Essay

Soil management in organic carbon conservation

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Abstract

The anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), distinguish these greenhouse gases (GEI) as the main causes of global warming. Which come from the energy (25.9%), industrial (19.4%), forestry (17.4%) and agricultural (13.5%) sectors worldwide. Of the total GEI flows, the agricultural sector contributes 25% of CO_2, 55-60% of CH_4 and 65-80% of N_2O. The CO_2 is generated mainly by deforestation in tropical regions, CH_4, by livestock and rice crops, N_2O by the use of fertilizers. Mexico is located within the 15 countries with the highest GEI production. Approximately 30% of its total emissions correspond to the agricultural, livestock and forestry sectors: two thirds are produced by land use activities (including change in use) and forestry the rest, by agriculture and livestock conventional. Due to the fact that soil organic carbon is related to the sustainability of agricultural systems, and in its content, affects soil management, various practices have been developed to favor their storage in the country's agricultural and forestry sectors. However, it is necessary to implement public policies that benefit the adoption and promotion of these practices and, at the same time, facilitate the fulfillment of the commitments that Mexico has acquired nationally and internationally, to minimize its GEI emissions.

Keywords: organic soil carbon, greenhouse gases, conservation tillage, carbon sequestration, land use.

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Introduction

The anthropogenic emissions of CO_2, methane (CH_4) and nitrous oxide (N_2O), distinguish these greenhouse gases (GEIs) as the main causes of global warming. According to the Intergovernmental Panel on Climate Change (IPCC, 1996), the current concentration of GEIs is the highest of the last 160 000 years: CO_2 increased more than 30%, CH_4 100% and N_2O 15%.

The GEIs distinguish CO_2 due to its high production and residence time in the atmosphere. Casanova-Lugo *et al*. (2011) mention that, on a global scale, the total annual amounts of CO_2 reach 444 million of tons. Of this amount, 70% is related to various combustion processes in the energy, industrial, transport and other services sectors, 30%, with changes in land use associated with agriculture and conventional livestock (Masera and Sheinbaum, 2004).

Robertson (2004) indicates that agricultural activities emit 25% of anthropogenic CO_2 emissions, 55-60% of total CH_4 emissions and 65-80% of total N_2O emissions. CO_2 is generated, mainly, by deforestation in tropical regions; CH_4, from livestock and rice crops; N_2O from the use of fertilizers in agriculture (FAOSTAT, 2014). Honty (2011) suggests that agricultural activities, silviculture and deforestation are responsible for 63% of GEI emissions in Latin America.

Soil management and carbon capture

In the soil, there is an amount of organic carbon (CO) three times greater than that stored in vegetation (Eswaran *et al*., 1993) and represents 69.8% of the total existing in the biosphere (FAO, 2002). Annually, in its natural breathing process, it releases between 75 and 80 Gt (giga tons) (Gt= billion tons) of CO_2-C (Santacruz, 2010). So, the soil acts as a source or reservoir of atmospheric carbon, according to the management that it presents.

There is evidence of when an agricultural system becomes a forest or pasture, you get a profit, whose rate of accumulation of CO in the soil is 0.338 or 0.332 megagrams per hectare per year (Mg C ha^{-1} $year^{-1}$), respectively (Post and Kwon, 2000). If the change occurs from agricultural to forestry under management systems, the gain rises to 7 Mg C ha^{-1} $year^{-1}$, in temperate regions, between 0.2 and 0.6 Mg C ha^{-1} $year^{-1}$ and in tropical forest systems and subtropical, between 1 and 7.4 Mg C ha^{-1} $year^{-1}$ (Izaurralde *et al*., 2001).

Likewise, agroforestry systems remove significant amounts of carbon from the atmosphere, since tree species retain this element in their wood for a long time. These systems could accumulate between 1.1 and 2.2 Pg in the next 50 years around the world (Albrecht and Kandji, 2003). Even the secondary vegetation of natural forests under suitable practices can overcome the fixation of this gas with respect to the native forest (Montaño *et al*., 2016). This implies that small changes in the stores of soil organic carbon (COS) directly affect the CO_2 content in the atmosphere (Weihermuller *et al*., 2011).

Agricultural sector

Agricultural soils occupy about 38% of the earth's surface (12% crops and 26% induced grassland), which represents the most widespread use of land on the planet (FAOSTAT, 2014). In them, about 10% of the total CO of the land surface is stored (Paustian *et al*., 1997) and they contribute 30-35% of the GEI (Saynes *et al*., 2016).

Agricultural production systems are one of the factors that cause a significant increase in CO_2 emissions into the atmosphere (Lal, 1997). Particularly, conventional agriculture has caused the loss of 20-80 Mg C ha^{-1} in tropical agricultural areas; agricultural activities and changes in land use over the last 200 years have caused losses of around 78 ±12 Pg (Lal, 2004). And, it is that since new soils are incorporated into agriculture, until the establishment of intensive farming systems, there are decreases in CO that fluctuate between 30 and 50% of the initial level (Reicosky, 2002).

The aforementioned, due to the reduction of the organic matter (MO) of the arable layer, derived from a lower contribution and incorporation of residues that in turn cause an increase in the temperature of the soil; and the destruction of macro and microaggregates by tillage (Trumper *et al*., 2009). Additionally, the loss of humic material from cultivated soils is higher than the rate of humus formation in undisturbed soils (Reicosky, 2002). When the modifications occur in forest ecosystems or pastures to agricultural systems, the losses represent between 42 and 59%, respectively (Guo and Gifford, 2002).

The tillage systems that propitiate the mechanical manipulation of the soil with the purpose of altering its structure and diminishing its resistance to the penetration of the roots, at the same time that they transform it into a medium with the optimal conditions for the seeds to germinate and develop the crops cause the loss of CO, which in the form of CO_2 flows into the atmosphere (Janzen, 2003). Therefore, the losses and gains of COS depend on the form of agricultural management and its capacity to tolerate or resist the increase in atmospheric CO_2 concentrations (Janzen, 2003).

Several agronomic practices have been developed in order to favor the capture of soil carbon (West and Post, 2002). Conservation tillage (LC) consists of the least possible movement of the soil (plow) and only in the sowing line, it requires handling the residues of the previous crop (at least 30%) to avoid erosion and increase fertility. This practice, which includes reduced tillage (LR) and zero tillage (LZ) (FAO, 2001) has potential capacity to sequester carbon in the soil (Rasmussen and Parton, 1994). Regardless of the type of tillage, the income of CO is lower than the emission of CO_2, which responds to the loss of MO as years of agriculture increase (Wilson *et al*., 2000). The rotation of crops and the introduction of several species in the LC increases the productive and environmental benefits.

The management of fertilization (MF) provides the necessary nutrients for the development of the crop and the fertility of the soil, through the improvement of its physical, chemical and biological properties. The management of crop residues (MRC) also increases fertility and protects the soil against water and wind erosion. The waste is applied on the surface or is incorporated by means of the traditional plow or the mouldboard; in both cases, they are decomposed and transformed into organic fertilizer for the next planting. This practice can be combined with LR and LZ.

Crop residues can hinder the preparation of the soil prior to planting, so in some areas its management combines burning, packing or incorporation into the soil with the plow and harrow (Fregoso, 2008). The maintenance of crop residues increases the MO content and favors microbial activity, the availability of nutrients, the infiltration and storage of water and the yields of crops (Prasad and Power, 1991).

Crop rotation (RC) maintains soil fertility and reduces erosion. The RC can be done in conjunction with other practices (such as intercropping, CI), to increase its usefulness. Cover crops (Cc) include legumes, cereals or a mixture of crops that are characterized by developing abundant foliage, which protects the soil from the impact of raindrops and wind action more efficiently than crops of weeding or in orchards. Forage or grain production can be incorporated into the soil to protect it from a critical erosion stage and improve fertility.

Agroforestry systems (SAF) handle woody species in association with agricultural crops or livestock. The following types are distinguished: sequential, where there is a chronological correspondence between the annual crops and the tree plantations that follow one another in time and the simultaneous ones, which continuously integrate the annual or perennial crops, timber, fruit trees or fruit trees multiple or livestock.

In the SAF, sustainable low-input practices are used that minimize the alteration of soils and plants, favoring perennial vegetation and recycling nutrients, which also contributes to long-term carbon storage (Nair, 2004). In the SAF, the capture potential varies between 12 and 228 t ha^{-1} (Dixon, 1995), with significant values in the humid tropical zones, whose possibility of sequestration reaches 70 t ha^{-1} in the aerial biomass, 25 t ha^{-1} in the first 20 cm of soil depth (Mutuo *et al*., 2005). The SAFs retain carbon in vegetation and soil at a rate of 0.2 to 3.1 t ha^{-1} year^{-1}, which suggests a sequestration potential of up to 7 Gt of carbon in a period of approximately 50 years (Casanova-Lugo *et al*., 2011). SAFs have GEI mitigation power when harvest residues are conserved, since tillage is reduced and cover crops are introduced (Lal, 2003). The mulch (Ac) covers the soil with a material, usually organic, to maintain soil moisture and heat, and stimulate the growth and development of the crop.

Forestry sector

Vegetation plays an important role in the carbon cycle, which is why forests are an essential element in the sequestration of atmospheric CO_2, in addition to acting as global climate regulators. Forest ecosystems store more than 80% of carbon compared to other terrestrial reservoirs (Six *et al*., 2002). On a global scale, forests contain 861 Pg of carbon, of which 44% are part of the soil, 42% of the aerial biomass, 8% of the dead wood and 5% of the mulch (Pan *et al*., 2011).

Tropical forests contain 32% carbon in the soil; the temperate and boreal 60% (Pan *et al*., 2011). Particularly, the temperate forests occupy 10 000 000 km^2 in the planet: they represent 25% of the forest area, 8% of the continental surface and 13.7% of the world net primary productivity (Galicia *et al*., 2016); with a CO reserve of 175 Pg in the aerial biomass and of 262 Pg in the soil (Haine *et* *al*., 2003 in Galicia *et al*., 2016). However, the transformation of forests into other land uses has reduced edaphic carbon reserves by approximately 22% (Murty *et al*., 2002), the natural flow of CO_2 between the soil and the atmosphere has also been altered (photosynthesis and respiration), which has been estimated at 50 Pg year^{-1} (Brown *et al*., 1996).

Tropical forests have a deforestation rate of 13 000 000 ha year^{-1} (UNEP, 2007 in Alvarez and Rubio, 2013), which released between 1 and 2 t ha^{-1} of carbon in the 1990s; that is, from 15 to 20% of the global annual GEI emissions (Fearnside and Laurance 2003). Currently, deforestation is responsible for 10% of the anthropogenic emissions of GEIs, for the opening of new farmland and for timber harvesting.

In the context of Latin America and the Caribbean, Mexico is the second GEI emitter, based on changes in land use and the forestry sector, which accounts for 27% of the country's total production (UNFCCC, 2005). In Mexico, about 40% of the area occupied, originally by temperate forests, was transformed by other land uses, such as agriculture and grazing (Challenger, 1998). At present, these ecosystems occupy an area of 323 305 km^2, which represents 17% of the national territory (Gamboa and Galicia, 2011), whose carbon capture potential has been estimated at 200 and 327 Mg ha^{-1} in vegetation and on the ground, respectively (Monreal *et al*., 2005).

The most recent estimates of the forestry sector indicate that the national CO_2 emissions are 87 × 10^6 (±34.4) Mg year^{-1}, of which 74.2% originate from the loss of biomass, 5.6% from the use of forests, 34.8% due to edaphic carbon leakage and a compensation of -14.8% corresponding to carbon sequestration in abandoned land (De Jong *et al*., 2010). The arid and semi-arid ecosystems constitute a third of the global terrestrial surface and 60% of the Mexican territory (Montaño *et al*., 2016). In them, the soil is the main storage of carbon, constitutes between 45 and 90% in the biomass of scrub and pasture, respectively. The change in land use decreases in these areas, up to 50% of its CO content.

According to estimates of the United Nations Environment Program (UNEP) (Valdes, 2010), wetlands occupy 570 M ha, which means around 6% of the land surface, and are distributed in lakes (2%), grass or reed bogs (30%), swamps (20%) and alluvial plains (15%). In the year of 2002, there were approximately 4.5 million hectares of hydrophilic vegetation in Mexico, corresponding to wetlands, where mangroves extended over 240 000 km^2 of the coastal zone (Valdes, 2010). Mangrove soils are characterized by low averages of MO decomposition and high carbon storage potential, which is why they constitute an alternative for the sequestration of this element (Moreno *et al*., 2002).

Armentano (1981) indicated in the 1980s that 230 000 ha of mangroves in the tropics had been transformed into fish ponds, which, he estimated, would result in the release of 86 250 000 t of carbon in subsequent years, as a consequence of the exposure of soils and restoration of natural balance. It is estimated that after 10 to 20 years these deposits had released between four and nine M t of carbon into the atmosphere (Valdes *et al*., 2011).

In natural forests, the soil carbon is in equilibrium, which is modified when an alteration occurs. According to the FAO (2002), between 15 and 17 million hectares are deforested every year, mainly in the tropics. Whereas, the conversion of forest lands and pastures to arable land has meant a significant loss of CO, previously stored in the soil and a release to the atmosphere of CO_2 (Álvaro *et al*., 2010).

In Mexico, three models of deforestation have been presented: i) in tropical and subtropical temperate forests, for subsistence agriculture and livestock grazing; ii) in tropical forests due to colonization under land reform; and iii) for large-scale livestock and agriculture activities (Jhonson *et al*., 2009). However, the implementation of certain practices for the management of forest ecosystems can increase carbon sequestration; for example, the natural development of forests and their biomass, a lesser use of timber resources (Niles, 2002), the repopulation of secondary vegetation or reforestation (Guo and Gifford, 2002) and afforestation -planting of tree species in sites where they did not exist, at least in the last 50 years-, among others (Six *et al*., 2002).

Paul *et al*. (2002) point out that after 10 years of afforestation in a soil with agricultural history, the COS increases 0.87% per year in the first 30 cm of depth (1.88% per year in the 10 cm). Guo and Gifford (2002) report that this increase occurs at a rate of 18%. Andrade and Muhammand (2003) cite that when deforestation is imminent, correct management is needed to minimize carbon losses, so that agroforestry systems remove significant amounts of atmospheric CO_2.

Due to the logging and changes in land use of the forest ecosystems of Mexico, reforestation and afforestation have been studied as soil management practices to conserve soil carbon. Which have numerous benefits, among which are the improvement of the soils by contribution of MO and penetration of roots, protection against water erosion and regulation of the hydrological cycle, restoration of the ecosystem, increase and conservation of biological diversity, habitat for terrestrial and avifauna fauna, and absorption of CO_2 from the atmosphere that reduces the impact of GEIs.

Livestock sector

Grazing lands represent about 30% of the land surface. They occupy 3 200 million of hectare and store between 200 and 420 thousand millions of megagrams per hectare (Mg ha^{-1}= t ha^{-1}) of carbon (FAO, 2002), equivalent to 70 Mg ha^{-1}, similar to the amount stored in forest soils (Trumbmore *et al*., 1995). Particularly, in tropical grazing areas, soil carbon and herbaceous carbon is estimated between 16 and 48 t ha^{-1} (Houghton *et al*., 1985).

The grasslands of improved grasses, compared with the savannas, sequester more carbon in the deep parts of the soil profile, which makes it less exposed to the oxidation processes and, therefore, to its loss as a gas (Fisher *et al*., 1994). And is that the grasses used in tropical animal production, in general, are of C4 metabolism; characteristic that increases its capacity to integrate the gas in the MO of the plants (Botero, 1999). When this material is consumed by animals, between 30 and 70% returns to the soil in the form of feces and urine, which ensures the reincorporation of MO.

The use of soil determines, to a large extent, the decomposition of MO (Fisher *et al*., 1994). An agricultural land loses 40% of the soil carbon that existed when its use was forest; a pasture, 20% (after five years of tomb). Added to this, poor management practices in grazing lands have led to the decay of carbon stocks in recent decades, in this regard overgrazing is the main cause (Lal, 2004a). On the one hand, livestock reduces plant cover with consequences on soil fertility and carbon erosion (Mchunu and Chaplot, 2012). On the other hand, the trampling of the animals reduces the porous space and the infiltration. Thus, overgrazing reduces the development of biomass and the carbon inputs associated with the soil.

Livestock activities, due to poor handling of the carrying capacity, present low productivity in pastures and pastures, which often leads to their abandonment; this allows for the development of species considered invasive and undesirable by producers, since they are unaware of their qualities as mitigators of climate change (Yerena *et al*., 2014). The carbon capture potential decreases with the increase in the time of abandonment of the systems: it is considered that older individuals have lower growth and productivity, which is related to carbon sequestration (Yerena *et al*., 2014).

Due to the above, there is currently a change in the management of pastures, in order to provide some environmental services to society, such as carbon sequestration (Brown and Thorpe, 2008). For example, revegetation of degraded pastures offers a global GEI mitigation potential of up to 300 Pg C (Ravindranath and Ostwald, 2008).

In Mexico, pastoral use of the land is widespread, especially towards the arid and semi-arid north, where grasslands and shrubs are the basis of extensive livestock farming (Jurado *et al*., 2013). Jiménez (1989) considers that 50% of the territory (±98 million hectare), is occupied by diverse plant communities adapted to grazing with animals, such as the natural grassland (pasture), thickets, deciduous tropical forest and mixed forests of conifers and oaks. Arroyo (1990) points out that 38% of the territory is used as grazing land, of which 76% is located in the north of the country.

In the country, land management practices in the livestock sector are limited. In this regard, the rotation of livestock and the capacity of animal load have been studied. Intensive rotational grazing consists in allocating for that purpose an area in a relatively short period of time (less than one year), in which short periods of intensive grazing (a high animal pressure) alternate with periods of long rest, for that the meadow recovers. The animal load implies the number of animals that graze a certain surface for a certain time, expressed as the amount of animal unit per hectare. That is, an animal unit such as an adult cow (450 kg with calf at the foot) or its equivalent.

Among the benefits of these soil management practices, we can mention the obtaining of better quality forage, better control of consumption and feed ration for livestock, balance between the amount of forage produced (per unit area) and its optimum exploitation by livestock; carbon capture and lower CO_2 emissions. In this sense, the rotation of livestock in paddocks allows the capture of COS because the vegetation recovers between the periods of grazing and rest.

Conclusions

In the context of climate change, soil organic carbon has received particular attention in recent years. This is due to its influence within the global carbon cycle and what it represents, the main reserve of this element in the terrestrial environment.

This has led to a growing development of research on the behavior of soil carbon, from analytical methods and predictive models to determine their soil content, to evaluations of different practices in soil management that help maintain and increase these reserves.

Even though there have been several investigations that have contributed to the generation of knowledge and that have allowed a greater understanding on the importance of the conservation and increase of carbon in the soil, the topic ‘capture of organic carbon’ in relation to the practices of land management, in the agricultural and forestry sectors of Mexico, is in the process of development.

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