Eco. Env. & Cons. 29 (May Suppl. Issue) : 2023; pp. (S332-S340)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i03s.060

A Review on Soil Carbon Sequestration in Different Land Use and Land Cover

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(Received 27 December, 2022; Accepted 17 February, 2023)

ABSTRACT

Decomposing organic matter and soil are crucial components of the global carbon cycle in terrestrial environments where carbon is stored in living biomass. Carbon is transferred between these systems and the atmosphere through photosynthesis, respiration, decomposition, and combustion. Human activities alter the carbon stocks in these pools by altering the land use patterns of the region. Hence, soils are both carbon sources and sink with great potential to reduce climate change. In the significant terrestrial carbon sink, soil holds twice as much carbon as the atmosphere and vegetation combined. After being the primary terrestrial carbon storage of the planet, even so, there is strong evidence that over the past several decades, significant amounts of carbon have been lost from soils of natural and agricultural ecosystems due to erosion, leaching, and enhanced soil respiration. Therefore, even a minor change will significantly affect soil carbon sequestration, the global carbon cycle, and climate change. The dynamics of soil organic carbon are strongly influenced by land use management; however, the impact varies depending on the climate, soils, and management techniques. Thus, a thorough understanding of soil organic carbon pool changes and their fractions is required to minimize carbon emissions and implement effective land use planning for sustainable soil management. This paper reviews the literature on carbon sequestration in soil and the effects of land use conversions on soil carbon stocks.

Key words : *Soil, Carbon, Organic carbon, Climate change, Land use*

Introduction

The earth's atmosphere consists of about 78.09% nitrogen, 20.95% oxygen, 0.9% argon, and other 0.03% trace gases, including carbon dioxide (CO_2), methane, nitrous oxide, and ozone by volume. In recent years, urbanization has driven a tremendous increase in fossil fuel utilization and CO_2 emissions, causing a dramatic expansion of CO_2 concentration. For instance, two human sources that have increased the atmospheric concentration of CO_2 arefossil fuel burning, estimated at 425 ± 20 Pg (Pentagrams), and land use change (235 ± 95 Pg) since 1750 (Lal, 2021). As a result, CO_2 has become a massive contributor among all anthropogenic greenhouse gases (GHGs) (Inter-governmental Panel on Climate Change, 2002).

Soil is an essential resource for human beings to establish the quality of our environment (Palm *et al*., 2007). Using plants to absorb CO_2 from the atmosphere and then store it as carbon in the soil, plant partsare known as terrestrial or biological sequestration**.** Giri and Mandla (2017) defined terrestrial sequestration as a combination of land management techniques that increases the amount of long-term carbon in the soil and plant. The largest terrestrial carbon pool is found in the earth's soils, where more than two-thirds of terrestrial carbon is stored

(Paustian *et al*., 2000). A slight change in these carbon stocks might cause significant changes in the atmosphere's CO_2 concentration (Sandeep *et al*., 2016). In the top 1m of the soil layer, around 1500 Pg C is stored as soil organic carbon (SOC) (Yost and Hartemink, 2019; Stockmann *et al*., 2013). Plant biomass holds the remaining carbon, i.e., 560 Pg (Paustian *et al*., 1997), atmosphere retains less carbon than the soil (750 Pg) (Yost and Hartemink, 2019; Paustian *et al*., 1997), with oceans holding the most (38,000 Pg) (Stockmann *et al*., 2013). SOC is the primary element of soil organic matter (SOM), the energy source for soil. SOM supports essential soil processes, stabilizing soil structure, retaining and releasing plant nutrients, and water percolation (Fig. 1). Therefore, it is crucial for maintaining soil health, fertility, and food production. According to Food and Agriculture Organization (FAO) (2018), land degradation is a serious problem since it causes hunger and poverty and basis of many conflicts**.**

Soil carbon sequestration

Johnson *et al*. (2007) defined terrestrial carbon sequestration as the net atmospheric CO_2transfer into carbon reservoirs over time. Keim *et al*. (2002) defined soil carbon (C) sequestration as the process of trapping and storing atmospheric CO_2 in soil for a longer duration. Therefore, one of the possible ways to decrease CO_2 levels in the atmosphere is a carbon reservoir, accumulating over 53% of terrestrial carbon. According to the Ecological Society of America (2000), carbon sequestration is storing long-term carbon in soils, forests, oceans, and other vegetation and geological formations. Therefore, (ESA) refers carbon sequestration as long-term storage and mentions the soil's role in balancing the global carbon cycle. At the same time, FAO (2017) defined carbon sequestration as the process through which carbon is captured from the atmosphere and stored in the soil using plants or organic residue.

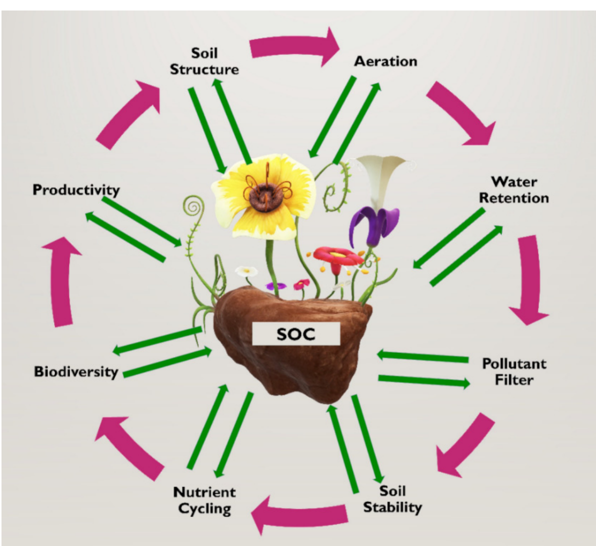

Fig. 1. Role of Soil Organic Carbon in the Biosphere
Source: Adapted from FAO and ITPS 2018

The biosphere's largest pool of terrestrial organic carbon is inthe soil, compared to plants and the atmosphere combined (Alani *et al*., 2017). As a result, the quantity of carbon in the soil in terrestrial ecosystems is typically higher than in living vegetation. Therefore, it is crucial to understand soil carbon dynamics and their function in the carbon balance in terrestrial ecosystems and the global carbon cycle (Post and Kwon, 2000). Luo *et al*. (2017) mentioned that the soil is the terrestrial biosphere's most significant carbon reservoir. Therefore, to mitigate climate change and sustainably manage soil, it is essential to understand how well the soil C pool responds to environmental and management changes. Several mechanisms are proposed to explain SOC dynamics over time and space. Three categories of components are involved in these mechanisms: (1) climatic variables like rainfall and temperature, (2) physicochemical characteristics of soil, and (3) biotic characteristics like the quantity and quality of C inputs into soil. A combination of several variables regulates SOC dynamics. Bradford *et al.* (2016) mentioned that the soil is the terrestrial biosphere's primary reservoir of carbon (1,500–2,400 Pg C), storing more than twofold the carbon in the atmosphere. So, a slight change in the proportions of the reservoirmay result in higher atmospheric CO_2. However, the top 1 m of the global SOC reserves are estimated to contain roughly 1500 PgC (FAO and ITPS, 2015).

Merits of carbon sequestration

Lal (2015), study on "carbon sequestration in soil", highlighted thebenefits of SOClike enhancing food security, increasing water quality and biodiversity, and strengthening elemental recycling. The quantity of SOC is among the essential factors in determining the fertility or quality of the soil. In addition, the SOC is vital for improving the soil's biological, chemical, and physical properties. According to Elbasiouny *et al*. (2022), soil fertility, the C stocks in soil biomass, agricultural productivity, and food security might all be improved by preventing and limiting soil overuse and promoting sustainable land uses. As a result, the effects of climate change are reduced and maintained soil nutrients.

To mitigate greenhouse effects, it is essential to provide managers and policymakers with accurate information on the status, dynamics, and geographical distribution of carbon sources and sinks. The carbon cycle may be managed more effectively by evaluating the potential for carbon sequestration and the potential increase in carbon stocks in biomass and soils within a specific geographical area due to a change in land use and land cover (LULC) and land management. Prabha *et al*. (2019) highlighted many benefits of carbon sequestration, including increased SOC content, enhanced soil's ability to deliver nutrients, and improved soil physical and microbiological qualities that benefit crop growth. Organic matter impacts crop development and production directly by providing nutrients or indirectly by changing the physical characteristics of the soil, which enhances the root and encourages plant growth.

Factors affecting soil carbon pool

Soil's ability to act as a CO_2 sink or source is highly reliant on several factors, including soil characteristics and land use (Wilson *et al.*, 2009). A study was carried out in this context by Sheikh *et al.* (2009) that several variables, such as climate, flora type, nutrient availability, land use, and management practices, impact changes in SOM. In addition, therate of decomposition of SOC depends on soil particle size. Ingram and Fernandes (2001) mentioned that finer textured soils often have greater SOC concentrations. The adsorption of SOC to clay and silt particles is crucial in enhancing SOC's stability. Awoonor *et al.* (2022) in the study, highlighted that land use, geography, soil characteristics, climate, and the composition of the dominant flora are the main variables regulating and stabilizing soil C and Nitrogen stocks. Alani *et al*. (2017) highlighted that plant type, altitude, precipitation, temperature, soil depth, and texture influenced SOC. SOC is also governed by soil pH, affecting organic matter turnover, soil nutrient availability, and other soil processes (Li *et al.*, 2020).

One of the critical considerations in SOC measurement is sampling depth. Many researchers observed that the SOC content in soil is a function of the sampling depth (Nayak *et al*., 2019; Wuest, 2009). Kalambukattu *et al.* (2013), in a study reported a high concentration of SOC in the top 0–5 cm soil, which after that decreased as depth increased in all

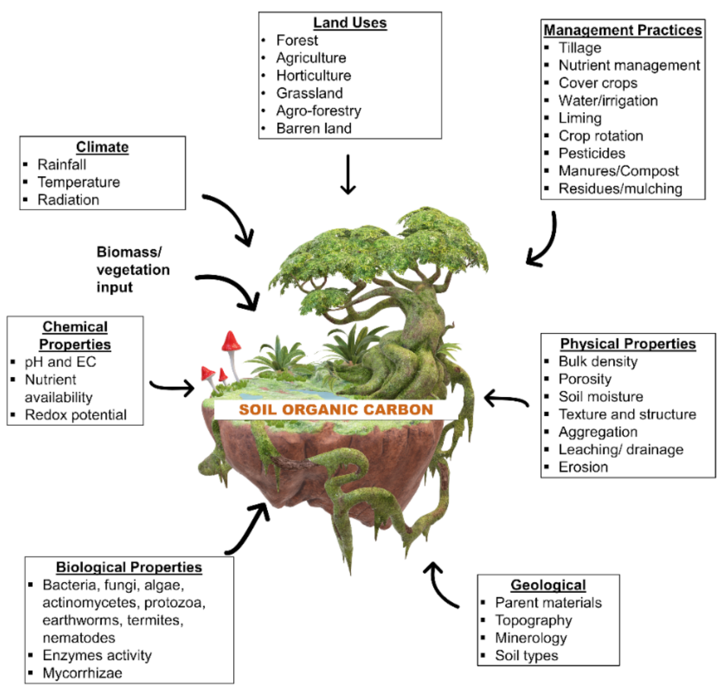

Fig. 2. Schematic diagram of the factors influencing organic carbon dynamics in soil *Source:* Adapted from Thangavel *et al.,* 2019

land use. The Alani *et al.* (2017) study showed that the highest SOC concentration was found in the bottom soil. This finding suggests that soil depth is one of the most important variables influencing the SOC content of the soil. It also shows that SOC concentrations rise with depth. Batjes (1996) highlighted that subsoil below 30 cm contains approximately 50% of the soil carbon measured at 1 m soil depth of the world's entire land surface. According to Liang *et al.* (2019), the highest terrestrial carbon storage in the world varies from 1220-2000 Pg C in the top 1 mand 2376-2456 Pg C in 2 m of the soil layer. According to the IPCC (2006) guideline, SOC measurements are typically conducted in the top 30 cm of the sample.

FAO (2017) stated in its report that the most significant variables influencing SOC dynamics are temperature and precipitation. According to Jenny (1980), several variables affect the capacity of soil to store soil organic matter; mean annual rainfall has the most significant impact on SOC.

Bulk density is an essential aspect of soil that affects root development, aeration, infiltration rates, and plant growth. Bulk density is critical for calculating the size of SOC and mineral nutrientsand is also necessary for mass-to-volume or area conversions (Throop *et al.*, 2012). According to Kakaire *et al.* (2015), a greater soil bulk density indicates less water stored in the soil at field capacity. In contrast, a lower soil bulk density means soils are less compacted and can hold more water. Thus, bulk density is used to measure soil health. The majority of variations in SOC decomposition at both global and regional sizes are frequently explained by differences in climate, which is typically considered the dominating influence over soil C dynamics (Carvalhais *et al.*, 2014; Luo *et al.*, 2017). According to Micheni *et al.* (2004), SOM is crucial for maintaining soil quality.

Mantano *et al.* (2015) indicated how changes in LULC affect the physicochemical characteristics of soil and, result in nutrient losses and a decrease in organic matter. While the effects vary, most agree that LULC change typically results in nutrient losses and a reduction in organic matter inputs in the soil (Gol, 2009; Emadi *et al.*, 2008). Choudhary and Saxena (2015) highlighted that converting forested land into cultivated land alters the soil's qualities, including loss of organic matter, increased bulk density, and decreased soil pH. Therefore, assessing the effects of various LULC changes requires monitoring soil's physical, chemical, and biological properties.

Land use and land cover potential in soil carbon sequestration

Earth's biogeochemistry, hydrology, and climate are all impacted by changes in LULC. After fuel consumption, land use change is regarded as the second-largest source of carbon emissions (Watson *et al.*, 2000; Novara *et al.*, 2012). Over the past 250 years, LULC changes have released around 200 Pg of carbon dioxide into the atmosphere (Scholes and Noble, 2001). In a global meta-analysis study, Don *et al.* (2011) reported that SOC losses from converting tropical forested areas to croplands, perennial crops, and grasslands were 25, 30, and 12%, respectively, and emphasized that land conversion causes SOC loss from subsurface soils. According to reports, soils under deserts store the least SOC, while soils under tropical forests retain the most SOC (Yost and Hartemink, 2019; Batjes, 2016).

The net carbon flux from LULC change was responsible for 12.5% of human-causedcarbon emissions (1990-2010). After fossil fuel burning, LULC change is the second largest human-induced source of carbon in the atmosphere (Scharlemann *et al.*, 2014; Houghton *et al.*, 2012). As per FAO, 2005, 13 million hectares of forest are lost yearly, and a significant portion of the area is converted from forests to agricultural systems. A study by Yimer *et al.* (2007) compared grazing, forest, and agriculture fields and reported that croplands had lower soil organic carbon levels than forest lands.

Sharma *et al.* (2019) highlighted that LULC significantly impacts soil carbon stocks and their distribution in ecosystems, therefore playing an essential role in global carbon dynamics. Scharlemann *et al.* (2014) mentioned that LULC changes influence a larger region. The land is being utilized more intensely than in the past, affecting local to global environmental processes and characteristics such as climate change, biodiversity, and pollution. Girmay *et al.* (2008) concluded that soil carbon losses result from natural forests to agricultural ecosystems, aggravated by human disturbance. Converting natural forests to agriculture, soil carbon loss may be severe during the first few years.In addition, changes in land use, particularly the conversion of tropical native forests to plantations and farmland, can affect soil carbon. Therefore, SOC concentrations for agricultural and non-agricultural soils reflect past management approaches and ecosystem activities (Collins *et al.*, 2000).

Ingram and Fernandes (2001), while studying "managing carbon sequestration in soils", highlighted that native soil carbon reserves are always depleted when converted to crops or grazing. For instance, estimates of the typical loss of SOC in the top 1 m within 2–8 years after the conversion of natural tropical flora to agriculture range between 15 and 40%. Kalambukattu *et al.* (2013) found that total organic carbon (TOC) in undisturbed oak forests showed the highest accumulation, whereas barren ground displayed the lowest amount. The more significant annual contribution of organic matter is in the form of leaf litter**.** After considering the factors of season and depth, undisturbed forests maintained the greatest TOC level regardless of the seasonal and depth variations.

Lal (2010) highlighted that comparing agricultural soils to their undisturbed or natural ecosystems, they contain 25% to 75% less SOC. The mineralization rate of SOM is slowed down by land use conversion, soil tillage, biomass burning, and other farming techniques, which result in a negative C budget. A study was carried out by Deng *et al*. (2016) "global patterns of the effects of land use changes on soil carbon stocks", reported that land use conversions have considerably decreased soil C stocks throughout allland use changes (0.39 Mg ha^{-1} yr^{-1}). However, soil C stocks significantly fell after conversions from grassland to farmland, forest to farmland, and forest to forest. Conversely, soil C stocks significantly increased after conversions from cropland to grassland and forest to grassland.

Benbi and Brar (2009) analyzed 25 years of soil data to determine the effect of intensive agriculture on carbon sequestration and found that theorganic carbonlevel in the soilhad improved dueto intensive agriculture. In addition, the IPCC acknowledged the potential of agroforestry to store carbon as part of climate change mitigation measures (Prabha *et al.*, 2019). Over one-third of all arable land worldwide is used for agriculture (World Bank, 2015). Agricultural soils have lower quantities of soil carbon than naturally occurring, undisturbed ecosystems (Gupta *et al*., 2009; Woomer *et al.,* 1994). Hence, a strategy to reduce growing atmospheric carbon will be to identify ways to improve SOC storage in agricultural systems (Thangavel *et al*., 2019). Post and Kwon (2000) reported that after 30- 50 years of agriculture, there is a loss of SOC up to 50% from surface soils (0.20m) and about 30% in the top 1m of soil.Reduced biomass carbon input lowers the SOC stock in the agroecosystems soil. A negative ecosystem carbon budget affects soil biodiversity, degrades soil structure, increases the potential of soil erosion, raises the risk of drought, interferes with elemental cycling, and lowers soil fertility (Fig. 4).

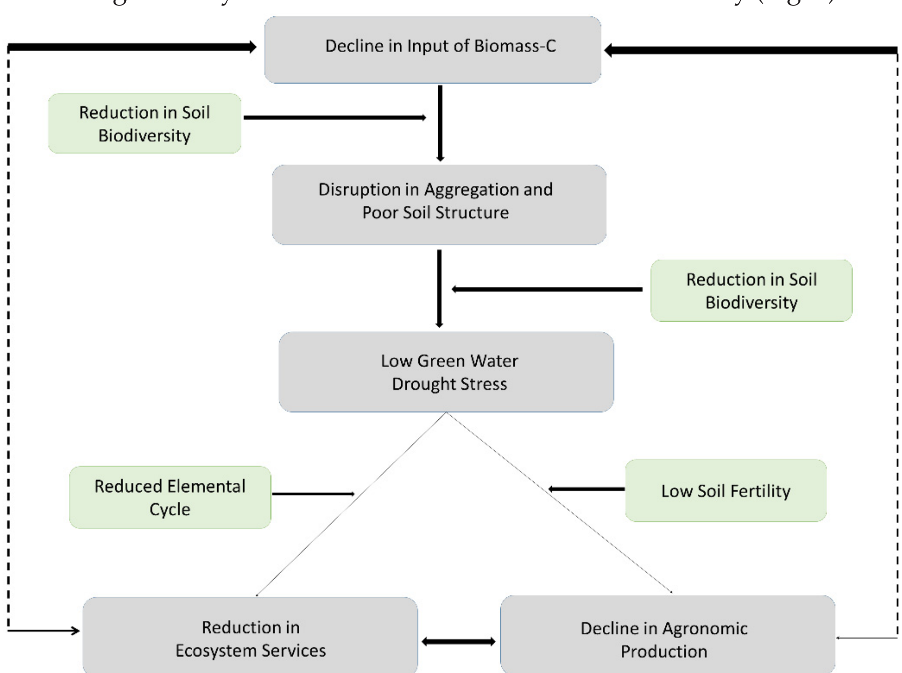

Fig. 4. Factors affecting soil organic carbon pool depletion in agroecosystems
Source: Zdruli *et al*., 2017

Lal (2021) highlighted that SOC stocksdepleted in managed ecosystems (such asbuilt-up, agricultural, mining, and recreational sites). SOC stocks decrease when natural ecosystems are converted into the farm ecosystem, and this is because of loss by erosion, leaching of organic carbon, and less input of carbon biomass.

Conclusion

One of the most prevalent greenhouse gases, CO_2, contributes to global warming, which causes a rise in sea level, droughts, deforestation, and other effects. Carbon is stored in forests, soils, seas, and the atmosphere, and long-term storage of carbon dioxide or different types of carbon is referred to as carbon sequestration. It is done to either defer or mitigate global warming and prevent disastrous climate change. All terrestrial life and the conservation of natural resources are based on SOC. Therefore, it is essential to boost SOC sequestration and decrease

Table 2. Literature reviews on the studies of assessment of carbon sequestration in soil

Reference	Primary outcome	Conclusion
Dixon., *et al.*, 1994	Roughly 1146 Pg of C remains in forest vegetation and soils, with about 37% of this C found in low-latitude forests, 14% in mid-latitudes, and 49% in high-latitude forests.	Slowing deforestation potentially preserves or stores considerable amounts of C if coupled with increased forestation, other management techniques, and improvements to the productivity of the forest ecosystem.
Jobbágy *et al.*, 2000	The amount of SOC stored globally in the upper 3 meters of soil was 2344 Pg C, or 56% greater than the 1502 Pg calculated for the first meter. The biomes with the highest SOC at 1-3m depth were tropical evergreen forests (158 Pg C) and tropical grasslands/ savannas (491 & 351 Pg C, respectively.	According to research, plant functional categories may influence how SOC distributions change with soil depth through changes in allocation. Additionally, analysis shows how SOC pools and vegetation change may be significant for carbon sequestration plans.
Chhabra *et al.*, 2003	Most of India's forest land is covered by moist deciduous forests, which contain significant SOC pools of 1.73 Pg C (50 cm) and 2.64 Pg C (1m) of the soil, accounting for 42 and 38.7% of the total SOC pool. SOC reservoirs in Indian forests amount to 4.13 Pg C (top 50 cm) and 6.81 Pg C (top 1 m).	Indian forest soil carbon estimates are essential because soils can potentially mitigate rising CO_2 levels through soil carbon sequestration.
Xia *et al.*, 2010	The research might experience 0.10 Gt of carbon emissions due to warming temperatures and 0.09 Gt due to changing land use. Thus, both anthropogenic factors contribute to the soil's source of carbon.	SOC content decreases with temperature increases.About 55% of the carbon source is attributable to rising temperatures, and 45% comes from land use change.
Jamala *et al.*, 2013	The TOC content of the surface soil (0–15 cm) was highest in the natural forest (1.94%), and lowest in agriculture (1.46%), and the amount of organic carbon added by fallow land was minimal.	Management of land use and soil depth affect the contents of the total, particle, and mineral-associated SOC fractions. The findings revealed that natural forests could raise SOC levels significantly.
Ma *et al.*, 2016	Wetlands showed higher SOC density than grassland. SOC stock in the top 1 m of wetland soils was 514 Tg C (*tetragrams of carbon)*, with the top 0.3 m storing half of that amount.	In the top 0.3 m of the soil, SOC content and density declined with increasing depth. Wetland and grassland regions showed similar trends.
Awoonor *et al.*, 2022	Soil C and N stores in the top 50 cm of soil have been severely decreased by 50.77% and 47.77%, respectively, due to the conversion of native forest to agricultural land.	Soil C and N stocks of various land-use systems are influenced by soil type, depth, and land-use change.

CO_2 emissions to the environment to slow global warming. A natural technique for partially offsetting anthropogenic emissions is soil carbon sequestration, which has a finite sink capacity and multiple co-benefits. One of the main problems is the loss of soil organic carbon (SOC). In extreme circumstances, it causes the soil to deteriorate physically, chemically, and biologically. SOC and organic matter inputs are essential for creating healthy, functional soils that can support both agricultural and natural land uses that are productive and sustainable. It is commonly accepted that combinations of changes to land use and land management can enhance equilibrium SOC contents.

The world's forests and agroforests are highly regarded for contributing to decreasing atmospheric CO_2. For instance, over the last few decades, the quantity of CO_2 emissions absorbed by global forests has been almost equal to that of the ocean. Agroforestry is a crucial method for storing C in biomass and soil, where it may support soil production. SOC storage and the C dynamics stock change in agroforestry are crucial for assessing the effect of agroecosystem management on global climate change. The research on C stocks from different regions of the world revealed that if agroforestry systems are adopted worldwide, large amounts of C might be removed from the atmosphere. IPCC has identified agroforestry as having the highest potential for carbon sequestration of any land management. Many studies reviewed in this article showed that numerous factors, such as the climate, soil texture, site management, vegetation type, previous land use, etc., are anticipated to impact soil C sequestration due to changing land use. Also, land use and land cover change play a consistent and critical role in estimated soil C stocks. Therefore, identifying appropriate land use and management techniques is crucial in reducing climate change through more significant soil carbon sequestration.

Acknowledgements

The authors are thankful to Guru Gobind Singh Indraprastha University (GGSIPU), Delhi, India, for providing a financial grant in the form of a short-term research fellowship.

Declarations

Conflict of interest -The authors declared that there are no competing or conflicting interests.

Ethics approval This article does not contain any studies with human participants or animals performed by any authors.

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