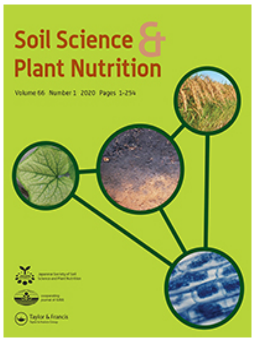

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REVIEW

Managing soils for negative feedback to climate change and positive impact on food and nutritional security

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ABSTRACT

The increase in atmospheric concentration of carbon dioxide from 278 ppm in the pre-industrial era to 405 ppm in 2018, along with the enrichment of other greenhouse gases, has already caused a global mean temperature increase of 1°C. Among anthropogenic sources, historic land use and conversion of natural to agricultural eco-systems has and continues to be an importance source. Global depletion of soil organic carbon stock by historic land use and soil degradation is estimated at 133 Pg C. Estimated to 2-m depth, C stock is 2047 Pg for soil organic carbon and 1558 Pg for soil inorganic carbon, with a total of 3605 Pg. Thus, even a small change in soil organic carbon stock can have a strong impact on atmospheric CO_2 concentration. Soil C sink capacity, between 2020 and 2100, with the global adoption of best management practice which creates a positive soil/ecosystem C budget, is estimated at 178 Pg C for soil, 155 Pg C for biomass, and 333 Pg C for the terrestrial biosphere with a total CO_2 drawdown potential of 157 ppm. Important among techniques of soil organic C sequestration are adoption of a system-based conservation agriculture, agroforestry, biochar, and integration of crops with trees and livestock. There is growing interest among policymakers and the private sector regarding the importance of soil C sequestration for adaptation and mitigation of climate change, harnessing of numerous co-benefits, and strengthening of ecosystem services.

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KEY WORDS
Soil carbon; anthropocene; historic carbon loss from soils; soil carbon sink; international initiatives on soil carbon sequestration

1. Introduction: anthropogenic climate change

With the baseline to year 1750, the atmospheric concentration by 2018 increased from 278 to 407.8 ppm (+47%) for CO_2, 722 to 1869 ppb (+159%) for CH_4 and 270 to 331.1 ppb (+23%) for N_2O (WMO 2019). The atmospheric concentration of CO_2 had reached 415 ppm on 13 May 2019 and was 413.2 ppm on 31 December 2019 (NOAA 2019). The annual rate of enrichment of greenhouse gases (GHGs) for 2016–2017 was 2.26 ppm (0.57%) for CO_2, 7.1 ppb (0.38%) for CH_4 and 0.95 ppb (0.27%) for N_2O (WMO 2019). There are three principal anthropogenic sources of these gases: 1) fossil fuel combustion, 2) tropical deforestation and land use change, and 3) accelerated soil erosion. Human activities have caused about 1°C of global warming above the pre-industrial level (with a range of 0.8–1.2°C) (IPCC 2018). Further, global warming may be as much as 1.5°C between 2030 and 2050. The present rate of global warming is 0.2°C/decade (IPCC 2018).

For the decade of 2009–2018, the average annual emission from the fossil fuel combustion was 9.5 ± 0.5 Pg (Petagram = 10^{15}g = 1 billion metric ton = 1 Gt). For the year 2018, the growth in fossil fuel emission was 1.5% and it increased to 10.0 ± 0.5 Pg C/y. For the decade of 2009–2018, the annual rate of emission from tropical deforestation and other land use changes was 1.5 ± 0.7 Pg C/y. For the year 2018, the emission from the land use change was estimated at 1.5 ± 0.7 Pg C/y (Friedlingstein et al. 2019). Considering these two factors, total emission as an average of the decade was 11.0 Pg C/y. Of this, the uptake by natural sink (land + ocean) was estimated at 5.7 ± 0.02 Pg C/y by the atmosphere, 2.5 ± 0.6 Pg C/y by the ocean, 3.2 ± 0.6 Pg C/y by the land-based sinks, and leaving a budget imbalance of 0.4 Pg C/y (Friedlingstein et al. 2019). Uptake by natural sinks as a percentage of the total anthropogenic emission was 53.7% for 1960 to 2018, with a decadal range of 51.1% in 1960s to 56.9% in 1970s (Table 1) (Nachimuthu and Hulugalle 2016; Lugato et al. 2016; Naipal et al. 2018).

However, there are other sources of anthropogenic emissions that are not accounted for in the calculations for the global carbon budget (Lal 2003; Chappell et al. 2013; Wang et al. 2014; Cilek 2017). Accelerated soil erosion, by water and wind along with other agents (i.e., stream bank, coastal, gravity, tillage), may also cause an un-estimated amount of gaseous emission. For example, soil organic carbon (SOC) transported and redistributed over the landscape and eventually carried into the aquatic ecosystems, may emit as much as 1.1 Pg C/y without accounting for the emission of CH_4 and N_2O under anaerobic conditions (Lal 2003). Walling (2008) estimated the contemporary sediment flux in the absence of reservoir trapping at 36.6 Pg/y compared with the pre-human land-ocean flux of 14.0 Pg/y. Similar estimates have been reported by others. Assuming that the delivery ratio is 10%, SOC concentrations in sediment is 1% and 20% of it is emitted into the atmosphere as CO_2, this crude (and highly tentative) calculations provide an estimate of CO_2-C emission at 7.32 Pg C/y. Yet, there are other sources of erosion (e.g., wind, gravity, coastal, stream

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Table 1. Natural sinks as a percent of the total anthropogenic emissions (Recalculated from Friedlingstein et al. 2019).

		Decade							
Parameter	Units	1960-69	1970-79	1980-89	1990-99	2000-2009	2009-2018	2018	Cumulative Total (Pg C)
Total Emission	Pg C/y	4.5	5.8	6.7	7.7	9.2	11.0	11.5	449
Natural Sinks	Pg C/y	2.3	3.3	3.5	4.4	4.9	5.7	6.1	241
Uptake by Natural Sinks	% of Total Emission	51.1	56.9	52.2	57.1	53.3	51.8	53.0	53.7

Natural sinks = Uptake by Land + Ocean
Cumulative Total = Sum total from (1960 to 2018) multiplied by 10

bank) which also affect the gaseous emission. Thus, erosion-induced emission of all gases (i.e., CO_2, CH_4, N_2O) must be accounted for in any global C budget. Accelerated soil erosion may be the second largest source of anthropogenic emission of GHGs, and its credible estimates are not known.

Between 1750 and 2017, total anthropogenic emissions are estimated at 440 ± 20 Pg C from fossil fuel combustion and 235 ± 75 Pg C from land use change and deforestation, with a cumulative total emission of 675 ± 80 Pg (Friedlingstein et al. 2019). While this estimate of cumulative emission does not include any assessment of erosion-induced emissions, yet the uptake by known sinks is estimated at 275 ± 5 Pg by the atmosphere, 170 ± 20 Pg by the ocean, and 220 ± 50 Pg by the land-based sinks, with the budget imbalance of 10 Pg between 1750 and 2018 (Friedlingstein et al. 2019). The natural sink capacity, for 1750 to 2018 is estimated at ~50%, and of the land-based sinks at 32.6%.

The historic depletion of the soil C stock is estimated at about 133 Pg C (Sanderman, Hengl, and Fiske 2017; Lal 2018). With the urgent need to identify options to limit the global warming to 1.5°C (IPCC 2018), there has been a growing interest in the potential of world soils to absorb atmospheric CO_2 and mitigate global warming. There is a growing emphasis on identifying and implementing natural solutions (Griscom et al. 2017) toward adaptation and mitigation of climate change. For example, two of the five top-ranked priority research questions within thematic areas for soil science in the 21st century include (Adewopo et al. 2014), 1) what are the critical levels of soil carbon below which soil ecosystem function is considered impaired for a given ecotype? and 2) what processes control the coupling of soil organic matter (SOM) with climate change and how will differences in biotic and abiotic components of the ecosystem include these processes? Thus, the objective of this article is to deliberate the role of managing soil to sequester atmospheric CO_2 emitted during the Anthropocene (Crutzen 2002). The Anthropocene is characterized by the dominance of agriculture managed by energy-based inputs. Agricultural land use and the attendant activities had and are having a strong impact on the planetary processes (Waters et al. 2016). Therefore, the focus of this article is to determine the role of sustainable soil management in adaptation and mitigation of climate change while also addressing Sustainable Development Goals (SDGs) of the United Nations.

2. Global soil carbon stock

Total quantity of carbon in top 1-m of soil estimated at 2200 Pg to 1-m depth (Banwart et al. 2015) comprises of two distinct but related components: soil organic carbon (SOC) and soil inorganic carbon (SIC). The SOC is a small part (~5%) of the solid component of the soil matrix that is derived from the live biomass and remains of plants and animal tissues at different stages of decomposition along with the by-products of microbial processes. The SOC may also comprise of soot and biochar as a result of natural and managed fires and the attendant combustion of biomass and the detritus material. The SIC comprises of carbonates and bi-carbonates of cations (Ca^{2+}, Mg^{2+}, K^+, Na^+). Two types of carbonates include primary or lithogenic derived from weathering of the parent rock and secondary or pedogenic formed from the soil processes. Pedogenic carbonates may be linked to the SOC through microbial respiration, dissolution of CO_2 in soil water to form a weak carbonic acid, and its reprecipitation through reaction with cations (Ca^{2+}, Mg^{2+}) brought-in from outside the system. Estimates of SOC, SIC and total C stocks to varying depths are shown in Table 2. In comparison with the amount contained in 0–0.3-m layer, total C stock is 2.48 times in the 0–1-m layer and 3.91 times in the 0–2-m layer. The additional amount of SOC stock contained is 47.4% in 0–1 m and 63.4% in 0–2 m compared with that in 0–0.3-m layer. Similarly, the additional amount of total stock contained is 59.7% more in 0–1 m and 74.4% more in 0–2 m compared with that contained in 0–0.3-m layer. Therefore, it is important that estimates of C stocks (total, SOC, and SIC) are made to at least 1-m, and preferably to 2-m depth. In a short-time period (1–2 years), management-induced changes (i.e., soil, land use) on total and especially the SOC stocks are expected to occur in the surface 0–0.3-m layer. However, changes in total and SOC stock in 0–0.3-m layer caused by accelerated soil erosion may be observed even over a shorter time period (i.e., on a seasonal basis). These estimates of soil C stocks are based on the assumption of the flatness of Earth's surface. In comparison with the assumed surface area of 15 G ha for the flat terrain, Earth's surface area is > 65 G ha for the hilly slope undulation and topsoil relief detail. That being the case, the SOC stock to 1-m depth may be 8580 Pg, which may likely be an under-estimate. Similarly, the C stock in the terrestrial biosphere may be 2–3.5 times greater and the net primary productivity (NPP) as much as 270 Pg C/y rather than 63 Pg C/y (Blakemore 2018).

Soil C stock is an important component of the global C cycle or GCC (Figure 1). A sub-cycle within the GCC involves exchange of C between the atmosphere, biota, and the soil (solid line). Through another sub-cycle (dotted line), the C is

Table 2. Estimates of total global soil organic carbon and soil inorganic carbon stocks (adapted from Plaza et al. 2018).

	Pg C			% Below 0.3 m Layer	
Depth (m)	SOC	SIC	Total	SOC	Total
0-0.3	750 ± 15	173 ± 5	923	-	-
0-1	1425 ± 21	868 ± 10	2293	47.4	59.7
0-2	2047 ± 39	1558 ± 19	3605	63.4	74.4

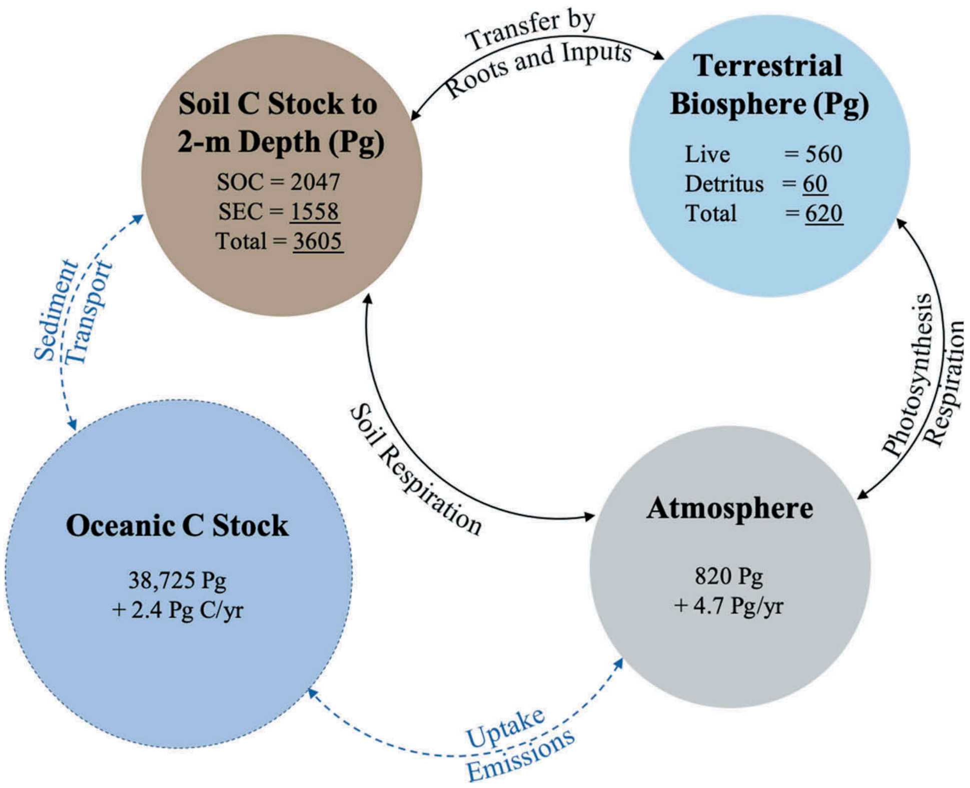

Figure 1. Components of the global carbon cycle. The data on pool and fluxes are from Plaza et al. (2018) and Lal (2018).

continuously exchanged between the ocean, soil, and the atmosphere (Figure 1). The stock of the total soil C to 2-m depth of 3605 Pg is about 4.4 times the amount contained in the atmosphere (820 Pg) and 5.8 times that in the biota (620 Pg). Even small changes in soil C stock can lead to large changes in the atmospheric concentration of CO_2. Therefore, protection, restoration, and sustainable management of soil C stock (both SOC and SIC) can strongly impact the atmospheric C stock, and thus, the trend and the absolute increase in global warming.

3. Historic carbon loss from world soils

Conversion of natural to managed ecosystems leads to the depletion of the terrestrial C stocks, both in the vegetation and soil (Lal 2004). The loss of C stock from the soil is estimated at about 133-135 Pg C (Sanderman, Hengl, and Fiske 2017; Lal 2018). The negative C budget in soils of the agro-ecosystems is attributed to a range of factors including i) lower input of biomass-C into soil, especially that of the root biomass, ii) higher rate of decomposition or mineralization of SOC because of alterations in soil temperature and moisture regimes upon change in land use, iii) more risks of soil erosion by water and wind in agroecosystems than those under the protective cover of natural vegetation, and iv) increase in leaching losses of dissolved organic C (DOC) because of alterations in the components of the hydrological cycle. In general, the depletion of SOC in soils of agro-ecosystems vis-à-vis that of natural ecosystems is more in coarser than in finer-textured soils, in tropical than those in temperate biomes, in well-drained than in poorly drained conditions, and in south-facing than north-facing slopes in northern latitudes and vice versa in southern latitudes.

4. Soil carbon sink capacity and carbon saturation

Soil C saturation implies an upper limit of SOC sequestration regardless of the input of biomass-C into the soil (Stewart et al. 2007). In other words, soil C sink capacity depends on the historic C loss because of the past land use and management along with the severity and type of degradation. It also refers to the SOC sequestration efficiency as defined by an increase in SOC stock per unit impact of biomass-C (Δ SOC ÷ Δ biomass-C input) (Six et al. 2002). In addition to historic loss per se, the saturation level (or the sequestration efficiency) is also related to the amount of soil colloids or silt + clay content (Hassink 1997; Merante et al. 2017; Schjønning et al. 2012), molecular structure of organic substance (Baldock and Skjemstad 2000), physical access (Dungait et al. 2012), soil fertility management (Schjønning et al. 2018), among others.

5. Soil carbon sequestration

The SOC sequestration is the process of transferring atmospheric CO_2 into soil C stock by creating a positive soil/ecosystem C budget through the input of biomass-C from plants grown on the same land unit (Olson et al. 2014). In addition, sequestration of SIC is also an important process especially in arid and semi-arid climates (Lal 2019a; Monger et al. 2015). Some contrasting attributes among SOC and SIC include the followings: i) the mean residence time (MRT) of SIC, estimated at 78,000 years (Schlesinger 1985) is much longer than that of

SOC, ii) the concentration of SIC increases with increase in soil depth but that of SOC follows an opposite trend, and iii) the concentration and stock of SIC in soil decrease with the increase in rainfall amount but that of SOC increase with increase in precipitation-induced increase in soil wetness.

6. Techniques of soil carbon sequestration

The SOC is a dynamic entity, and it changes with changes in endogenous and exogenous factors (Figure 2). Predominant among endogenous factors are soil/solum and terrain/undulation. Soil properties that determine C saturation are texture, cation exchange capacity (CEC) as determined by clay mineralogy. The latter affects the surface area (internal and external), charge characteristics, water retention and transmission or internal drainage, and the plant nutrient reserves along the intensity and capacity factors that influence plant uptake and the net primary productivity (NPP). Pertinent among the solum characteristics are depth above the parent rock, horizonation or distinct layers, stratification (i.e., depth distribution) of SOC, clay content and plant nutrients, activity and species diversity of soil biota, depth of root penetration, etc. Some examples of exogenous factors are climate and management (Figure 2). Regional climatic factors (micro and macro) are precipitation, temperature, P:T ratio, potential evapotranspiration (PET), aridity index (P:PET), seasonality, and the water budget. The latter, in conjunction with seasonality, affects the NPP, and thus the amount of biomass-C (root, shoot) that can be potentially returned to the soil. The NPP, its magnitude, and quality or composition also depend on the land use (i.e., agricultural, forestry, urban, recreational, mine land, natural) and the input of nutrients/amendment and conservation of soil and water resources. Farming systems, especially those involving a combination of seasonal vegetation with perennials and livestock, are pertinent to the NPP and its quality (Figure 2).

With the objective of enhancing SOC sequestration, the choice of land use and of residues (plants and animals) retention are important determinants of the soil/ecosystem C budget. In all of the managed ecosystems, the strategy is to minimize land area under the built or sealed surfaces and maximize those that are covered by vegetation.

Among agricultural and forestry-based land uses, complex systems are pertinent to conservation, protection, and restoration of soil resources. Pertinent among these are agro-forestry, agro-pastoral, silvo-pastoral, and agro-silvo-pastoral systems (Figure 3). Similarly, urban agriculture, urban forestry, green roofs and sustainable management of recreational grounds are appropriate to environmental improvement. Increasing the ground cover and optimizing the use of chemicals (e.g., reducing leakage) are pertinent to protecting the environment. Reducing the rate of tropical deforestation, estimated at 12 million ha in 2018 (Showstack 2019), and increasing favorable soil biodiversity (Lognoul et al. 2017) are essential to controlling the anthropogenic emissions. In addition to storing C in soil and vegetation, forests also moderate the global hydrological cycle and are habitat for numerous species of flora and fauna.

Among cropland systems (arable land), adoption of conservation agriculture (CA) can protect soil C stock against losses by soil erosion and reduce emissions from farm operations. The SOC stock must be protected against losses by soil erosion while also reducing emissions from farm operations. The SOC

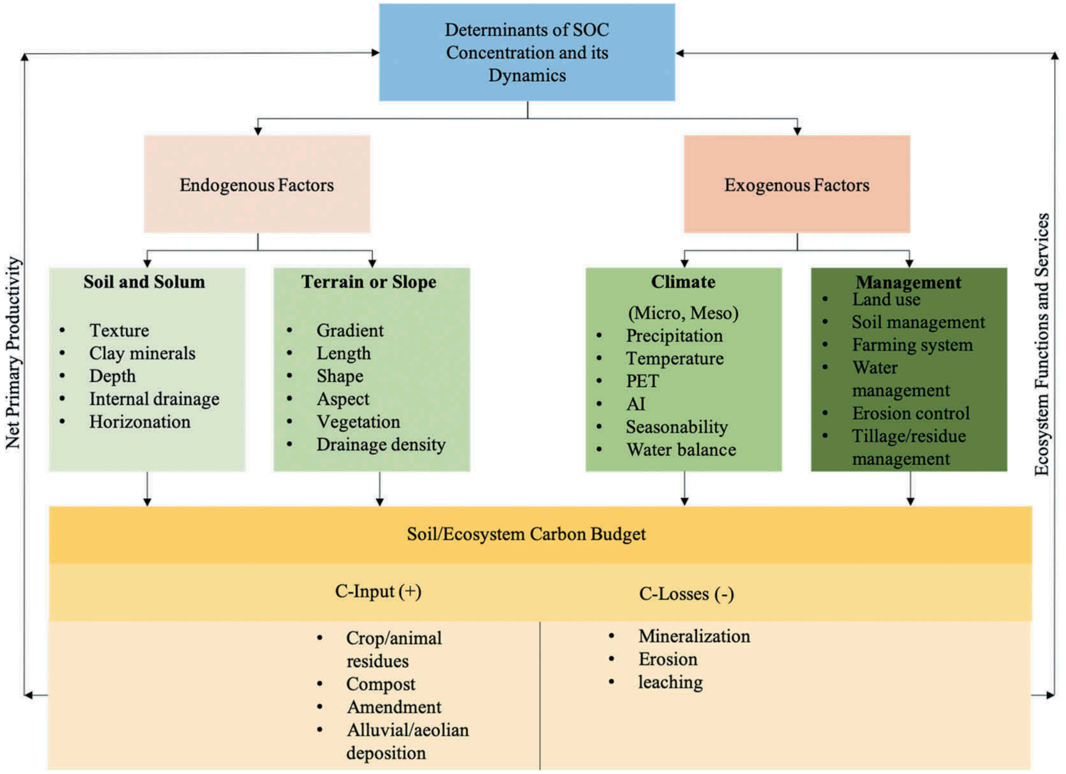

Figure 2. Factors affecting the soil organic carbon (SOC) concentration and its dynamics (PET = potential evapotranspiration, AI = aridity index or precipitation: PET).

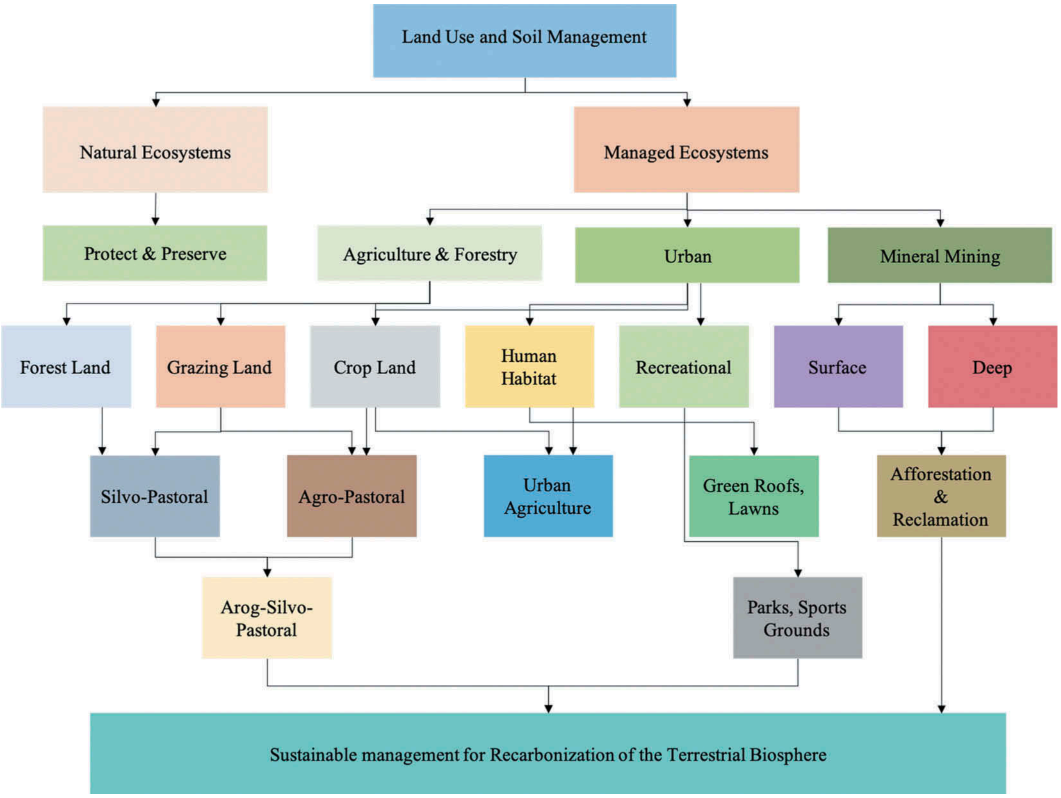

Figure 3. Determinants of soil/ecosystem C budget through land use and management of the residues of plants and animals.

stock under CA is protected in stable micro-aggregates with reduced access to microbial processes (Dungait et al. 2012), and better aeration leads to oxidation of CH_4 and reduction of gaseous emissions (Lognoul et al. 2017), favorable soil biodiversity (Degrune 2017) and better soil health (Lal 2015). Thus, CA-based crop-management systems have a lower global warming potential and reduced carbon footprint than those of the plow-based systems (Lal 2015). Whereas the plow-based systems can produce better agronomic yield than CA systems (Hiel et al. 2018), other factors must also be considered including fuel consumption and labor demand.

Sequestration of SIC is important in global drylands which cover 66.7 M km^2 (Lal 2019b). There are some common practices for sequestration of both SOC and SIC. There are no 'one-size-fits-all' practices that are universally applicable. Important among these practices include irrigation/fertigation, use of organic amendments, and other techniques that enhance production and retention of biomass-C in soil. In addition to enhancing agronomic productivity and, thus, increase of SOC sequestration (Gillabel et al. 2010), supplemental irrigation with a good quality of water also enhances SIC (Entry, Sojka, and Shewmaker 2004) and increases leaching of bicarbonates into the groundwater (Monger et al. 2015). Formation of neo-pedogenic carbonates is also facilitated by long-term application of organic fertilizers. In a semi-arid region of China, Bughio et al. (2016) observed that neoformation of pedogenic carbonates occurred at the rate of 0.38, 0.27, 0.23, and 0.12 Mg C/ha per year for organic fertilizer at high rates, organic fertilizer at low rates, mineral fertilizer, and the control treatment, respectively. Liming can also impact the mineralization of native soil C, and CO_2 emission from soil carbonate dissolution (Ahmad et al. 2015).

The impact of sustainable soil management (SSM) practices, after 3 to 5 years, on soil health should be quantifiable by measuring physical, chemical, biological, and ecological parameters (Figure 4). Simple tests, based on standardized methodology, must be designed to measure the impact of SSM on soil health on a periodic (every 2 to 4 year) basis. From the parameters listed in Figure 4, a few (2 to 3) key attributes must be selected for soil/site-specific conditions that researchers can quantify, and farmers/land managers can understand and relate to.

Over and above the measurable impact on soil health, there must also be obvious environmental benefits of SSM. Important among these are erosion control, decline in non-point source pollution (e.g., reduction in algal bloom), low risks of salinization, low susceptibility to crusting, increase in soil biodiversity, and overall resilience against climate change as evidenced by lower emission of greenhouse gases.

7. The environment and economic co-benefits

Restoration of soil functionality by enhancement of SOC concentration in the root zone has numerous environmental and economic co-benefits (Figure 5). In addition to creating climate-resilient soil and agriculture, through adaptation and mitigation of climate change, restoration of soil health through sequestration of SOC is also pertinent to improving the quality

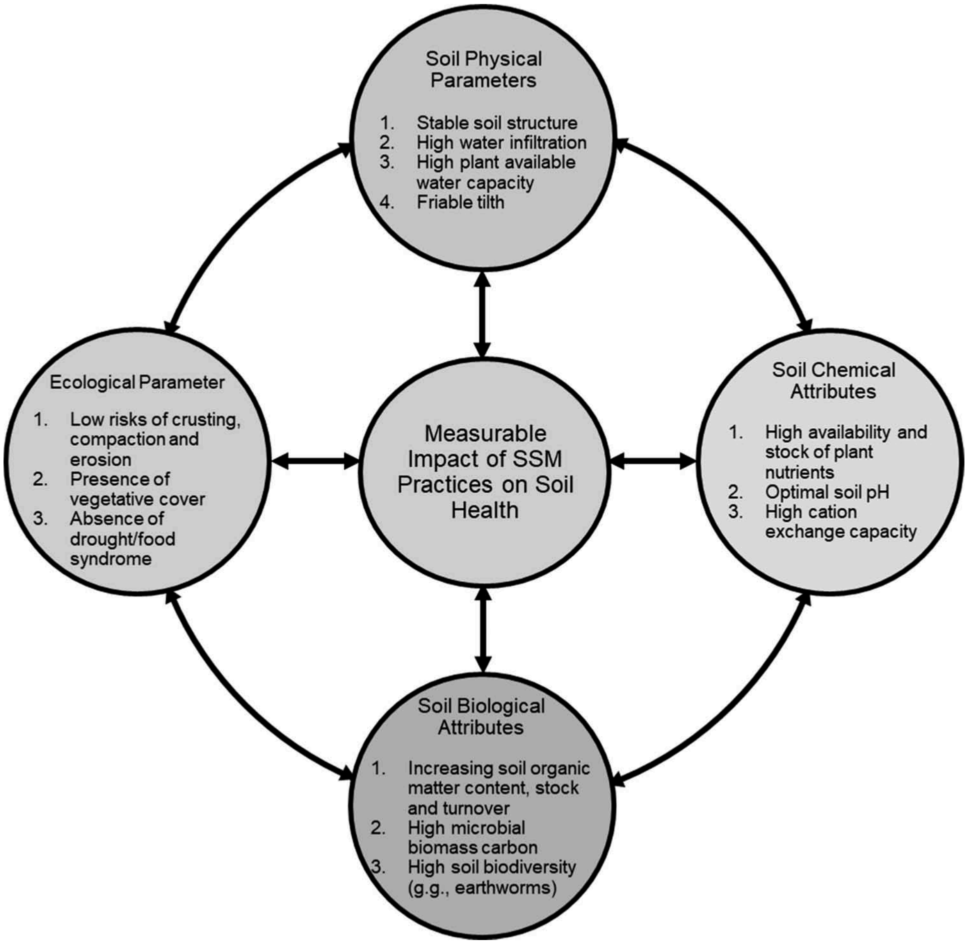

Figure 4. Quantifiable impact of sustainable soil management practices on SOC-induced changes in soil health.

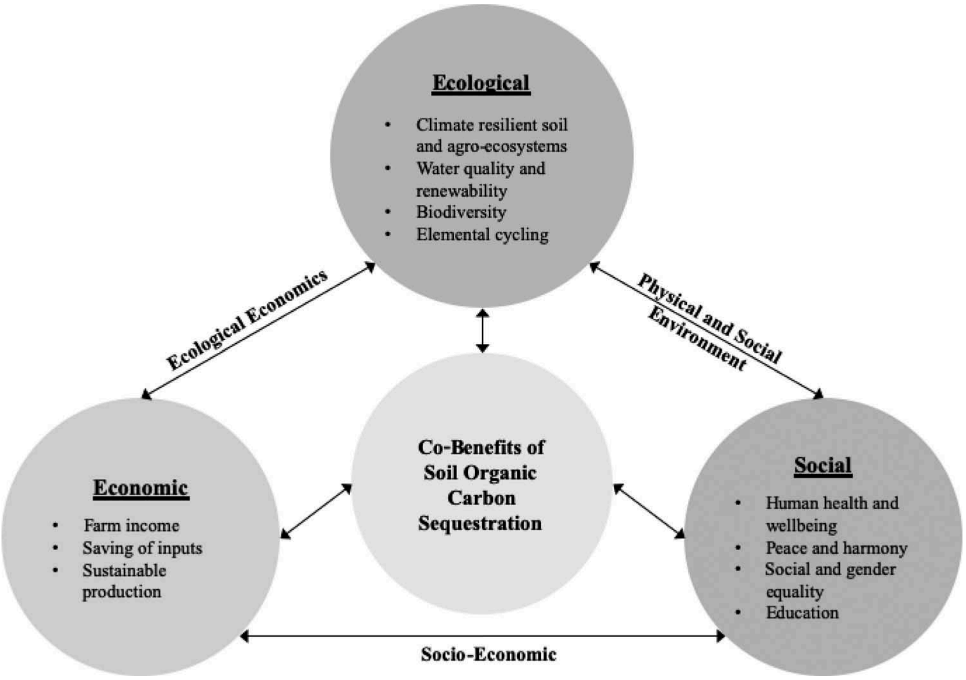

Figure 5. Co-benefits of soil organic carbon sequestration.

and renewability of water resources, enhancing biodiversity, and strengthening elemental cycling. The coupled cycling of C with those of H_2O, N, P, and S is also improved by an increase in SOC concentration to the threshold level of ~2%. Increasing farm income by reducing inputs and enhancing their effectiveness is an important economic benefit. Sustainable productivity in a changing and uncertain climate is an important economic co-benefit because climate-resilient soil can stabilize productivity, reduce uncertainty, and produce an assured yield response even under extreme weather conditions. The assured minimum yield under harsh climate will increase with the restoration of soil functionality through an increase in SOC concentration and stock. Closely related to the economic co-benefits are favorable societal impacts of the restoration of soil health and carbon sequestration. Pertinent among these are improvements in human health through better nutrition, clean water and air, and improved landscape. The truisms that 'the health of soil, plants, animals, people, and the environment is one and indivisible' and that 'people are the mirror image of the land' translate into a better human wellbeing, social and gender equity, and the overall peace and harmony (Figure 5). Restoration of soil health has long-term positive effects on humanity and the planet.

8. The way forward and international initiative

An increase in awareness about the importance of harnessing the co-benefits of SOC sequestration for advancing the SDGs of the United Nations, achieving food and nutritional security (Lal 2004), and adapting to and mitigating anthropogenic climate change (Lal et al. 2018) is indicated by the launch of several international initiatives. Important among these are '4 Per Thousand' launched at COP21 in Paris in 2015 (Chambers, Lal, and Paustian 2016; Minasny et al. 2017), 'Adapting African Agriculture' launched at COP22 in Marrakesh in 2016 (Blakemore 2018), the Great Green Wall across Sahel (UNCCD 2015; FAO 2017), Platform for Climate Action (PLACA) at COP25 in Chile/Madrid in 2019 etc. The strategy is to translate science into practices that can be widely adopted for reversing the global degradation and desertification trends. The entry point for breaking the vicious cycle 'land misuse-soil mismanagement-soil degradation and desertification-poverty and hunger-civil strife and political instability' is through the restoration of soil health by harnessing soil carbon sequestration. Restoration of soil health is also critical to advancing the SDGs of the U.N. (Figure 6). Directly, soil health is critical to advancing SDG #1 (No Poverty), #2 (Zero Hunger), #6 (Clean Water and Sanitation), #13 (Climate Action), and #15 (Life on Land) (Figure 6). Restoration of soil functionality is also relevant to advancing SDG #3 (Good Health and Wellbeing), SDG #4 (Quality Education), SDG #5 (Gender Equity), SDG #8 (Decent Work and Economic Growth), and SDG #16 (Peace, Justice, and Strong Institutions) (UN 2015).

9. Increasing awareness about the need to protect and enhance soil functionality

Potential of the terrestrial biosphere to create a CO_2 drawdown between 2020 and 2100 through the adoption of restorative land use and soil management practices is 333 Pg C or about 157 ppm (Lal et al. 2018). Of this, 178 Pg C (84 ppm of CO_2 drawdown) exists in soil and 155 Pg (73 ppm) in the biomass (Lal et al. 2018). However, the scientific community must work with the policy-makers to enhance awareness about this potential and facilitate

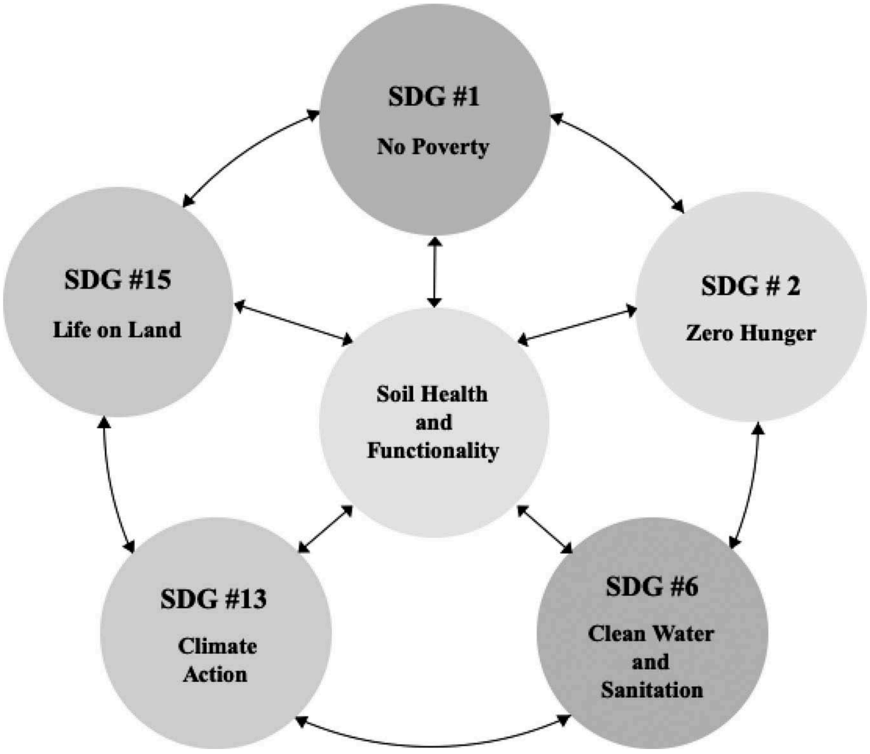

Figure 6. Soil health and functionality in relation to advancing sustainable development goals of the U.N.

the translation of science into action. There are three options to enhance awareness about the need to protect, restore, and sustain global soil resources which are finite, unequally distributed geographically, and prone to degradation by land misuse, soil mismanagement and the current and projected climate change. One, it is logical to encourage religious organizations to preach the importance of soil, water, vegetation, and other natural resources among the believers of a specific faith. Soil, water, air, vegetation, and natural resources are worshipped and revered by most religions of the world (Lal 2013). Therefore, it would be appropriate to highlight the importance of soil and other natural resources as is narrated in the ancient scriptures. Two is economic incentivization and payment to farmers and land managers for provisioning of ecosystem services (e.g., sequestration of carbon in the soil, improving quality and renewability of water, and strengthening of biodiversity). Any payment must be based on the basis of the societal value of soil carbon (Lal 2014) and paid in a transparent, just and fair manner. Three, is a legal option based on the concept that soil has rights. Being a living entity, soil also has rights (like any other living being) to be protected, restored, and thrive (Lal 2019c). Any deliberate misuse and mismanagement that endangers soil quality must have legal connotations. In the U.S., there is a Clean Water Act (the Federal Water Pollution Control Act of 1972), and the Clean Air Act of 1963. Similarly, there should be a Healthy Soil Act that protects against misuse and mismanagement of soil. Environment comprises of three components: water, air, and soil. Thus, the Healthy Soil Act is long over-due as an effective environmental protection.

10. Conclusion

Soils of agricultural and other managed ecosystems contain lower carbon stocks than their counterparts under natural vegetation because of the historic land use and degradation (i.e., erosion) induced depletion of soil organic carbon stock. Adoption of restorative land use and site-specific best management practices, which conserve soil and water and strengthen elemental cycling, can create a positive soil/ecosystem carbon budget and sequester atmospheric CO_2 as soil organic and inorganic carbon. The cumulative technical potential of carbon sequestration at 178 Pg in soil and 155 Pg in vegetation between 2020 and 2100 can create a drawdown of atmospheric CO_2 by 157 ppm. In addition to creating climate-resilient soils and farming practices, carbon sequestration has numerous co-benefits. The concept is being translated into action by policymakers and the private sector. Healthy Soil Act is needed to complement the Clean Air Act and Clean Water Act for the protection and restoration of soil resources.

Disclosure statement

No potential conflict of interest was reported by the author.

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