**The Role of Soil in Carbon Sequestration: Implications for Climate Change Mitigation**

**Abstract**

Soil, as the Earth's largest terrestrial carbon reservoir, plays a pivotal role in the global carbon cycle and presents a significant opportunity for mitigating climate change. This review explains current research on soil carbon sequestration, details how it works, what differences it makes and what it could mean for lowering global greenhouse emissions. Examples of land practises we cover are planting trees, farming food without ploughing and swapping pastures to enrich soil carbon. We investigate the impact of a changing climate on the carbon in soil. The study then points out the main obstacles to using soil to fight climate change and suggests combining environmental and economic strategies. As it is full of carbon, even more so than anywhere else, the soil helps manage changes in the Earth’s carbon and climate. Even though terrestrial ecosystems begin with their soil, plants within these ecosystems need photosynthesis to take in carbon dioxide from the air, convert it into what they need and put leftovers into the soil. Carbon is affected by a range of interactions between living and nonliving organisms in the soil. Soil organic matter is the top way soil maintains its carbon by taking in plant, animal and microscopic organism waste along with the products of their breakdown. The movement of soil carbon depends on whether more carbon is being added from litter, roots or amendments or more of it is released by decomposition, breathing or erosion.

Keywords: carbon cycle, greenhouse emissions, photosynthesis, ecosystems, Climate Change Mitigation

**1. Introduction**

Soils represent a substantial reservoir of terrestrial carbon, exerting considerable control over climate regulation through the intricate processes of greenhouse gas emission and sequestration, biogenic volatile organic compound release, and aerosol dynamics (Lal et al., 2021). The pressing need to address escalating concentrations of atmospheric greenhouse gases has amplified the importance of understanding the role of terrestrial ecosystems, particularly soils, in the global carbon cycle (Bardgett et al., 2008). Small changes in the amount of carbon stored in soil may have significant effects on the global carbon cycle, which in turn has repercussions on global change (Léopold et al., 2021). The importance of agricultural practices in mitigating climate change has been brought to light, with an emphasis on how they can affect soil carbon sequestration (Zhang et al., 2024). The soil's ability to hold carbon is essential to maintaining soil structure, supporting agricultural output, and sequestering carbon (Yadav & Malanson, 2007). Soils' dual role as both a source and sink of greenhouse gases underscores the importance of sustainable soil management practices in climate change mitigation strategies (Brevik, 2013).

**2. Soil's Role in Carbon Sequestration: An Overview**

Because soils capture carbon globally, they show us why soils play a key role in climate change action. Terrestrial ecosystems, particularly soils, have absorbed about 30% of the carbon released by human activities between 1960 and 2008, highlighting their crucial function in reducing atmospheric carbon dioxide (Yan et al., 2014).

Supporting soil, farming more efficiently and dealing with climate change all result from building carbon in the ground. Soil carbon sequestration encompasses a range of processes, including the conversion of atmospheric carbon dioxide into plant biomass through photosynthesis, the transfer of carbon-rich organic matter into the soil, and the long-term storage of carbon in soil aggregates and mineral associations (Katti et al., 2020). The dynamics between carbon inputs, such as plant debris and root exudates, and carbon outputs, such as microbial respiration and decomposition, determine the soil's capacity to sequester carbon. Moreover, how quickly land sequesters carbon depends mainly on management, weather, soil and land use practises.



**Fig.1: Soil's Role in Carbon Sequestration**

Agricultural soils, which make up a sizable portion of the world's land surface, are particularly well-suited to sequestering carbon and reducing greenhouse gas emissions. Altering land and soil management techniques can significantly lessen the detrimental effects of agriculture on soils and the environment (Keenor et al., 2021). Practises that increase the soil’s ability to store carbon also make soil more fertile, use less water and reduce its erosion. Agroforestry, which strategically integrates trees into agricultural landscapes, is becoming increasingly recognized for its potential to sequester carbon and provide additional environmental benefits (Zomer et al., 2016). Stopping the use of nitrogen fertilisers and afforesting farmland with poor yields is advised because simultaneously helps the soil get and keep the water and nutrients it needs.

**3. Chances for cutting down greenhouse gas emissions**

Many actions are possible to raise soil carbon levels and address global warming. Using no-till farming, cover crops and crop rotation in agriculture greatly increases the soil’s carbon content and helps reduce emissions lost by erosion and breakdown. Furthermore, the adoption of integrated nutrient management strategies, including the use of organic amendments and biochar, can enhance soil fertility, promote plant growth, and sequester carbon in the soil (Alcántara et al., 2020). Sequestering carbon and returning damaged lands to health can be achieved through agriculture, restoration and afforestation.

Peatlands, despite covering only a small fraction of the Earth's land surface, store a disproportionately large amount of soil carbon, underscoring their importance as carbon reservoirs. However, drainage of organic soils for agriculture and peat extraction has resulted in significant greenhouse gas emissions, highlighting the need for sustainable management practices to mitigate carbon losses (Tubiello et al., 2016). Modified agricultural practices, such as reduced tillage and the maintenance of soil cover, hold substantial promise for mitigating greenhouse gas emissions (Sanz-Cobeña et al., 2016). Besides, setting up actions to restore land and support reconstruction with trees is useful for holding carbon and protecting various species.

**4. How Soil Stores Carbon**

The mechanisms governing soil carbon sequestration are multifaceted, encompassing physical, chemical, and biological processes that influence the stabilization and persistence of organic matter in soil (Peichl et al., 2014). One primary mechanism involves the formation of stable soil aggregates, where organic matter becomes physically protected from decomposition within the aggregate structure (Bhayal et al., 2018). The interactions between organic matter and soil minerals, such as clay minerals and iron oxides, also play a crucial role in carbon sequestration by forming organo-mineral complexes that are less susceptible to microbial degradation (Amundson & Biardeau, 2018). In addition, microbes in the soil help keep carbon out of the atmosphere by making tough organic compounds, like humic substances which take a long time to decompose.

A chart of soil sequitration factors

AI-generated content may be incorrect. **Table 1. Soil carbon sequestration factors**

Land use change has a substantial impact on carbon dynamics in soil, where converting peatland to agricultural land is expected to alter organic matter and C-biomass population (Munawaroh et al., 2022). Turning natural areas into farms often causes soil carbon stocks to go down because soil structure is disturbed, more soil is lost from erosion and less organic matter becomes available. In addition, eco-friendly farming practises such as planting trees and reduced tilling, increase soil carbon storage and improve unhealthy land. In addition, climate change is known to alter patterns in temperature and rainfall which can influence soil carbon by altering how fast plants, microbes and associated processes function.

Soil carbon sequestration is determined by the specific physical, chemical and biological qualities of different soil types, making each type important. In addition, soils rich in clay have a chance to lock away more carbon, because their stable compounds and secure groupings prevent carbon decay. Just like materials with high amounts of calcium, soils rich in iron and aluminium oxides can also increase carbon storage by linking closely with organic matter which makes it more resistant to being broken down. Besides, the pH level of the soil is significant for controlling carbon cycling; with acid soils often showing slower decomposition and holding more carbon than soils with a high pH. Vegetation cover plays a vital role in influencing soil organic carbon levels, contingent on the quantity, arrangement, and biodegradability of plant residues reintroduced into the soil (Saljnikov et al., 2013). Soil organic carbon allows us to tell the quality of soil, as it can shape the productivity in the ecosystem.

**5. Impacts Soil’s Ability to Sequester Carbon**

How land is addressed and farmed by individuals is studied.

How soil is managed, by tillage, crop rotation and fertiliser, plays a major role in how much carbon it holds. Reduced tillage practices, such as no-till farming, can minimize soil disturbance, reduce erosion, and enhance carbon accumulation in the topsoil (Chan et al., 1992). Just like no-till farming, rotating certain crops and using cover cropping increases the amount of carbon that soil absorbs, makes the soil safer to work with and encourages more microorganisms, helping to trap more carbon. Furthermore, the application of organic amendments, such as compost and manure, can enhance soil fertility, increase carbon inputs, and improve soil physical properties, thereby promoting carbon sequestration (Yadav & Malanson, 2007). Incorporating plant litter into the soil can substantially affect its fertility, impacting the accessibility of nutrients and, consequently, influencing plant growth, variety, makeup, framework, and output (Hassan et al., 2021). Also, the carbon stored in the soil may face increased degradation due to global climate change (Rajan et al., 2019).

The ability of soil to function sustainably relies on various interacting factors, including its capacity to support plant life, facilitate the cycling of essential elements, and regulate the flow of water and energy (Badha et al., 2017).

**6.** **Climate Change and impact of Carbon in Soil**

The change in climate could seriously influence the amount of carbon held in soil through the soil carbon sequestration process. If we don’t pay attention to temperature and moisture levels, earthworms might release stored carbon into the air. Land use change, such as agricultural expansion and deforestation, can exacerbate the impact of climate change on soil erosion, while reforestation, agricultural land abandonment, and soil conservation practices can potentially offset these effects (Eekhout & Vente, 2022). Furthermore, management options that use conservation tillage, residue control and crop rotation work to raise carbon storage and enhance the well-being and productivity of soil.

**Table 2: . Climate Change and impact of Carbon in Soil**

|  |  |  |  |
| --- | --- | --- | --- |
| **Factor** | **Impact on Soil Carbon** | **Key Data/Projections** | **Mitigation Strategies** |
| **Warming Temperatures** | Accelerates microbial decomposition of soil organic matter (SOM), increasing CO₂ emissions. | - 4°C warming could increase soil CO₂ emissions by **37%** . - Arctic/boreal soils have shortest intrinsic turnover time, increasing vulnerability | - Reduce tillage to protect soil aggregates. - Use organic amendments (e.g., compost) to stabilize carbon. |
| **Land-Use Change** | Conversion of forests/grasslands to croplands depletes soil organic carbon (SOC). | - **25–30% SOC loss** in tropical forests converted to cropland  - Global croplands lost **50–70%** of historical carbon | - Agroforestry reduces SOC loss by **~12%**  - Afforestation and perennial crops |
| **Soil Management** | Intensive farming (tillage, monocropping) disrupts carbon sequestration. | - Cover crops and no-till farming can sequester **1.85 Gt C/yr** globally  - Compost application increases SOC by **1.5 t C/ha/yr** | - Conservation tillage, crop rotation, and organic amendments |
| **Permafrost Thaw** | Thawing releases millennia-old stored carbon as CO₂/CH₄. | - Permaffrost holds **1,500 Gt C**; thaw could release **37% more CO₂** by 2100 | - Limit land disturbance in Arctic regions. - Restore peatlands |
| **Precipitation Changes** | Extreme rainfall increases erosion; droughts reduce plant biomass (carbon inputs). | - NSW (Australia) projects **7–21% increase in soil erosion** by 2080  - Wet-dry cycles destabilize SOC | - Maintain vegetative cover (>70% soil coverage) |

Longbottom et. al., 2022

Rising temperatures can accelerate the decomposition of soil organic matter, releasing carbon dioxide into the atmosphere and reducing the soil's capacity to store carbon. Changes in precipitation patterns, such as increased drought frequency or intensity, can also affect soil carbon sequestration by limiting plant growth and reducing the input of organic matter into the soil (Muchane et al., 2020). As a result of climate change, soil formation and its stability change which can straight away or indirectly affect carbon protection and other soil activities. Changes in how temperature and rainfall occur can affect plant growth, the speed at which waste breaks down and plant activities within soil, all of which shape the process of storing soil carbon.

Transforming land such as deforestation and growing crops, may enhance the way climate change reduces the amount of carbon in soil. Deforestation, in particular, can result in a significant loss of soil carbon, as forests store large amounts of carbon in their biomass and soils (Mukhopadhyay et al., 2020). The replacement of rainforest with grasslands, for example, has been shown to increase surface temperature, decrease evapotranspiration and precipitation, and lead to a more prevalent dry season (Guo et al., 2021). Soil carbon may be lost when expanding agriculture relies on tilling which injures the soil and reduces the breakdown time of organic materials. Water and wind erosion caused by warming climate and poor land care are making conditions worse for soil carbon. The impact of rainfall greatly contributes to soil erosion which leads to soil damage, where the eroded soil, especially on cropland, causes decreasing quality of physical, chemical, and biological properties of the soil (Herawati et al., 2018).

A diagram of climate change

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**Figure. 2: How Climate Change Changes the Carbon in Soil**

Alternatively, reforestation, leaving agricultural land untreated and preserving soil can really help to control climate change on soil carbon sequestration. When forests are lost, reforestation helps to put more trees on the land and secure carbon in both tree tissue and soil. Many soil conservation practises, for example, reduced tillage, growing cover crops and contour farming, support soil improvements, lessen erosion and build up carbon in the soil. By helping to lock up carbon, these systems also boost soil health, provide cleaner water, increase the variety of animals and plants and increase vegetable and grain yields. Using some of these alternate climate change measures can boost conservation agriculture, help reduce greenhouse gas emissions and boost farming yield.

The combined climate and carbon-cycle effects of large-scale deforestation have implications for climate change mitigation strategies (Bala et al., 2007). While reforestation and afforestation projects are often proposed as a means of sequestering carbon dioxide from the atmosphere, the biogeophysical effects of these projects, such as changes in albedo and evapotranspiration, can influence regional and global climate patterns (Portmann et al., 2022). Changes in land-use practices, like the conversion of forests to pastures, can also affect soil carbon levels, with some studies even showing an increase in soil carbon after the conversion from forest to pasture (Paul et al., 2010). The role of grazing land management in carbon sequestration is also a key consideration, as improved grazing practices can lead to increased carbon stocks in grazing land soils (Conant et al., 2016).

**7. There is a connexion between soil Carbon Sequestration and helping fight Climate Change.**

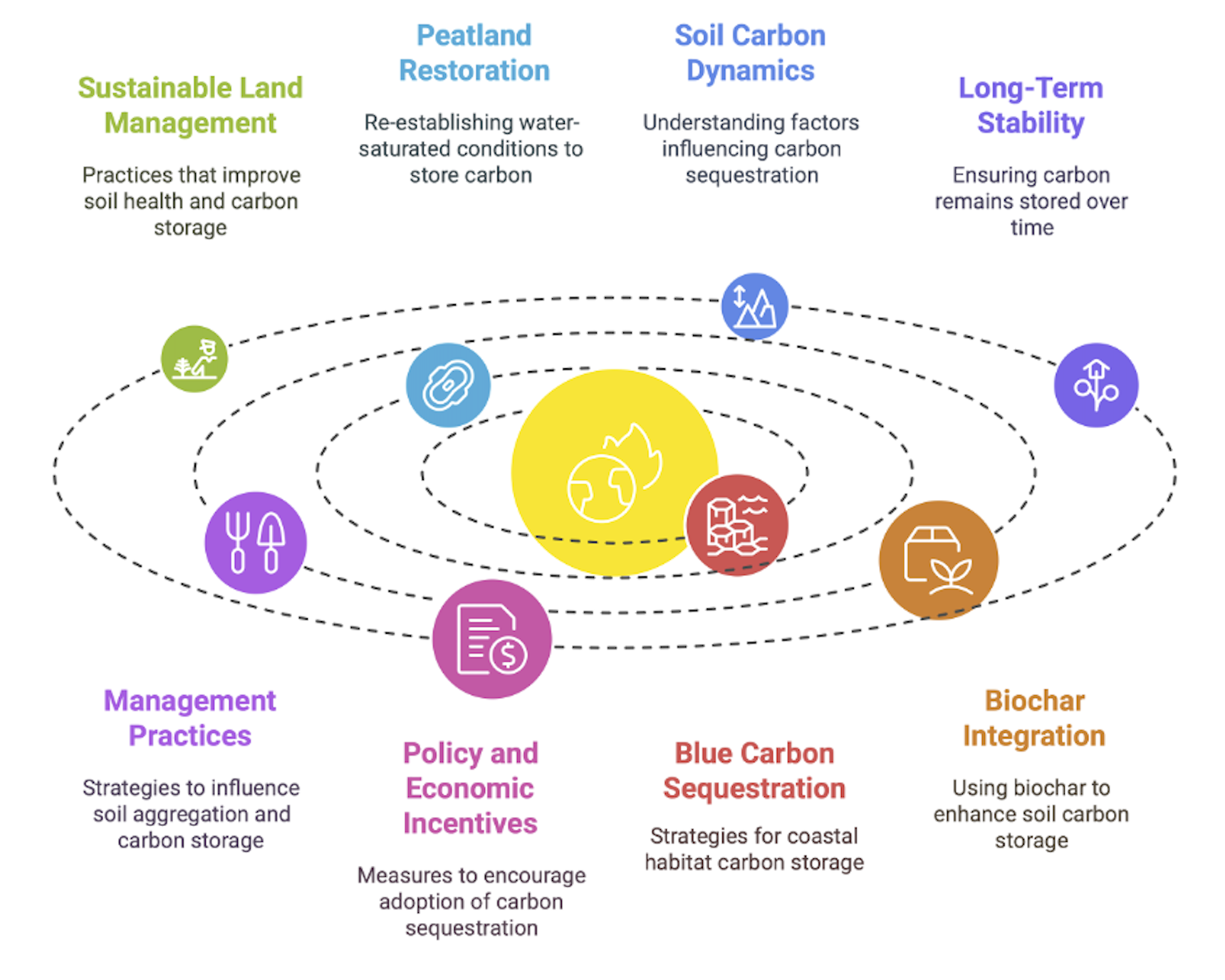
Soil carbon sequestration plays a crucial role in mitigating climate change by removing carbon dioxide from the atmosphere and storing it in the soil (Schwartz et al., 2020). Carbon sequestration is the process of capturing CO2 from the atmosphere or capturing anthropogenic CO2 from large-scale stationary sources like power plants before it is released to the atmosphere (Maiti et al., 2016). Soils can safely store a huge amount of carbon, making them important in reducing the greenhouse emissions from our activities. Increasing soil organic carbon stocks can improve soil health, enhance agricultural productivity, and reduce the concentration of greenhouse gases in the atmosphere (Lal, 2007). Using soil to lock up carbon dioxide from the air is a process called carbon sequestration. The soil's capacity to act as a carbon sink depends on various factors, including soil type, climate, land management practices, and vegetation cover. Certain ecosystems, like forests and wetland ecosystems, play a role in buffering extreme storms and flooding related to climate change (Cullman et al., 2003).

Carbon is stored in soil thanks to land management, yet agricultural activities have often meant that soil carbon has been lost where the land is intensely used. Strategies such as conservation tillage, cover cropping, crop rotation, and the application of organic amendments can promote carbon sequestration in agricultural soils and enhance their overall health and productivity (Carey et al., 2020). Peatland ecosystems, with their waterlogged conditions and slow decomposition rates, accumulate substantial amounts of organic matter over time, forming deep peat layers that act as long-term carbon stores (Hikmat et al., 2022). However, the carbon sequestration function of peatland ecosystems is threatened by drainage and land use change, which leads to the oxidation of organic matter and increased emission of greenhouse gases (Jaenicke et al., 2008). Restoring degraded peatlands can help reinstate their carbon sequestration capacity and mitigate climate change (Harenda et al., 2017) (Amesbury et al., 2019). In intact peatland ecosystems, oxygen deficiency resulting from high-water tables causes the formation of organic soils (Leifeld & Menichetti, 2018). Plant productivity exceeds decomposition in these ecosystems, leading to a slow, steady accumulation of carbon-rich organic matter (Amesbury et al., 2019). Peatlands, covering only about 3% of the Earth's land surface, store approximately twice the amount of carbon found in all forests (Mrotzek et al., 2020). When peatlands are drained for agriculture, forestry, or peat extraction, the organic matter decomposes, releasing large quantities of carbon dioxide into the atmosphere (Harenda et al., 2017).

**8. Opposite effects**

Boosting the amount of carbon in soil helps address climate change in many ways and can create problems that should be handled thoughtfully. Introducing land-management practises that preserve nature is a major opportunity available to agriculture. Through these practises, farmers can both grab more carbon from the air and make their soil healthier, support plant and animal life and raise crop yields. Making use of conservation tillage, growing cover crops and rotation of crops can strongly raise carbon in the soil on farms. Helping peatland recover adds an important means of curbing climate change. New peat development and climate carbon cooling will be promoted by creating the appropriate wetness conditions for restored peatlands.

Even so, there are several problems associated with increasing soil carbon sequestration. A main difficulty is that soil carbon moves in complex ways. The ability to estimate and measure soil carbon sequestration rates is made difficult by the influence of many factors such as soil, weather, farm practises and vegetation.

**Fig 3:Enhancing Soil Carbon sequestering**

Unfortunately, the reliability of soil carbon levels over a long period is not certain. Changes in land use, climate, or management practices can lead to the release of previously sequestered carbon back into the atmosphere (Salim et al., 2021). Knowing how management practises impact soil aggregation which means groups of soil particles being held together, is very important for improving sources of stored carbon. Besides, making soil carbon sequestration strategies work generally calls for big investments in technology, building infrastructure and training people. Incentives for policy and economics are essential for encouraging the use of soil carbon sequestration practises. The process of carbon dioxide sequestration involves isolating carbon dioxide from the atmosphere for extended periods using physical, chemical, biological, or engineered processes (Pawde & Parekh, 2013).

To promote blue carbon sequestration, it is important to implement management strategies that consider the environmental variables that influence this process (Macreadie et al., 2017). It is necessary to measure changes in carbon from coastal habitats with great accuracy using remote sensing and artificial intelligence. Biochar, a carbon-rich product derived from the pyrolysis of organic materials, has emerged as a promising tool for carbon sequestration and soil amendment (Senadheera et al., 2023). Integrating biochar into soil can enhance its capacity to store carbon, improve its physical and chemical properties, and promote plant growth (Resnik & Vallero, 2013).

**Conclusion**

Thanks to its ability to hide carbon, healthy soil is key to efforts to tackle global climate change. Soils are able to pull carbon dioxide from the air, making there less greenhouse gases and helping to improve the quality and healthfulness of the soil. To realise the full value of this potential, we must bring together methods for managing land sustainably, using technology and creating helpful policies.

When we use conservation tillage and growing cover crops, we can lock carbon into the soil, combat climate change and help soils remain healthier for farming. The ocean, geological formations, and terrestrial ecosystems are viable places for carbon sequestration (Lal, 2009). Understanding carbon sequestration technology is still limited and written reviews on the many options are lagging. As a result, polices and research agendas are developed without considering all relevant scientific research. Work should continue to precisely adjust carbon sequestration and fully understand what impact these strategies can have on soil, the environment and climate change. We should be aware that changing land use and the production of further greenhouse gases can happen with carbon sequestration projects. It is important to use a standard set of measurement, reporting and verification approaches to observe how well carbon sequestration efforts succeed. Carbon sequestration is an important way to fight climate change and soils help make it possible. To advance in soil carbon sequestration and build a steadier plan for the future, we must combine strategies, research and new ideas.

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## **References**

Alcántara, J. C., González, I., Pareta, M. M., & Vilaseca, F. (2020). Biocomposites from Rice Straw Nanofibers: Morphology, Thermal and Mechanical Properties. Materials, 13(9), 2138. https://doi.org/10.3390/ma13092138

Amelung, W., Bossio, D., Vries, W. de, Kögel‐Knabner, I., Lehmann, J., Amundson, R., Bol, R., Collins, C. D., Lal, R., Leifeld, J., Minasny, B., Pan, G., Paustian, K., Rumpel, C., Sanderman, J., Groenigen, J. W. van, Mooney, S., Wesemael, B. van, Wander, M. M., & Chabbi, A. (2020). Towards a global-scale soil climate mitigation strategy [Review of Towards a global-scale soil climate mitigation strategy]. Nature Communications, 11(1). Nature Portfolio. https://doi.org/10.1038/s41467-020-18887-7

Amesbury, M. J., Gallego‐Sala, A., & Loisel, J. (2019). Peatlands as prolific carbon sinks. Nature Geoscience, 12(11), 880. https://doi.org/10.1038/s41561-019-0455-y

Amundson, R., & Biardeau, L. (2018). Soil carbon sequestration is an elusive climate mitigation tool. Proceedings of the National Academy of Sciences, 115(46), 11652. https://doi.org/10.1073/pnas.1815901115

Araújo, A. S. F. de, Leite, L. F. C., Iwata, B. de F., Lira, M. A., Xavier, G. R., & Figueiredo, M. do V. B. (2011). Microbiological process in agroforestry systems. A review [Review of Microbiological process in agroforestry systems. A review]. Agronomy for Sustainable Development, 32(1), 215. Springer Science+Business Media. https://doi.org/10.1007/s13593-011-0026-0

Atia, M. A. M., Jiang, W., Sedeek, K., Butt, H., & Mahfouz, M. M. (2024). Crop bioengineering via gene editing: reshaping the future of agriculture. Plant Cell Reports, 43(4). https://doi.org/10.1007/s00299-024-03183-1

Badha, J. H., Capasso, J., Schindelbeck, R. R., & Bacon, A. R. (2017). Tools for Evaluating Soil Health. EDIS, 2017(3). https://doi.org/10.32473/edis-ss657-2017

Bala, G., Caldeira, K., Wickett, M., Phillips, T. J., Lobell, D. B., Delire, C., & Mirin, A. A. (2007). Combined climate and carbon-cycle effects of large-scale deforestation. Proceedings of the National Academy of Sciences, 104(16), 6550. https://doi.org/10.1073/pnas.0608998104

Bardgett, R. D., Freeman, C., & Ostle, N. (2008). Microbial contributions to climate change through carbon cycle feedbacks [Review of Microbial contributions to climate change through carbon cycle feedbacks]. The ISME Journal, 2(8), 805. Springer Nature. https://doi.org/10.1038/ismej.2008.58

Bellassen, V., & Luyssaert, S. (2014). Carbon sequestration: Managing forests in uncertain times. Nature, 506(7487), 153. https://doi.org/10.1038/506153a

Bhayal, D., Khaddar, V. K., Bhayal, L., Yadav, T. C., Bangar, K. S., & Singh, B. (2018). Effect of Sunhemp Green Manuring and Intercropping on Soil Properties. International Journal of Current Microbiology and Applied Sciences, 7(12), 371. https://doi.org/10.20546/ijcmas.2018.712.046

Brevik, E. C. (2013). The Potential Impact of Climate Change on Soil Properties and Processes and Corresponding Influence on Food Security. Agriculture, 3(3), 398. https://doi.org/10.3390/agriculture3030398

Carey, C. J., Gravuer, K., Gennet, S., Osleger, D. J., & Wood, S. A. (2020). Supporting evidence varies for rangeland management practices that seek to improve soil properties and forage production in California. California Agriculture, 74(2), 101. https://doi.org/10.3733/ca.2020a0015

Chan, K., Roberts, W., & Heenan, D. (1992). Organic carbon and associated soil properties of a red earth after 10 years of rotation under different stubble and tillage practices. Soil Research, 30(1), 71. https://doi.org/10.1071/sr9920071

Conant, R. T., Cerri, C. E. P., Osborne, B., & Paustian, K. (2016). Grassland management impacts on soil carbon stocks: a new synthesis [Review of Grassland management impacts on soil carbon stocks: a new synthesis]. Ecological Applications, 27(2), 662. Wiley. https://doi.org/10.1002/eap.1473

Cullman, G., Gibbs, J. P., Johnson, E. I. M., Laverty, M. F., Murphy, L., & Sterling, E. J. (2003). Why is Biodiversity Important? https://doi.org/10.5531/cbc.ncep.0007

Davidson, E. A., & Janssens, I. A. (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change [Review of Temperature sensitivity of soil carbon decomposition and feedbacks to climate change]. Nature, 440(7081), 165. Nature Portfolio. https://doi.org/10.1038/nature04514

Dollinger, J., & Jose, S. (2018). Agroforestry for soil health. Agroforestry Systems, 92(2), 213. https://doi.org/10.1007/s10457-018-0223-9

Dooley, S., & Treseder, K. K. (2011). The effect of fire on microbial biomass: a meta-analysis of field studies. Biogeochemistry, 109, 49. https://doi.org/10.1007/s10533-011-9633-8

Eekhout, J., & Vente, J. de. (2022). Global impact of climate change on soil erosion and potential for adaptation through soil conservation. Earth-Science Reviews, 226, 103921. https://doi.org/10.1016/j.earscirev.2022.103921

Efosa, O. P., Chukwuma, U., Stanley, E., & Robert, O. E. (2021). Relationship Between Soil Organic Matter and Some Physical Properties in Selected Soils of the Oil Palm Belt of Nigeria. Journal of Natural Sciences Research. https://doi.org/10.7176/jnsr/12-7-01

Fargione, J., Bassett, S., Boucher, T. M., Bridgham, S. D., Conant, R. T., Cook‐Patton, S. C., Ellis, P. W., Falcucci, A., Fourqurean, J. W., Gopalakrishna, T., Gu, H., Henderson, B., Hurteau, M. D., Kroeger, K. D., Kroeger, T., Lark, T. J., Leavitt, S. M., Lomax, G., McDonald, R. I., … Griscom, B. W. (2018). Natural climate solutions for the United States. Science Advances, 4(11). https://doi.org/10.1126/sciadv.aat1869

Gelybó, G., Tóth, E., Farkas, C., Horel, Á., Kasa, I. W., & Bakacsi, Z. (2018). Potential impacts of climate change on soil properties. Agrokémia És Talajtan, 67(1), 121. https://doi.org/10.1556/0088.2018.67.1.9

Georgiou, K., Koven, C. D., Wieder, W. R., Hartman, M. D., Riley, W. J., Pett‐Ridge, J., Bouskill, N., Abramoff, R., Slessarev, E., Ahlström, A., Parton, W. J., Pellegrini, A. F. A., Pierson, D., Sulman, B. N., Zhu, Q., & Jackson, R. B. (2024). Emergent temperature sensitivity of soil organic carbon driven by mineral associations. Nature Geoscience, 17(3), 205. https://doi.org/10.1038/s41561-024-01384-7

Guo, B., Subrahmanyam, M. V., Ai-guo, L., & Guang-zhe, L. (2021). Application of Remote Sensing Technology to Monitoring of Vegetation Recovery and Regional Precipitation in Wenchuan Earthquake Area: Case Study of Longxi River Basin. Sensors and Materials, 33(11), 3693. https://doi.org/10.18494/sam.2021.3337

Hamidov, A., Helming, K., Bellocchi, G., Bojar, W., Dalgaard, T., Ghaley, B. B., Hoffmann, C., Holman, I., Holzkämper, A., Krzeminska, D., Kværnø, S., Lehtonen, H., Niedrist, G., Øygarden, L., Reidsma, P., Roggero, P. P., Rusu, T., Santos, C., Seddaiu, G., … Schönhart, M. (2018). Impacts of climate change adaptation options on soil functions: A review of European case‐studies [Review of Impacts of climate change adaptation options on soil functions: A review of European case‐studies]. Land Degradation and Development, 29(8), 2378. Wiley. https://doi.org/10.1002/ldr.3006

Harenda, K. M., Lamentowicz, M., Samson, M., & Chojnicki, B. H. (2017). The Role of Peatlands and Their Carbon Storage Function in the Context of Climate Change. In GeoPlanet: earth and planetary sciences (p. 169). Springer International Publishing. https://doi.org/10.1007/978-3-319-71788-3\_12

Hassan, N., Sher, K., Rab, A., Abdullah, I., Zeb, U., Naeem, I., Shuaib, M., Khan, H., Khan, W., & Khan, A. (2021). Effects and mechanism of plant litter on grassland ecosystem: A review [Review of Effects and mechanism of plant litter on grassland ecosystem: A review]. Acta Ecologica Sinica, 41(4), 341. Elsevier BV. https://doi.org/10.1016/j.chnaes.2021.02.006

Herawati, A., Suntoro, S., Widijanto, H., Pusponegoro, I. H., Sutopo, N. R., & Mujiyo, M. (2018). Soil degradation level under particular annual rainfall at Jenawi District– Karanganyar, Indonesia. IOP Conference Series Earth and Environmental Science, 129, 12010. https://doi.org/10.1088/1755-1315/129/1/012010

Hikmat, M., Yatno, E., & Heryanto, B. R. (2022). Potentials of peatlands for agriculture in Tanjung Jabung Barat Regency, Jambi Province. IOP Conference Series Earth and Environmental Science, 1025(1), 12035. https://doi.org/10.1088/1755-1315/1025/1/012035

Jaenicke, J., Rieley, J. O., Mott, C. J. B., Kimman, P., & Siegert, F. (2008). Determination of the amount of carbon stored in Indonesian peatlands. Geoderma, 147, 151. https://doi.org/10.1016/j.geoderma.2008.08.008

Katti, J., Gurumurthy, K. T., Ravikumar, D., & Vageesh, T. S. (2020). Carbon Dynamics under Different Land-Use Systems of Nandipura Mini-Watershed of Chikkamagaluru District, Karnataka, India. International Journal of Current Microbiology and Applied Sciences, 9(10), 3968. https://doi.org/10.20546/ijcmas.2020.910.456

Keenor, S. G., Rodrigues, A. F., Mao, L., Latawiec, A. E., Harwood, A. R., & Reid, B. J. (2021). Capturing a soil carbon economy. Royal Society Open Science, 8(4). https://doi.org/10.1098/rsos.202305

Kingra, P. K., Setia, R., Kaur, S., Kaur, J., Singh, S., Singh, S. P., Kukal, S. S., & Pateriya, B. (2018). ANALYSIS AND MAPPING OF SPATIO-TEMPORAL CLIMATE VARIABILITY IN PUNJAB USING CLASSICAL STATISTICS AND GEOSTATISTICS. MAUSAM, 69(1), 147. https://doi.org/10.54302/mausam.v69i1.246

Kobayashi, H. (2004). Climate change and future options for carbon sequestration. Foresight, 6(3), 153. https://doi.org/10.1108/14636680410547753

Koch, A., McBratney, A. B., Adams, M. A., Field, D. J., Hill, R. W., Crawford, J. W., Minasny, B., Lal, R., Abbott, L. K., O’Donnell, A. G., Angers, D. A., Baldock, J., Barbier, E. B., Binkley, D., Parton, W. J., Wall, D. H., Bird, M. I., Bouma, J., Chenu, C., … Zimmermann, M. (2013). Soil Security: Solving the Global Soil Crisis. Global Policy, 4(4), 434. https://doi.org/10.1111/1758-5899.12096

Kowalska, A., & Grobelak, A. (2020). Organic matter decomposition under warming climatic conditions. In Elsevier eBooks (p. 397). Elsevier BV. https://doi.org/10.1016/b978-0-12-818032-7.00014-x

Lal, R. (2007). Carbon sequestration [Review of Carbon sequestration]. Philosophical Transactions of the Royal Society B Biological Sciences, 363(1492), 815. Royal Society. https://doi.org/10.1098/rstb.2007.2185

Lal, R. (2008). Sequestration of atmospheric CO2 in global carbon pools. Energy & Environmental Science, 1(1), 86. https://doi.org/10.1039/b809492f

Lal, R. (2009). Sequestering Atmospheric Carbon Dioxide. Critical Reviews in Plant Sciences, 28(3), 90. https://doi.org/10.1080/07352680902782711

Lal, R. (2020). Soil organic matter and water retention. Agronomy Journal, 112(5), 3265. https://doi.org/10.1002/agj2.20282

Lal, R., Monger, C., Nave, L. E., & Smith, P. (2021). The role of soil in regulation of climate [Review of The role of soil in regulation of climate]. Philosophical Transactions of the Royal Society B Biological Sciences, 376(1834), 20210084. Royal Society. https://doi.org/10.1098/rstb.2021.0084

Leifeld, J., & Menichetti, L. (2018). The underappreciated potential of peatlands in global climate change mitigation strategies. Nature Communications, 9(1). https://doi.org/10.1038/s41467-018-03406-6

Léopold, A., Drouin, J., Drohnu, E., Kaplan, H., Wamejonengo, J., & Bouard, S. (2021). Fire-fallow agriculture as a sustainable cropping system for maintaining organic carbon in Maré Loyalty Island (New Caledonia, southwest Pacific). Regional Environmental Change, 21(4). https://doi.org/10.1007/s10113-021-01814-x

Li, C., Li, Z., Yang, M., Ma, B., & Wang, B. (2021). Grid-Scale Impact of Climate Change and Human Influence on Soil Erosion within East African Highlands (Kagera Basin). International Journal of Environmental Research and Public Health, 18(5), 2775. https://doi.org/10.3390/ijerph18052775

Loboguerrero, A. M., Campbell, B., Cooper, P. J. M., Hansen, J., Rosenstock, T. S., & Wollenberg, E. (2019). Food and Earth Systems: Priorities for Climate Change Adaptation and Mitigation for Agriculture and Food Systems. Sustainability, 11(5), 1372. https://doi.org/10.3390/su11051372

Longbottom, T., Wahab, L., Min, K., Jurusik, A., Moreland, K., Dolui, M., ... & Berhe, A. A. (2022). What’s soil got to do with climate change?. *GSA Today*, *32*(5), 4-10.

Luyssaert, S., Schulze, E., Börner, A., Knohl, A., Hessenmöller, D., Law, B. E., Ciais, P., & Grace, J. (2008). Old-growth forests as global carbon sinks. Nature, 455(7210), 213. https://doi.org/10.1038/nature07276

Macreadie, P. I., Nielsen, D. A., Kelleway, J. J., Atwood, T. B., Seymour, J. R., Petrou, K., Connolly, R. M., Thomson, A. C. G., Trevathan‐Tackett, S. M., & Ralph, P. J. (2017). Can we manage coastal ecosystems to sequester more blue carbon? [Review of Can we manage coastal ecosystems to sequester more blue carbon?]. Frontiers in Ecology and the Environment, 15(4), 206. Wiley. https://doi.org/10.1002/fee.1484

Maiti, R., Rodríguez, H. G., & Ivanova, N. S. (2016). Carbon capture, carbon sequestration and carbon fixation (p. 199). https://doi.org/10.1002/9781119104452.ch16

Malhi, Y., Franklin, J., Seddon, N., Solan, M., Turner, M. G., Field, C. B., & Knowlton­, N. (2020). Climate change and ecosystems: threats, opportunities and solutions. Philosophical Transactions of the Royal Society B Biological Sciences, 375(1794), 20190104. https://doi.org/10.1098/rstb.2019.0104

Mampitiya, L., Rozumbetov, K., Rathnayake, N., Erkudov, V. O., Esimbetov, A., Arachchi, S., Kantamaneni, K., Hoshino, Y., & Rathnayake, U. (2024). Artificial intelligence to predict soil temperatures by development of novel model. Scientific Reports, 14(1). https://doi.org/10.1038/s41598-024-60549-x

Mrotzek, A., Michaelis, D., Günther, A., Wrage, N., & Couwenberg, J. (2020). Mass Balances of a Drained and a Rewetted Peatland: on Former Losses and Recent Gains. Soil Systems, 4(1), 16. https://doi.org/10.3390/soilsystems4010016

Muchane, M. N., Sileshi, G. W., Gripenberg, S., Jonsson, M., Pumariño, L., & Barrios, E. (2020). Agroforestry boosts soil health in the humid and sub-humid tropics: A meta-analysis. Agriculture Ecosystems & Environment, 295, 106899. https://doi.org/10.1016/j.agee.2020.106899

Mukhopadhyay, R., Sarkar, B., Jat, H. S., Sharma, P. C., & Bolan, N. (2020). Soil salinity under climate change: Challenges for sustainable agriculture and food security [Review of Soil salinity under climate change: Challenges for sustainable agriculture and food security]. Journal of Environmental Management, 280, 111736. Elsevier BV. https://doi.org/10.1016/j.jenvman.2020.111736

Munawaroh, H., Rauf, A., Razali, Bintang, & Sabrina, T. (2022). Preliminary study on C-organic and C-microbial biomass of peatland in Toba highlands. IOP Conference Series Earth and Environmental Science, 1025(1), 12017. https://doi.org/10.1088/1755-1315/1025/1/012017

Nair, P. R. (2007). The coming of age of agroforestry. Journal of the Science of Food and Agriculture, 87(9), 1613. https://doi.org/10.1002/jsfa.2897

Nalluri, N., & Karri, V. R. (2023). Superior effect of nature based solutions in soil and water management for sustainable agriculture. Plant Science Today. https://doi.org/10.14719/pst.2159

Pallikonda, M. (2017). CLIMATE CHANGES AND ITS IMPACT ON AGRICULTURE OF NORTHERN TELANGANA ZONE. International Journal of Advanced Research, 5(12), 1737. https://doi.org/10.21474/ijar01/6142

Panchami, L. R., Gudi, N., & Patil, D. S. (2023). Sustainable agricultural practices in South Asia: A comprehensive review [Review of Sustainable agricultural practices in South Asia: A comprehensive review]. CABI Reviews. https://doi.org/10.1079/cabireviews.2023.0032

Parmesan, C. (2023). Terrestrial and Freshwater Ecosystems and Their Services. In Cambridge University Press eBooks (p. 197). Cambridge University Press. https://doi.org/10.1017/9781009325844.004

Paul, M., Catterall, C. P., Pollard, P., & Kanowski, J. (2010). Recovery of soil properties and functions in different rainforest restoration pathways. Forest Ecology and Management, 259(10), 2083. https://doi.org/10.1016/j.foreco.2010.02.019

Pawde, C., & Parekh, R. (2013). A Discussion of the HSE Aspects of Carbon Dioxide Sequestration. SPE Asia Pacific Oil and Gas Conference and Exhibition. https://doi.org/10.2118/165781-ms

Peichl, M., Arain, A. M., Moore, T. R., Brodeur, J., Khomik, M., Ullah, S., Restrepo‐Coupé, N., McLaren, J., & Pejam, M. R. (2014). Carbon and greenhouse gas balances in an age sequence of temperate pine plantations. Biogeosciences, 11(19), 5399. https://doi.org/10.5194/bg-11-5399-2014

Pérez‐Alonso, M., Guerrero‐Galán, C., Scholz, S. S., Kiba, T., Sakakibara, H., Ludwig‐Müller, J., Krapp, A., Oelmüller, R., Vicente‐Carbajosa, J., & Pollmann, S. (2020). Harnessing symbiotic plant–fungus interactions to unleash hidden forces from extreme plant ecosystems [Review of Harnessing symbiotic plant–fungus interactions to unleash hidden forces from extreme plant ecosystems]. Journal of Experimental Botany, 71(13), 3865. Oxford University Press. https://doi.org/10.1093/jxb/eraa040

Portmann, R., Beyerle, U., Davin, É. L., Fischer, E., Hertog, S. D., & Schemm, S. (2022). Global forestation and deforestation affect remote climate via adjusted atmosphere and ocean circulation. Nature Communications, 13(1). https://doi.org/10.1038/s41467-022-33279-9

Pralhad, B. S., Rajendran, P., Divya, M., Rajeswari, R., Thangamani, G., & Ramaha, C. (2020). Assessing the Effect of Different Agroforestry Practices on Soil Physico-chemical Properties and Microbial Activity. International Journal of Current Microbiology and Applied Sciences, 9(9), 2802. https://doi.org/10.20546/ijcmas.2020.912.335

Proietti, I., Frazzoli, C., & Mantovani, A. (2015). Exploiting Nutritional Value of Staple Foods in the World’s Semi-Arid Areas: Risks, Benefits, Challenges and Opportunities of Sorghum [Review of Exploiting Nutritional Value of Staple Foods in the World’s Semi-Arid Areas: Risks, Benefits, Challenges and Opportunities of Sorghum]. Healthcare, 3(2), 172. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/healthcare3020172

Rahadiarta, I. K. V. S., Putra, I. D. N. N., & Suteja, Y. (2018). Simpanan Karbon Pada Padang Lamun di Kawasan Pantai Mengiat, Nusa Dua Bali. Journal of Marine and Aquatic Sciences, 5(1), 1. https://doi.org/10.24843/jmas.2019.v05.i01.p01

Rajan, K., Kumar, S., Dinesh, D., Raja, P., Bhatt, B. P., & Karan, D. (2019). Appraisal of Soil Potential to Store Organic Carbon in Different Land Uses under Old Alluvium of Indo- Gangetic Plains. International Journal of Current Microbiology and Applied Sciences, 8(3), 2089. https://doi.org/10.20546/ijcmas.2019.803.249

Raza, A., Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., & Xu, J. (2019). Impact of Climate Change on Crops Adaptation and Strategies to Tackle Its Outcome: A Review [Review of Impact of Climate Change on Crops Adaptation and Strategies to Tackle Its Outcome: A Review]. Plants, 8(2), 34. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/plants8020034

Resnik, D. B., & Vallero, D. A. (2013). Geoengineering: An Idea Whose Time Has Come? Journal of Earth Science & Climatic Change, 4(2). https://doi.org/10.4172/2157-7617.s1-001

Rodríguez, B. C., Zuazo, V. H. D., Soriano, M., Tejero, I. F. G., Ruíz, B. G., & Tavira, S. C. (2022). Conservation Agriculture as a Sustainable System for Soil Health: A Review [Review of Conservation Agriculture as a Sustainable System for Soil Health: A Review]. Soil Systems, 6(4), 87. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/soilsystems6040087

Salim, A., Narendra, B. H., Lisnawati, Y., & Rachmat, H. H. (2021). Hydro-physical properties of agriculturally used peatlands in Liang Anggang Protected Forest, South Kalimantan, Indonesia. IOP Conference Series Earth and Environmental Science, 789(1), 12048. https://doi.org/10.1088/1755-1315/789/1/012048

Saljnikov, E., Čakmak, D., & Rahimgaliev, S. (2013). Soil Organic Matter Stability as Affected by Land Management in Steppe Ecosystems. In InTech eBooks. https://doi.org/10.5772/53557

Sanderman, J., & Amundson, R. (2003). Biogeochemistry of Decomposition and Detrital Processing. In Elsevier eBooks (p. 249). Elsevier BV. https://doi.org/10.1016/b0-08-043751-6/08131-7

Sanderman, J., Jodie, R., Wurst, M., Mary-Anne, Y., & Austin, J. (2015). Impacts of Rotational Grazing on Soil Carbon in Native Grass-Based Pastures in Southern Australia. PLoS ONE, 10(8). https://doi.org/10.1371/journal.pone.0136157

Sanz-Cobeña, A., Lassaletta, L., Aguilera, E., Prado, A. del, Garnier, J., Billen, G., Iglesias, A., Sánchez, B., Guardia, G., Ábalos, D., Plaza‐Bonilla, D., Puigdueta-Bartolomé, I., Moral, R., Galán, E., Arriaga, H., Merino, P., Infante‐Amate, J., Meijide, A., Pardo, G. O., … Smith, P. (2016). Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: A review [Review of Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: A review]. Agriculture Ecosystems & Environment, 238, 5. Elsevier BV. https://doi.org/10.1016/j.agee.2016.09.038

Schmitz, O. J., Wilmers, C. C., Leroux, S., Doughty, C. E., Atwood, T. B., Galetti, M., Davies, A. B., & Goetz, S. J. (2018). Animals and the zoogeochemistry of the carbon cycle [Review of Animals and the zoogeochemistry of the carbon cycle]. Science, 362(6419). American Association for the Advancement of Science. https://doi.org/10.1126/science.aar3213

Schwartz, N. B., Aide, T. M., Graesser, J., Grau, H. R., & Uriarte, M. (2020). Reversals of Reforestation Across Latin America Limit Climate Mitigation Potential of Tropical Forests. Frontiers in Forests and Global Change, 3. https://doi.org/10.3389/ffgc.2020.00085

Semeraro, T., Scarano, A., Leggieri, A., Calisi, A., & Caroli, M. D. (2023). Impact of Climate Change on Agroecosystems and Potential Adaptation Strategies. Land, 12(6), 1117. https://doi.org/10.3390/land12061117

Senadheera, S. S., Gupta, S., Kua, H. W., Hou, D., Kim, S., Tsang, D. C. W., & Ok, Y. S. (2023). Application of biochar in concrete – A review [Review of Application of biochar in concrete – A review]. Cement and Concrete Composites, 143, 105204. Elsevier BV. https://doi.org/10.1016/j.cemconcomp.2023.105204

Shahzad, M. F., Abdulai, A., & Issahaku, G. (2021). Adaptation Implications of Climate-Smart Agriculture in Rural Pakistan. Sustainability, 13(21), 11702. https://doi.org/10.3390/su132111702

Shanmugam, P. M., Sangeetha, S. P., Prabu, P. C., Varshini, S. V., Renukadevi, A., Ravisankar, N., Parasuraman, P., Parthipan, T., Satheeshkumar, N., Natarajan, S., & Gopi, M. (2024). Crop–livestock-integrated farming system: a strategy to achieve synergy between agricultural production, nutritional security, and environmental sustainability. Frontiers in Sustainable Food Systems, 8. https://doi.org/10.3389/fsufs.2024.1338299

Srivastava, R. K., Purohit, S., Alam, E., & Islam, M. (2024). Advancements in soil management: optimizing crop production through interdisciplinary approaches. Journal of Agriculture and Food Research, 101528. https://doi.org/10.1016/j.jafr.2024.101528

Thomas, N. W., James, E. J., & George, C. (2023). Water-related impacts on agriculture due to climate change: a review with reference to Kerala. [Review of Water-related impacts on agriculture due to climate change: a review with reference to Kerala.]. Sustainability Agri Food and Environmental Research, 10. Temuco Catholic University. https://doi.org/10.7770/safer-v10n1-art2560

Tripathi, A., Tripathi, D. K., Chauhan, D. K., Kumar, N., & Singh, G. S. (2015). Paradigms of climate change impacts on some major food sources of the world: A review on current knowledge and future prospects [Review of Paradigms of climate change impacts on some major food sources of the world: A review on current knowledge and future prospects]. Agriculture Ecosystems & Environment, 216, 356. Elsevier BV. https://doi.org/10.1016/j.agee.2015.09.034

Tubiello, F. N., Biancalani, R., Salvatore, M., Rossi, S., & Conchedda, G. (2016). A Worldwide Assessment of Greenhouse Gas Emissions from Drained Organic Soils. Sustainability, 8(4), 371. https://doi.org/10.3390/su8040371

Udawatta, R. P., Gantzer, C. J., & Jose, S. (2017). Agroforestry Practices and Soil Ecosystem Services. In Elsevier eBooks (p. 305). Elsevier BV. https://doi.org/10.1016/b978-0-12-805317-1.00014-2

Vose, J. M., Peterson, D. L., & Patel-Weynand, T. (2012). Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. https://doi.org/10.2737/pnw-gtr-870

Wilson, M., & Lovell, S. T. (2016). Agroforestry—The Next Step in Sustainable and Resilient Agriculture. Sustainability, 8(6), 574. https://doi.org/10.3390/su8060574

Yadav, V., & Malanson, G. P. (2007). Progress in soil organic matter research. Progress in Physical Geography Earth and Environment, 31(2), 131. https://doi.org/10.1177/0309133307076478

Yan, Y., Luo, Y., Zhou, X., & Chen, J. (2014). Sources of variation in simulated ecosystem carbon storage capacity from the 5th Climate Model Intercomparison Project (CMIP5). Tellus B, 66(1), 22568. https://doi.org/10.3402/tellusb.v66.22568

Zhang, K., Liu, Z., McCarl, B. A., & Fei, C. (2024). Enhancing Agricultural Soil Carbon Sequestration: A Review with Some Research Needs [Review of Enhancing Agricultural Soil Carbon Sequestration: A Review with Some Research Needs]. Climate, 12(10), 151. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/cli12100151

Zomer, R. J., Neufeldt, H., Xu, J., Ahrends, A., Bossio, D., Trabucco, A., Noordwijk, M. van, & Wang, M. (2016). Global Tree Cover and Biomass Carbon on Agricultural Land: The contribution of agroforestry to global and national carbon budgets. Scientific Reports, 6(1). https://doi.org/10.1038/srep29987