0.7%), irrigated crops (3.5%) and rainfed crops (0.7%), agroforestry systems (1.4%), agrochemicals for pest control (2.8%), animal load capacity (6.3%) and livestock rotation (0.7%).

The selection and frequency of these study units within the research was attributed to the concern that was generated in the scientific community around two scenarios: i) the link between the loss of soil carbon and its effects in the CC; and ii) the development of agronomic strategies to improve soil fertility and productivity. Both aspects constitute, at present, challenges in the national and international agendas.

Trend in the use of methodologies

According to Jones (2010), research on quantification of carbon sequestration is based on three methodologies: carbon storage monitoring, experimental approaches and modeling. In this context, the studies reported that the COS content was evaluated in the organic matter (81%), in the microbial biomass (12%) and in the root biomass (8%). Mainly, analytical techniques were used (wet and dry combustion, fumigation-extraction and elemental analyzers), followed by computational models and mathematical methods (Table 1). Among the techniques of wet combustion, the one by Walkley and Black (1934) stood out and in those of fumigation-extraction, that of Vance *et al*. (1987).

Table 1. Methodologies used in Mexico to evaluate the organic carbon content in soils.

Organic material		Microbial biomass		Biomass of roots	
Method	(%)	Method	(%)	Method	(%)
Wet combustion	48.2	Fumigation-extraction	75	Elemental analyzers	50
Dry combustion	28.9	Elemental analyzers	17	Mathematical models	38
Computational models	10.8	Carbon isotopes	8	MacDiken (1997)	13
Mathematical models	4.8				
Carbon isotopes	3.6				
Ignition loss	3.6				
Total	100		100		100

In some publications, it was explained that among the reasons why these techniques were chosen, it was their low economic cost, which facilitated the processing of multiple soil samples. While mathematical models and computation, were favored because they allowed to manage a large amount of data in a short time, were affordable and ‘non-destructive’. The foregoing, showed that despite the existence of different methodologies to quantify the COS, financial availability was a factor that conditioned its use. At the same time, the development and use of simulation models was increased, as is the case of the RothC model (Coleman and Jenkinson, 2005), which predict the potential of COS sequestration and carbon dynamics under different scenarios.

On the other hand, the need to standardize the analytical techniques was detected, since it was difficult to compare the results produced in the studies, due to the heterogeneity of the conditions under which the measurements were made. This project would allow: generate results in the same scheme, the homogeneity of the data for comparison, prevent the occurrence of errors and minimize the variability of the results.

In Mexico, the experiments of the changes of the COS are of short duration (González-Molina *et al*., 2011), which makes it difficult to estimate the temporary storage or loss of the COS (Kaonga and Coleman, 2008). According to the registered publications, 2.9% evaluated the COS during the crop cycle, 17.1%, in a year, 31.4%, in more than two years and 48.6%, they were isolated samples and without follow-up. While much of the research was done in experimental plots, under destructive sampling.

This affects the advancement of knowledge. It is necessary to monitor the COS in long-term experiments, since the changes are slow and difficult to detect (Roldan *et al*., 2005). This is confirmed by studies of conservation tillage, in which periods of less than two years prevent significant differences, contrary to those older than five years (Alonso and Aguirre, 2011). The above, exposes the need to develop research, based on long-term experiments, in holistic (at the level of agroecosystems) and organized, to specify the carbon stocks in local, regional and global.

Investigations by state

The publications indicated the states of the Mexican Republic where the studies were conducted: State of Mexico (28.75%), Tabasco (12.5%), Chiapas, Oaxaca, Veracruz (6.25% each one), Hidalgo (5%) Mexico City, San Luis Potosí, Yucatán (3.75% each one), Baja California Sur, Chihuahua, Durango, Guanajuato, Michoacán, Morelos, Nayarit, Tlaxcala (2.5% each one), Aguascalientes, Puebla and Sonora (1.25% each one).

Participation and productivity of academic and research institutions

The dependencies that studied the subject of sequestration of COS are concentrated in Table 2. The COLPOS, the UNAM and the National Institute of Forestry, Agriculture and Livestock Research (INIFAP), stand out for the number of published studies.

Table 2. Academic and research institutions in Mexico, which study the issue of carbon sequestration in soil.

Academic or research institution	Participation (%)
Postgraduate School (COLPOS)	28.9
National Autonomous University of Mexico (UNAM)	14.8
National Institute of Forestry, Agriculture and Livestock Research (INIFAP)	8.1
Autonomous Metropolitan University (UAM), Autonomous University of the State of Mexico (UAEM), The South Border College (ECOSUR)	5.2 (each one)
Autonomous University Chapingo (UACH), National Polytechnic Institute (IPN)	4.4 (each one)
International Center for the Improvement of Maize and Wheat (CIMMYT)	3.7
Institute of Ecology, AC.	2.96
Veracruz University, Autonomous University of Chihuahua, Technological Institute of Roque	1.48 (each one)
Scientific Research Center of Yucatan, Center for Scientific Research and Higher Education of Ensenada, Center for Biological Research of the Northwest SC, Virtual Center for Climate Change of Mexico City (CVCCCM), National Forestry Commission (CONAFOR), National School of Higher Education, Institute of Science and Technology of the Federal District, Potosino Institute of Scientific and Technological Research, AC, Agricultural Technology Institute No. 10 of Torreón, Coahuila, Technological Institute of the Olmec Zone, Technological Institute of Sonora, Autonomous University of Baja California Sur, Autonomous University of San Luis Potosí, University of the Sierra Juárez, Autonomous University of Yucatán, Autonomous University Juárez of Tabasco y University M. San Nicolas de Hidalgo	0.74 (each one)
Total	100%

It should be noted that the 1997-2001 publications corresponded to the International Maize and Wheat Improvement Center (CIMMYT) and COLPOS, with support from the Food and Agriculture Organization of the United Nations (FAO). From the 2002-2006 five-year period, those of the UNAM and the UACH were added; in the last decade of analysis, those of other institutions were integrated (Table 2). In the total of registered researches, little international participation was appreciated.

The scientific articles were published in national (59.6%) and international (40.4%) media. Among the first ones, the PMC and the peer-reviewed scientific journals were distinguished: Agrociencia, Terra Latinoamericana, Chapingo Magazine (Forestry and Environmental Sciences Series and Arid Zones Series) and Mexican Journal of Agricultural Sciences (REMEXCA). In the international framework, scientific journals: Technical Agriculture, Applied Soil Ecology, Chilean Journal of Agricultural Research, Forest Ecology and Management, Global Change Biology, Interciencia, Journal Soils Sediments, Journal of Agricultural Science, Journal of Tropical Ecology, Plant and Soil, Soil & Tillage Research, Soil Biology and Biochemistry and Tropical and Subtropical Agroecosystems.

Factors of influence in the scientific advance

According to Ortiz (1993), the institutional development and the academic strengthening of soil science in Mexico allowed the construction of public policies that defined and marked the agricultural activity in the country in the middle of the last century. Which, influenced the deterioration of soils and affected about 45% of the territory (SEMARNAT-COLPOS, 2002).

Currently, the majority of temporary agricultural land is under a system of intensive tillage production (Cotler *et al*., 2016), which has led to the loss of soil fertility; to a lower capacity to retain water and to the detriment of its structural stability. This, in turn, has favored the erosive processes and the loss of COS. On the other hand, knowledge about pasture and scrubland soils in the country is scarce (SAGARPA-INIFAP, 2013) and in relation to carbon stores and the effects of grazing, there is only information at the macro level (Segura-Castruita *et al*., 2005). Both situations led to the study of soils since the 1990s, especially those of agricultural use.

Of great importance, has been the emergence of the National Council of Science and Technology (CONACYT) in the year of 1970. Which; through financial support and the implementation of various programs to date, it has favored the country’s scientific development in terms of knowledge generation, transfer and use of technology and training of human resources. It is important to highlight that the above is enriched by the work of the Research Centers and the Thematic Networks that depend on CONACYT. Where the availability of national laboratories, allows greater progress.

On the other hand, since the establishment of the PMC in 2005 (in liaison with the National Institute of Ecology), carbon cycle research has been oriented to the context of the CC and in that sense, academic teaching in areas has been promoted priority. It is worth mentioning that the PMC has also stimulated communications with incumbent government agencies on the issue, and has participated in the process of developing public policies associated with the CC.

It is worth mentioning that Mexico is an active member of the Kyoto Protocol. Which is an international agreement that was derived from the United Nations Framework Convention on Climate Change and came into force in February 2005. The protocol aims that developed countries reduce their emissions of greenhouse gases (GEI) by five percent for 2012, with respect to its 1990 levels. One of its greatest challenges is to ensure that the agricultural soils of the planet become carbon sinks and that their catch is quantifiable, which includes grazing land, because they occupy large areas and store between 200 and 400 Gt of carbon (FAO, 2000).

The treaty contemplates three mechanisms of action: joint application, emissions trading and clean development mechanism (MDL). The MDL involves CC mitigation activities between developing countries (situation of Mexico) and industrialized countries. Under the premise that GHGs modify the climate and are distributed evenly in the atmosphere, the sequestration of these gases anywhere in the planet, produces the same effect. Therefore, developed countries can assume their commitments to reduce emissions, through projects in developing countries.

The above, through the purchase of carbon credits or with financing for GEI capture or abatement projects, in other countries and accrediting them as their own. For Mexico to participate in this market, it is necessary to know the carbon dynamics in its ecosystems, as well as the changes that occur in its flow, due to changes in land uses (Yerena-Yamallel *et al*., 2011).

Additionally, Mexico and France signed a scientific cooperation agreement in 2015 to increase productivity in the field (SAGARPA, 2015). Which allows; through the link between the scientific areas-scientific areas of the SAGARPA: Postgraduate School (COLPOS), National Institute of Forestry, Agriculture and Livestock Research (INIFAP), National Commission of Arid Zones (CONAZA)-of the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) and the French Institute of Research for Development (IRD) for its acronym in French, research and action guidelines that in the framework of CC, affect the improvement of soils for agricultural use, rehabilitation of pastures and promotion of aquaculture.

In this context, the ‘4 x 1 000’ initiative for the sustainability and care of the environment in agricultural production processes, promoted by the IRD, is framed in the use of organic matter in soils and better agricultural practices for the capture of carbon. Therefore, it is expected that the agreement will potentiate the studies related to mitigation and adaptation to CC in the agricultural sector.

This implies that the limited budget that SAGARPA allocates to soil conservation (2.12% of the total amount available by the federal agency in 2014), and that more than 80% is invested in the hydraulic infrastructure (Cotler *et al*., 2016), should be consigned to soil carbon studies. For Mexico to assume the commitments it has acquired in terms of CC and to reduce 50% of GEI emissions, the government must have between 0.7 and 2.21% of annual GDP (224 billion pesos per year) and avoid the loss of 6.2% of GDP (630 billion pesos per year) due to environmental impacts (SEMARNAT, 2009).

Proposed lines for research in Mexico

The carbon sequestration potential of Mexican agricultural and rangeland lands is unknown on a national scale, due to the scarce information available. The analysis of this work, allowed to identify some gaps in knowledge, which are exposed immediately, as needs and proposals of lines of research.

- Standardization of analytical methodologies to evaluate the content of CO.
- A complete and constantly updated inventory of CO reserves in agricultural and grazing lands (pastures and bushes).

- Estimate the potential carbon sequestration of agricultural and rangeland soils, as well as their CO_2 emissions.
- Indicators of CO capture and carbon dioxide emissions, in accordance with land use management practices.
- Design and transfer of technologies for the sequestration of CO in agricultural and grazing lands.
- Instrument of national public policy, which in accordance with current norms and laws, requires the adoption of land management practices, to:
- Favor the sequestration and conservation of carbon in agricultural and grazing lands.
- Sponsor the adoption of technologies for carbon sequestration through economic incentives
- To fulfill the commitments of Mexico, with respect to international agreements.

Additionally, it is essential to disseminate the results of studies that have already been forged in the country's academic and research institutions and that constitute important sources of knowledge communication. For what is required, digitalize the physical collections and thus, favor the accessibility to information and increase its impact.

Conclusions

Mexico has had notable advances in soil science. However, there is still much to know. To determine the current conditions that occur in the country, particularly about the sequestration of CO in agricultural and grazing land, it is necessary to form interdisciplinary scientific teams that collaborate at local, regional and national scales. As well as direct the research to a congruent and hierarchical scheme that allows concrete short, medium and long term goals; and consequently, reach the levels of scientific productivity of the developed countries.

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