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Review

The increase of soil organic matter reduces global warming, myth or reality? A review

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Abstract: The soil has lost organic matter in the past centuries. Adding organic matter to soils is one of the management practices applied to recover the levels of soil carbon of the past. Is it a good practice to reduce global warming? In fact, one of the practices promoted to combat climate change is increasing soil organic matter. However, the addition of organic residues to the soil could facilitate the liberation of CO_2 and wastes could also have no positive effects on soil properties. In this sense, what it is important is: a) to know which is the expected effect of the organic matter added to the soil; b) how this application alters the soil processes; c) which are the management practices that should be applied; d) how much is the real amount of carbon sequester by the soil and; e) the balance at short and long period after the application of the organic matter. The adequate strategy should be to favour the increment of biologically stabilized soil organic matter considering medium and long time. However, it is necessary to adapt the strategies to the local environmental conditions.

Keywords: carbon stock; climate change; humus; organic wastes; soil management

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1. Introduction

We are made of carbon and we are part of the carbon cycle, like the soil organic carbon (SOC). This review offers an overview about the close relationship between man and soil, specifically considering organic matter. Both, people and soils, have a deterministic role in the global warming and carbon has the main one. A regolith, unconsolidated rock and dust in the surface, is transformed into a soil when it contents organic/biological compounds. When we talk about the soil, we should consider that the presence of organic matter is its essence, even in mineral soils that contain from a trace to 30% organic matter [1].

Our concern about organic matter nowadays is because of soils play a major role in the global carbon cycle and the amount of SOC is determined by the balance between the rates of organic carbon input and output [2]. The carbon input is the sum of all organic carbon compounds added to the soil per unit of time (usually a year). It consists of the carbon present in crop residues, roots that die off, organic carbon in manure and wastes, etc. Carbon gain in soil involves storage and a possible reduction of carbon in the atmosphere.

Carbon storage is determined by the environmental conditions (climatic factors) and the type of soil and transformation processes, including biological interactions. Several natural factors influence the amount of organic matter in the soils like temperature, soil moisture and water saturation, texture, topography, salinity, acidity, vegetation and biomass production [1,3]. Moreover, it is recognised the importance of the management practices to determine the carbon stock of soils [4]. Following Govers et al. (2013) [5], the carbon stock in a soil can be seen as the result of a balance between carbon input rate on the one hand and carbon loss, mainly through respiration, on the other hand. Moreover, microbial life decomposes the carbon compounds in the soils to extract chemical energy from them, which, under aerobic conditions, finally results in the emission of CO_2. When the oxygen content is low, anaerobic decomposition of organic carbon compounds, which occurs in waterlogged soils but is energetically far less efficient and proceeds at much slower rates, results in the emission of CH_4 to the atmosphere. Keeping everything else constant, the amount of SOC that will be microbially metabolized/decomposed will be proportional to the amount of carbon present in the soil. Hence, doubling the soil carbon stock will then result in a doubling of the respiration rate [5]. Not only do soils act as a carbon store, but it also provides carbon emissions increasing atmospheric greenhouse gases (GHGs).

However, the mechanisms involved in the transformation processes and the organic matter accumulation are influenced by humans, decreasing or increasing the amount of organic matter in the soil and changing the rates of the natural soil processes. The characteristics of organic matter and other fertilizers and amendments added to the soil determines the processes and type of soil biota.

The Food and Agricultural Organization of the United Nations (FAO) recognizes the need to preserve soil resources from degradation and boost healthy soils, and established a programme on SOC mapping to support countries and improve soil governance at global, regional and national levels [6]. As the greatest terrestrial carbon pool, soils also play a key role in climate change regulation processes [7] and in recent years, there has been a growing demand for up-to-date soil carbon information for global climatic and environmental models [8]. According with the previous considerations, the accumulation of organic matter in the soil, especially in the topsoil (0-30 cm depth), is a desirable target for sustainability and combat global warming. However, this premise should be nuanced.

Baldock and Skjemstad (1999) [9] defined soil organic matter (SOM) as all organic materials found in soils irrespective of origin or state of decomposition. These include a wide variety of organic compounds related with many different mechanisms and processes involving all the soil fractions (mineral, organic and biological fractions), and soil organic materials added by man. For these reasons, the type of organic matter and its stability are critical factors to ensure the storage of organic carbon in soil profiles. Soil organic matter is generally agreed to contain 58% organic carbon (OC), and in most cases, it is effectively measured [8].

On the other hand, the amount of carbon stock and the type of SOM influence many soil properties, associated to the SOM, as water holding capacity, aggregate stability, compaction characteristics and friability, soil erodibility, nutrient cycling, cation exchange capacity, buffering capacity to acidification, among others [2,10-12]. Moreover, SOM is basic for the cycles of major plant nutrients like N, P or S [13,14]. This means that SOM should be decomposed and mineralized to support mineral plant nutrition and biomass growth. Soil properties associated with organic matter accumulation proceed rapidly whereas those associated with weathering generally proceed more slowly [15]. Changes in the amount and type of organic matter can occur and modify the soil characteristics. Nevertheless, SOM is a key factor for soil properties, relations and interactions with the rest of the environmental elements, including the atmosphere and CO_2 and CH_4 exchange.

SOC is a very important component of the global carbon cycle and the fate of SOC will have an important impact on the future global climate [5]. But the effects are reciprocal. Climate change impacts on soil systems although it is very difficult to predict accurately the effects due to a complex variety of soil systems. Most of the time we can find contradictory effects. For instance, higher temperatures promote the faster breakdown of organic matter in the soil due to a thermal boost to microbial activity. This accelerates the release of CO_2 and CH_4 into the atmosphere through increased soil respiration, although it can also stimulate higher levels of plant growth with increased carbon sequestration and inputs to the soil. Raising emissions can, in turn, contribute to more warming while sequestration has the opposite effect. However, the effects of an elevated CO_2 atmosphere affect indirectly the SOM even if SOM is one of the most stable C pools in terrestrial ecosystems, and consequently, its changes are usually small compared with the most other pools [16]. Changes in precipitation and more extreme hydrological cycles are predicted for many parts of Europe, meaning that they will either experience heavier rain or snowfalls or prolonged periods with lower levels of precipitation. The rate of decomposition decreases in soils with less moisture but will increase when more water becomes available. Combined with fluctuations in temperature, the changes in rainfall will affect soil structure, acidity and, in turn, its ability to store water and sustain many of the organisms that live within it. Both drought and more intense rainfall can increase the risk of erosion which can cause the release of extra carbon into the atmosphere in addition to the climate-induced changes [17].

Despite everything indicated, we cannot forget that soil carbon storage is considered a vital ecosystem service, resulting from interactions of environmental processes, of which photosynthesis, respiration, and decomposition are key. Soil acts as a biochemical reactor of organic matter and carbon store [18]. In fact, SOC usually comes from the turnover of plant and animal residues in natural ecosystems while in agricultural ecosystems, the addition of amendments and wastes is important [19]. For the reasons commented above and the complexity of the soils, understanding soil and plant interactions, soil-plant system, natural and agricultural systems, is basic to achieve the target of soil carbon accumulation.

We can conclude that soil processes related with organic matter proceed rapidly comparing with other earth processes, interact with the rest of environmental elements and main sources of SOC are externals.

The importance of carbon is indubitable. It has been established the term "carbon footprint", becoming a popular term associate to Climate Change, while its definition may be a measure of the exclusive total amount of CO_2 emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product [20]. Carbon compounds emissions are the basis of the studies and strategies adopted to combat Climate Change, furthermore, global warming seems as more important and concerning than Climate Change [21]. A global carbon market, as the centrepiece of any serious attempt to reach the ambitious goal for GHGs reductions set by climate scientists [22], has been developed as a frame for trading after the Kyoto Protocol of 1997. Nevertheless, the role of soils is essential in both global negotiations (CO_2 market) as carbon storage mechanisms to mitigate Climate Change and as finite resource required for sustainable development [23].

There are two basic approaches to reduce CO_2 in the atmosphere which are the reduction its sources and capturing (sequestration) and storage [24]. The role of the soil in both strategies is crucial. We should understand that carbon sequestration means the transferring of atmospheric CO_2 into soil of a land unit through its plants [25]. Even more, plants residues should be preferentially added to soil and the natural processes may favour the integration and formation of SOM. Increasing carbon stocks in soil implies to favour humification processes forming stabilized organic compounds.

The contribution of soils, to reduce the presence of carbon in the atmosphere and the mitigation of global warming, is based on the sequestration and storage in stabilized forms. Due to the influence of human in soil systems, it is mandatory the development and implementation of sustainable land management practices and strategies that allow to maintain the stocks of SOC or even increase [5]. Sequestration of atmospheric CO_2 into the terrestrial ecosystems in general and soils in particular, is a win-win strategy. Among numerous co-benefits are: (i) advancing food security through improvements in soil quality, (ii) restoring degraded soils and desertified ecosystems, and (iii) mitigating climate change while improving the environment [26].

2. Carbon stored in soils

We should consider that it is difficult to determine the exact carbon stored in any of the environmental compartments, and it is obvious that it is not easy in the case of soil, a highly dynamic system. However, much effort has been done to know the carbon stock in soil. According to Batjes (1996) [27] the top 1 m of soil stores 1500 Gt SOC, about half of this is present in the top 30 cm. Taking into consideration the article published by Lal (2004) [28], the global soil carbon (C) pool is about 2500 gigatons (Gt), which includes 1550 Gt of soil organic carbon (SOC) and 950 Gt of soil inorganic carbon (SIC). The SOC pool is 3.3 times the size of the atmospheric pool (760 Gt) and 4.5 times the size of the biotic pool (560 Gt). Even more, soil inorganic carbon is greater than the carbon content in the atmosphere and the biotic pool (Figure 1). Other authors indicate that soil and biota pool is around 2000 Gt and vegetation reservoir is between 500-600 Gt [29]. Notwithstanding all of the above, there are numerous uncertainties in these estimates, especially about the sinks [26].

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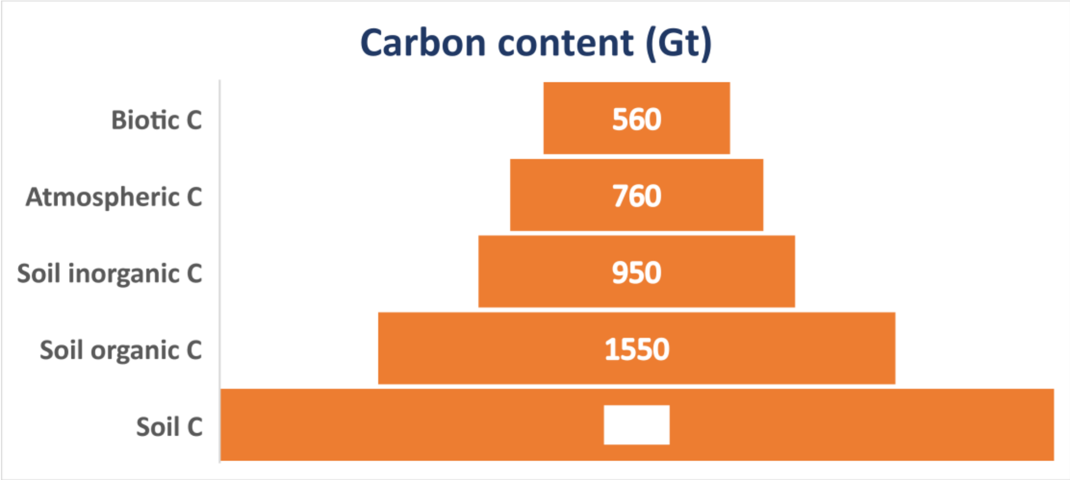

Figure 1. Carbon content in soil, atmosphere and biota based on Lal (2004) [28].

The amount of SOM is the result of the sum of inputs and losses from soil, but soil management is important to control the inputs. Lal (2004) [28] indicates that the conversion of natural to agricultural ecosystems, causes depletion of the SOC pool by as much as 60% in soils of temperate regions and 75% or more in cultivated soils of the tropics, suggesting that human-driven land-use decisions have resulted in substantial reductions in global SOC level, giving losses of 133 Pg (C) at 2 m soil depth [30]. The intensification of agriculture during 20th century gives clear evidence of a decline in the organic carbon contents in many soils as a consequence [31].

If soil carbon has been reduced for the past years in most of the soils, it seems an adequate strategy to combat global warming the increment of SOM, by adding organic matter, as natural or human induced processes (application of wastes and other organic amendments). Increasing SOC may decrease the atmospheric carbon, rather if the carbon stock will increase. But, environmental conditions and the type of soil would favour the emissions of carbon compounds to atmosphere. We are at a crossroads where we do not know exactly which is the best decision: to add organic matter or not. It may be that the solution depends on the type of organic matter and the environmental conditions of the soil.

This practice, increasing the organic matter inputs to soils, is promoted by several national and international organisms and is one of the objectives fixed by the Intergovernmental Panel on Climate Change [32]. However, the IPCC considers that, it may take a prolonged period for carbon stocks to recover past levels.

In Europe, soil carbon stocks in the EU-27 are around 75 billion tonnes of carbon; 50 % of which is located in Ireland, Finland, Sweden and the United Kingdom (because of the large area of peatlands in these countries) [33]. Such amount is more than 50 times the total CO_2-equivalent emissions of the 27 Member States of the European Union (EU-27) in 2009 (4.6 billion tonnes) [34].

Many works have been done to determine the carbon stocks but we can consider as an acceptable global mean value, that SOC pool in the first 1-2 meters is about 1500 Gt, even if some of the methods used to determine the SOC causes systematic overestimation [35]. From the Global Soil Organic Carbon Map, the first 30 cm of soil contains around 680 billion tonnes of carbon - almost double the amount present in our atmosphere. This is a significant amount compared with the carbon stored in the whole vegetation (560 billion tonnes) [36].

As a logical conclusion, one of the most important strategies, if we want to reduce the impact of global warming, is to favour the carbon sequestration and storage by soils which is the largest terrestrial carbon pool [37], increasing the levels of SOM. Its importance lies in the urgent need to offset increases in atmospheric enrichment of CO_2 (from 280 ppm in 1750 to 385 ppm in 2008) [38]. If we combine this with the re-use of organic wastes coming from human activities as soil amendments, under the Zero Waste strategy of the EU included in the Circular Economy Package [39], it seems a good practice to combat global warming.

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However, what is about the storage time of the organic matter in the soil? This time is greater the more stable the organic matter, their components forming the SOM.

2.1. Carbon storage and soil conditions

The functions and the services that soils provide to society are increasingly recognised by many administrations and international organisms, but not for the people. As EU reported, climate is one of the key factors driving soil development; at the same time, soils are important for mitigating climate change through their capacity for storing organic carbon [33].

The soil type determines the potential storage of carbon as soils have a finite capacity to sequester carbon [40] and limits the accumulation of organic matter. In mineral soils, the presence of clay and silt particles promote the stability of SOC by its adsorption (forming clay-humic complex). However, the amounts of carbon that can be associated with clay and silt is limited [41]. Moreover, the climate and microorganisms presented in the soil have a great influence in SOM decomposition and gas emissions.

We should consider that around 45 % of the mineral soils in Europe have low or very low organic carbon content (0–2 %) and 45 % have a medium content (2–6 %). According with this data, soils across Europe are likely to be accumulating carbon [42]. However, the accumulation depends not only of the amount of SOM presented in the soil in fact, but the environmental conditions that affect the soil and the type of organic matter added to increase the soil carbon. Therefore, we should take into consideration that SOM addition and accumulation do not mean that carbon sequestration and storage occur. It is necessary to check the environmental conditions affecting the soils and several examples are given bellow.

For instance, under good drainage conditions, grassland soils accumulate carbon [43]. However, croplands generally act as a carbon source, although existing estimates are varied and differs from ligneous crops to herbaceous. On the other hand, forest soils generally accumulate carbon, estimating ranges from 17 to 39 million tonnes per year [44].

However, considering the recently IPCC report [32], future net increases in CO_2 emissions from vegetation and soils due to climate change are projected to counteract increased removals due to CO_2 fertilisation and longer growing seasons. Even projected thawing of permafrost is expected to increase the loss of soil carbon [45]. The soil has a limit for carbon storage and surely, soil achieves a balance depending on environmental conditions where the annual removal of CO_2 from the atmosphere declines towards zero, while carbon stocks can be maintained. Accumulated carbon in vegetation and soils is at risk from future loss (or sink reversal) triggered by disturbances such as flood, drought, fire, or pest outbreaks, or future poor management [32]. The balance between these processes is a source of uncertainty for determining the future of the land carbon sink.

The problem may be solved considering many factors that improve or diminish the soil functionality as carbon store and can mitigate global warming. Following the IPCC recommendations [32], soil carbon management is potentially applicable across a broad range of land use types, not only in agricultural or forest areas. Moreover, the IPCC [32] recognised that given the site-specific nature of climate change impacts on food system components and wide variations in agroecosystems, adaptation and mitigation options and their barriers are linked to environmental and cultural context at regional and local levels. The socioeconomic context of each place has a great influence on soil management, and therefore, on the carbon storage capacity and the effects on global warming.

As a conclusion, soil carbon storage as a good strategy to mitigate global warming effects. It depends on the local environment (soil environmental conditions) and socio-economic conditions [32]. The reason is because the amount of carbon sequestered at site reflects the long-term balance between carbon uptake and release mechanisms [46]. To mitigate global warming, the balance should be positive to carbon storage in soils at place, considering environmental and socio-economic conditions where soils are involved.

3. Land management and SOM

For the preparation of the Conference on the Human Environment (Stockholm, 1972), FAO presented the Soils Bulletin No 13. The summary of it indicates "because of the rapid increase in the rate of use of the land as a result of pressures from population and technology, it is imperative that adequate attention be given to problems of land degradation" [47]. Human induces changes in soils, diminishing SOM, as an effect derived from the pressure exerted to land resources. An accurate definition for land degradation is given by the IPCC for this term, defined as a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity, or value to humans [32]. The non-sense of land degradation is that we are the main responsible (human induced) and the people affected by degradation processes (due to loss of ecosystem services, food supply and land value).

There are many factors responsible for the decline in SOM and most of them stem from human activity [48]: (i) conversion of grassland, forests and natural vegetation to arable land; (ii) deep ploughing of arable soils causing rapid mineralization of labile components of SOM; (iii) overgrazing, with high stocking rates; (iv) soil erosion, by water and wind; (v) leaching; (vi) forest fires. Moreover, urban expansion and soil sealing should be considered too.

As a general rule, one of the most important properties to study land degradation is the organic matter content of the soils. In general, SOC/SOM is extremely dynamic, because its highly reactive, its use as a source of energy for all microorganisms and other biota in the soil, and is preferentially removed by erosional processes because it has low density and is located in vicinity of the soil surface [49]. Because of this dynamic, land management options to increase SOM, such as improving management of cropland and grazing lands, and sustainable forest management, are desirable to be applied for carbon store and sequestration. In fact, the idea we should have is to promote the formation of humus, stabilized organic matter, and the most stabilized fractions of humus in the soils, including recalcitrant organic compounds, black carbon. It has been found that ancient soils kept organic matter as charcoal derived from forest fire (black carbon) which is a potential agent in the global C cycle [50,51].

Many associations and organisms have described soil management practices for the increment of SOC. We pay attention to the recommendations of the IPCC [32] and the American Society of Agronomy (ASA), Crop Science Society of America (CSSA) and Soil Science Society of America (SSSA), given by the Climate Change Position Statement Working Group ASA-CSSA-SSSA [52], and the FAO [53] to understand which management practices are the most adequate to achieve the carbon storage in soils. Nevertheless, if current trends continue, soils are likely to go on releasing large amounts of CO_2 into the atmosphere, adding to ongoing climate change and potentially cancelling out savings in emissions made by other sectors, such as industry and transport [17]. Several predictions to study future scenarios to estimate SOC and release of CO_2 have been developed giving similar results [54,55].

From the IPCC reports, we can find that land-based options that deliver carbon sequestration in soil or vegetation, such as afforestation, reforestation, agroforestry, soil carbon management on mineral soils, or carbon storage in harvested wood products do not continue to sequester carbon indefinitely. Moreover, IPCC indicates that peatlands can continue to sequester carbon for centuries. Hribljan et al. (2016) [56] worked in the Ecuadorian páramo peatlands and demonstrated that has been accumulating C in their soils for over 7000 years, although the local hydrology and regional climate that has supported their existence through millennia is facing increasing pressure from land use change and shifts in the Andean climate. Farming systems such as agroforestry, perennial pasture phases and use of perennial grains, can substantially reduce erosion and nutrient leaching while building soil carbon, which are parallel benefits from this strategy.

A consensus exits about conventional agricultural soil management, with intensive use of the plow, which promotes the release of C into the atmosphere, while conservationist use favours the accumulation of C in organic forms within the soil [57]. Traditional agriculture has the potential to mitigate the global warming [58] opposite to the intensively managed croplands that emit considerable CO_2, CH_4, and N_2O, which has increased their atmospheric concentrations [59].

However, there are many examples and we can learn from both the sustainable and unsustainable choices that earlier civilizations made following traditional methods for cultivation. Sustainable ancient systems and situations where ancient agriculture may have caused severe soil degradation, enough to have either caused or at least contributed to civilization decline [51].

The general consensus on the carbon balance of agricultural land is that SOC loss has dominated in nearly all areas of the world. Factors leading to SOC loss include: (i) less input of aboveground and belowground residues by agricultural crops compared with natural vegetation, (ii) acceleration of SOC decomposition by tillage disturbance that increases microbial oxidation, (iii) relocation of the C input by crops to the upper 20-30 cm soil compared with much deeper roots of native plants (with the consequence of faster decomposition and less long-term stabilization in soil, (iv) strong erosion leading to loss of surface rich organic matter [60].

Regarding to land use changes and soil management, Guo and Gifford (2002) [61] reported in the one hand that soil C stocks decline after land use changes from grassland to plantation (−10%), native forest to plantation (−13%), native forest to farmland (−42%) and grassland to farmland (−59%). In the other hand, these authors showed that soil C stocks increase after land use changes from native forest to grassland (+8%), farmland to grassland (+19%), farmland to plantation (+18%), and farmland to secondary forest (+53%).

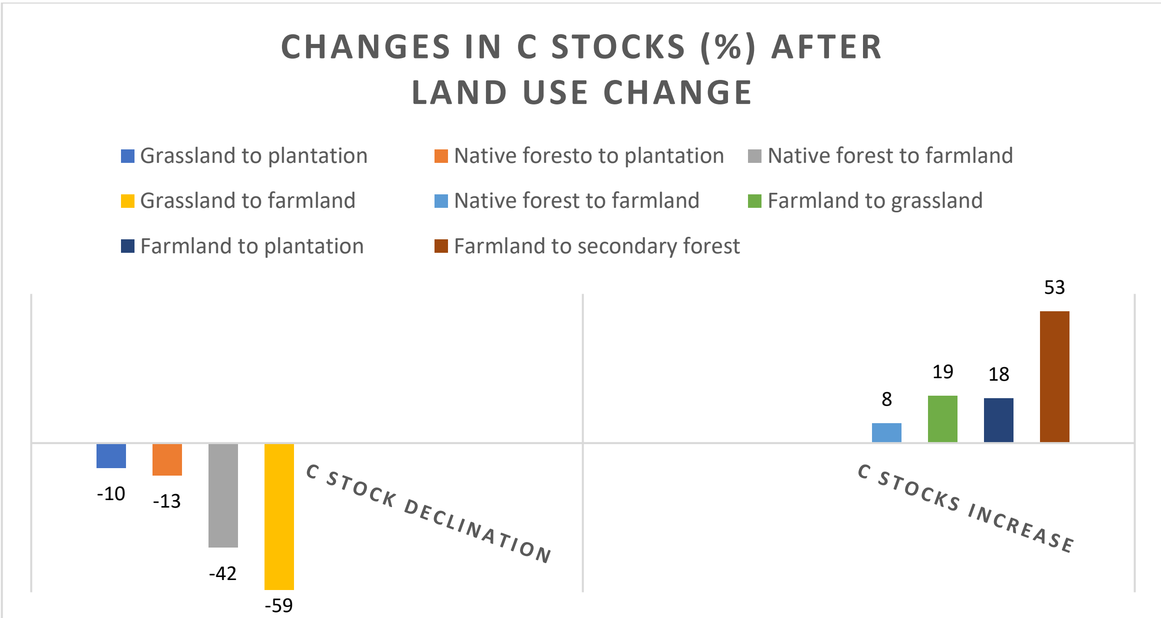

Figure 2. Changes in carbon stocks due to land use change based on Guo and Gifford (2002) [61].

The importance of grasslands is remarked by Leng et al. (2020) [62] showing that the organic carbon content of a plateau meadow in China increased when the disturbance intensity was small. However, an apparent contradictory result from Deng et al. (2016) [63] was observed with the land-use change from farmland to grassland, soil C sequestration change was not significant during 0–10 years, and then it was significantly increased. This result reinforces the idea of the IPCC that it may take a prolonged period for carbon stocks to recover past levels.

3.1. Charcoal and biochar

The use of stabilized organic compounds that can be stored in soils for centuries has been studied in the last decades, especially considering charcoal and biochar. The application of certain biochars can sequester carbon, and improve soil conditions in some soil types/climates. Biochar has significant effects on the physical nature of agricultural soils [64] and can mitigate anthropogenic climate change while improving agricultural soil fertility [65]. Enhancing soil carbon storage and the addition of biochar can be practised with limited competition for land, provided no productivity/yield loss and abundant unused biomass, but evidence is limited and impacts of large-scale application of biochar on the full GHG balance of soils, or human health are yet to be explored [32]. Recent works demonstrated that the application of biochars to forest soils generally results in the improvement of soil physical, chemical, and microbial properties while also mitigating soil GHG emissions [66]. But, the physicochemical properties of charcoal (from a wildfire) and biochar are very different and, therefore, their fates and C sequestration potentials may also differ substantially. The observed differences could also translate in different respective roles in soil functioning and other ecosystem properties [67].

Although it is well documented that biochar application into soil can mitigate the emission of CO_2, CH_4, and N_2O, few studies have also reported that biochar application enhances GHGs emission [59]. For instance, the application of wheat straw biochar (pyrolyzed at 350–550 °C) at 40 t ha^{-1} with or without N enhanced the CH_4 emission by 34 and 41 %, respectively, on a Hydroagric Stagnic Anthrosol soil [68]. Moreover, Liu et al. (2014) [69] reported 150 and 190 % increase in N_2O emission due to wheat straw biochar (pyrolyzed at 500 °C) application at 24 and 48 t ha^{-1} respectively, on a Stagnic Anthrosol. Likewise, the CH_4 emission was enhanced by 44.9 % by municipal biowaste biochar (40 t ha^{-1}) in rice [70]. As the last examples showed, soil moisture is critical point in the CH_4 emission even considering charcoal and biochar.

4. Best SOM management practices

Having commented on the previous examples, it is sometimes complex to affirm which are the best practices that we can be used to significantly increase the content of SOM as a general rule. Scientists have identified numerous best management practices including: (i) no-till; (ii) conservation tillage; (iii) groundcover and cover crops integrated in grain, forage, and agro-forestry systems; (iv) and grassland management which offer opportunities for to play a constructive role in the improved management of soil carbon, enhancing carbon sequestration and ensuring long term productivity [52]. However, it is environmental conditions and social and economic factors that will determine which of these practices is the most appropriate, together with the properties of the soil.

For instance, carbon stocks were 18% higher in soils of ex-arable land than in arable land as Kämpf et al. (2016) reported [71]. No-till significantly affected soil mechanical (bulk density, penetration resistance) and hydrological (infiltration rate and saturated hydraulic conductivity) properties in combination with residue application. Moreover, soil carbon concentration is enhanced through formation of macroaggregates under long term conservation tillage along with application of crop residue mulch [72].

Groundcovers as a strategy to improve soil characteristics for cultivation promote atmospheric CO_2 sequestration in the soil via increasing SOC stocks [73]. As García-Díaz et al. (2018) [74] demonstrated, the use of groundcover on degraded soils of Mediterranean vineyards improve soil quality in comparison with conventional tillage. Compared to tillage, groundcover increase soil organic carbon as a consequence of higher carbon inputs. Moreover, they found and increment of stabilised organic matter in soils associated to mineral fractions. This result is of great importance keeping in mind the objective of maintaining and increasing SOM levels, organic stabilized compounds.

Riu et al. (2016) [75] showed that there was further capacity for soil C storage in semi-arid coarse-textured soil through increasing and sustaining inputs of plant residues. However, long-term results were subjected to insufficient inorganic nutrients to form microbial biomass. These findings illustrate the difficulty of increasing the total soil C stock through extra plant residue inputs in semi-arid dryland cropping regions, while proper management of inorganic nutrients needs to be considered for further increase of soil C storage. In addition, soil texture would affect C stocks, facilitating the interaction of fine particles with organic matter, reducing its degradation, or favouring the aeration and gases emission in coarse-textured soils.

Chen et al. (2018) [76] found that the mean relative increase in SOC under the longer-term application of organic amendments, rendered the greatest relative increase in SOC were those with a low C:N ratio. This agrees with the difficulties to mineralised organic matter due to the lack of nitrogen for soil microorganisms due to an unbalanced.

Following the reports prepared by Rattan Lal [25] and FAO [53], centring in the transfer of atmospheric CO_2 into biotic and pedologic C pools, which is called terrestrial C sequestration, the recommended management practices for agricultural soils are the following:

i. Reduction or elimination of mechanical tillage and adoption of no-till (NT) or minimum till;
ii. Use of crop residues or synthetic materials as surface mulch in conjunction with incorporation of cover crops into the rotation cycle;
iii. Adoption of conservation-effective measures to minimize soil and water losses by surface runoff and accelerated erosion bioengineering;
iv. Enhancement of soil fertility through integrated nutrient management (INM) that combines practices for improving organic matter management (in situ), enhancing soil biological processes involving biological nitrogen fixation (BNF), and mycorrhizae, and additions of organic wastes (biosolids, slurry) and synthetic fertilizers;
v. Conservation of water in the root zone to increase the green water component by reducing losses through runoff (blue water) and evaporation (grey water), and increasing use efficiency through application of drip irrigation/fertigation techniques;
vi. Improvement of grazing systems that enhance the diet of livestock and reduce their enteric emissions; and
vii. Better use of complex farming systems including mixed crop-livestock and agroforestry techniques that efficiently use resources, enhance biodiversity and mimic the natural ecosystems.

As a general rule, the highest soil C stock increases occurred in land-use conversions from forest to grassland, and soil C stocks declined the most after conversion from forest to farmland. Deng et al. (2016) [63] concluded that soil C stocks significantly increased after the conversion from farmland to grassland and forest to grassland, and soil C stocks significantly declined after the conversion from grassland to farmland, forest to farmland and forest to forest. In addition, after conversion of farmland to forest and grassland to forest, soil C sequestration had no significant change, which is similar with the results obtained by Powers et al. (2011) [77], which reported that the conversion of unmanaged forests, grasslands, or savannas to plantations had no positive effect in the tropical regions. Powers et al. (2011) [77] also reported that the conversion of forests to shifting cultivation or permanent crops reduced soil C stocks by an average of 15.4% or 18.5%, respectively, and interestingly, both the conversions of forests to pastures and pastures to secondary forests increased soil C stocks, and the establishment of perennial tree plantations on lands that were previously grazed or cropped increased soil C stocks.

Good management practices are generally centred in addition of adequate organic residues and the application of conservation techniques to the soils if carbon stock is the objective, mainly considering agriculture systems. Moreover, changes into grassland are reported as the major land use change which benefits the SOM storage. However, the opposite could favour the liberation of CO_2.

We should remember that the successful implementation of management practices and the response depend on consideration of local environmental and socio-economic conditions. So, it is not possible to change land use without considering the environment of the site. Too often ambitious attempts to improve soils for the betterment of agricultural production have failed when soil scientists have not interacted with others, most notably local people, who have other perspectives. This is why a transdisciplinary, complex systems perspective is essential [78].

5. Conclusions and perspectives

Irrespective of the climate debate and the poor results regarding with soil from the Conference of the Parties COP25 held in Madrid (2019), the SOC stock must be restored, enhanced, and improved [13]. Moreover, the results of the COP23 held in Bonn (2017) and, the decision 4/CP.23 adopted, should be refreshing and considered. There, the "Koronivia joint work on agriculture", taking into consideration the vulnerabilities of agriculture to climate change and approaches to addressing food security, identifies the following elements to start the work [79]:

i. Modalities for implementation of the outcomes of the five in-session workshops on issues related to agriculture and other future topics that may arise from this work;
ii. Methods and approaches for assessing adaptation, adaptation co-benefits and resilience;
iii. Improved soil carbon, soil health and soil fertility under grassland and cropland as well as integrated systems, including water management;
iv. Improved nutrient use and manure management towards sustainable and resilient agricultural systems;
v. Improved livestock management systems;
vi. Socioeconomic and food security dimensions of climate change in the agricultural sector.

It is obvious that soil must be considered in any tentative to mitigate global warming. Even more, soils provide basic ecosystem services and their protection is an essential prerequisite for achieving the Sustainable Development Goals promoted by United Nations [80].

In Europe, the main strategies around agriculture and climate change are focussed to encourage farmers to adopt "simplified cultivation techniques" that enhance agricultural sustainability [42]. Results indicated by researchers addressing that changes in land use resulted in significantly higher SOC stocks in the less intensively used soil [71].

Regarding to the soil conditions, it is worthy to understand: (i) the type of soil; (ii) select the adequate organic matter as amendment; (iii) choose good management practices to maintain SOC levels; (iv) know the effects on carbon sequestration at short, medium and long term. Due to the organic matter dynamic and the relation with the environment and management practices, soil carbon sequestration can be still considered as a "stabilization wedge" among many other mitigation options and that this subject still deserves important attention for scientists, managers and policy makers [81]. Projects like LIFE CLIMAMED [82] among others, have the objective of checking and measuring GHGs emissions from soils and SOC sequestration, and know exactly what is happening under certain soil management practices.

Regarding plants and revegetation for carbon sequestration, it is necessary to consider the natural vegetation restoration, adapted to the soil and its environment, on degraded land. In general, most of the works demonstrate that these enrich, in the long term, carbon in the topsoil and subsoil. Even more, the preferably source of organic compounds within time may be the vegetation adapted to the local environmental conditions, favouring to achieve the maximum SOC stock in a soil, close to the limit of carbon storage.

Regarding to the question, myth or reality? The answer must be reality but, we should consider more than the simple addition of organic matter to the soil. Soil, environment, practice management and socio-economic factors should be integrated to achieve the goal of carbon storage. The addition itself would be the myth. We should know: (i) which is the expected effect of the organic matter added to the soil; (ii) how this application alters the soil processes; (iii) which are the management practices that should be applied; (iv) how much is the real amount of carbon sequester by the soil and; (v) the balance at short and long period after the application of the organic matter. We need to study more the type of soil organic matter added and their characteristics to be stabilized for long periods in order to combat global warming and be successful.

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