

Impact of Climate Change on Soil Characteristics

Surya G. B.¹, Sathish Thangarasu¹, Raji Swaroop² and Rekha V.R. Nair²

¹PG scholar, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani - 695522, Thiruvananthapuram, Kerala.

²Assistant professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani - 695522, Thiruvananthapuram, Kerala.

Corresponding Author: surya-2023-11-182@student.kau.in

Introduction

Climate change refers to long term shifts in temperature and weather patterns, mainly caused by human activities such as burning of fossil fuels like coal, oil and gas which release greenhouse gases. Climate change threatens not only the atmosphere, but also causes profound disruption to the soil health, fertility, and its ability to sustain life on earth. The increasing concentration of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and chlorofluorocarbons (CFCs) due to agricultural and industrial development is bringing about global warming, ocean acidification, soil degradation and biodiversity loss. The Intergovernmental Panel on Climate Change (IPCC) predicts that global temperatures will rise between 1.1°C and 6.4°C throughout the 21st century, which will also cause shifts in precipitation patterns.

Soil is the most important component of an ecosystem, which plays a crucial role in regulating the climate by storing carbon, supporting plant life, and maintaining water cycles. However, as global temperatures rise, extreme weather events become more frequent, and unsustainable land use continues and as a result soil health is deteriorating at an alarming rate. From droughts that dry out farmlands to floods that wash away nutrient-rich topsoil, climate change is pushing soil systems to their limits. The degradation not only threatens food security but also weakens soil's ability to store carbon, further fueling global warming.

Soil and climate change

Soil and climate change are deeply interconnected and influence global environmental health. Soil acts as both a carbon sink and source storing vast amounts of carbon. Poor management practices viz, deforestation and intensive agriculture can release CO₂ and methane which will increase the global warming. Climate change degrades soil through erosion, droughts, and shifting precipitation. This leads to desertification, reduced fertility, and food insecurity. Rising temperatures disrupt microbial

communities and nutrient cycles. In cold regions, thawing permafrost releases stored carbon creating a dangerous feedback loop. Protecting soil health is crucial for climate stability and sustainability.

Impact of soil on climate change

1. Soil as a carbon sink

Soils store large amounts of carbon in the form of soil organic matter, which includes decomposed plant and animal materials. By planting trees, cover crops, or land management, we can reduce carbon dioxide from the atmosphere which in turn reducing the greenhouse effect. Forests, grasslands, and wetlands are particularly effective in storing carbon in soil.

2. Greenhouse gases

When the soil is disturbed, it can release the stored carbon as carbon dioxide and other greenhouse gases.

- Deforestation and land use changes disturb soil and release carbon.
- Tillage and overgrazing break down organic matter, releasing carbon dioxide.
- Wetlands and agricultural soils emit methane through anaerobic decomposition.

3. Soil degradation and carbon loss

Soil erosion caused by wind and water removes nutrient rich topsoil, reducing the ability of land to store carbon and support plant life. Additionally, the permafrost thawing due to rising global temperatures releases large amounts of methane and carbon dioxide, accelerating the greenhouse effect. Soil compaction, which occurs when heavy machinery or overgrazing, compresses soil, limits root growth and reduces the ability of plants to absorb carbon from the atmosphere.

4. Urbanization and soil sealing

As the cities expand, vegetation is removed, reducing the amount of organic matter that would otherwise contribute the soil carbon storage.

Construction and paving cover large areas of soil with concrete and asphalt, preventing carbon sequestration and disrupting the natural carbon cycle. Additionally, landfills and waste dumps in urban areas become major sources of methane emissions as decomposing organic waste releases this potent greenhouse gas.

Effect of climate change on soil properties

Soil temperature is closely linked to air temperature and is influenced by radiation, evaporation, and heat transmission. Higher soil temperatures accelerate organic matter decomposition, microbial activity, nutrient release, and chemical weathering. Climate change affects soil moisture through altered precipitation and increased evapotranspiration, leading to drought conditions. These changes impact soil water regimes, nutrient cycling, and plant absorption, which in turn influence overall soil fertility and stability.

➤ Soil physical properties

Soil structure depends on its composition, consistency, and the balance of inorganic materials and biological processes. Climate change can reduce soil aggregate levels. Soils with high clay content, especially those containing smectitic minerals, shrink when dry, leading to large cracks. Soil porosity and water retention affect key physical properties, including aeration, plant water availability, and field capacity (Reynolds *et al.*, 2009). Future climate conditions with high CO₂, rising temperatures, and extreme rainfall can change soil porosity, impact root growth and biological activity, and alter soil functions in unpredictable ways (Allen *et al.*, 2011). Soil water availability responds quickly to climate change, especially to extreme rainfall and drought. Management practices like using organic manure, can help improve water infiltration and retention, reducing the impact of these extreme weather events. Bulk density has a negative correlation with organic soil (Weil and Magdoff, 2004). A decrease in organic carbon due to higher temperatures will increase bulk density, making soil more prone to compaction from land management and climate change stresses like extreme rainfall and drought (Birkas *et al.*, 2009).

➤ Soil chemical properties

Climate change influences organic matter, nutrient cycles, and water availability in soil. These changes affect plant growth and can alter soil pH levels. Soil electrical conductivity is linked to salinity,

crop growth, nutrient cycling, and biological activity with pH influencing structural stability. In climate change scenarios, higher temperatures and lower rainfall reduced electrical conductivity in semiarid regions, while soil pH increased. Higher temperatures accelerate decomposition and reduce soil organic matter, leading to a decline in cation exchange capacity (Davidson and Janssens, 2006). Plant nutrient cycling is closely linked to organic carbon cycling, meaning nitrogen cycling can influence climate change factors like rising temperatures, rainfall patterns, and atmospheric nitrogen deposition.

➤ Soil biological properties

Climate change affects key biological factors like soil organic matter and microbial biomass. Soil organic matter mainly comes from atmospheric carbon dioxide, which is absorbed by plants through photosynthesis and later added to the soil through plant residues. Soil organic matter, roots, and associated species respond differently to environmental and climate change factors, but carbon substrate availability influences both. Global warming and higher CO₂ levels can boost plant growth, adding more organic matter to the soil. However, rising temperatures also accelerate decomposition, leading to greater soil organic matter loss. Microorganism loss is regulated by the availability of organic matter in the soil rather than climate factors like temperature changes. Excessive depletion of organic matter negatively impacts the soil's physical, chemical, and biological properties.

Climate change and its impact on soil processes

Climate change affects soil processes by altering temperature, moisture, and nutrient cycles. Higher temperatures speed up decomposition, reducing organic matter, while extreme rainfall and drought impact soil moisture, erosion, and structure. Increased CO₂ may boost plant growth, but rapid decomposition offsets this benefit. Changes in microbial activity and soil chemistry further disrupt fertility and stability, making sustainable management crucial for soil health.

➤ Soil organic matter decomposition

Higher temperatures accelerate microbial activity, leading to increased organic soil degradation. Rising atmospheric temperatures can boost microbial activity, but this effect may be reduced if changing

rainfall patterns lead to drier conditions or a decline in litter quantity, quality, and decomposition (Castro *et al.*, 2010).

➤ Soil erosion

Climate change increases soil erosion by intensifying extreme weather events like heavy rainfall and droughts. Intense rainfall causes runoff that washes away topsoil, while dry conditions make soil more vulnerable to wind erosion. Rising temperatures also reduce organic matter, weakening soil structure and increasing erosion risks. Effective soil conservation practices, such as cover cropping and no-till farming, can help mitigate these effects.

➤ Nitrogen mineralization

As rising CO₂ increases the soil's carbon-to-nitrogen (C-N) ratio of the soil organic matter decomposition requires more nitrogen. Microbes consume this nitrogen during breakdown, reducing nitrogen mineralization (Reich *et al.*, 2006). Although higher temperature enhances nitrogen availability in the soil. Increased nitrogen mineralization positively influences plant growth.

➤ Nitrification and denitrification

Higher ammonium (NH₄⁺) levels in moderate pH and aerobic soil conditions promote nitrification, but the process is restricted in extremely dry soils. Denitrification is supported by abundant labile carbon as an energy source and nitrate (NO₃⁻) as an electron acceptor. It thrives in low-oxygen areas, responds to temperatures close to those optimal for nitrification, and can reach higher peak levels (Strong and Fillery, 2002). Denitrification is temperature-sensitive, and rising soil temperatures due to climate change can significantly increase N₂O emissions.

➤ Soil acidity and salinity

Climate change affects catchment hydrology by altering rainfall, runoff, and evapotranspiration, leading to drying and increased salinity. Irrigated regions are especially vulnerable, with rising temperatures worsening soil salinity issues. Rising soil temperatures significantly increase salt accumulation, especially at depths of 10–15 cm (Guo *et al.*, 2011). Higher precipitation can increase leaching of essential cations like Ca²⁺ and Mg²⁺, causing soil acidification, while lower rainfall reduces soil acidity.

Management strategies to mitigate climate change and its effects on soil

- **Conservation tillage** - Reducing soil disturbance helps retain moisture, prevent erosion, and enhance carbon sequestration.
- **Cover cropping** - Planting cover crops protects soil from erosion, improves organic matter, and enhances nutrient cycling.
- **Soil mulching** - Applying mulch retains moisture, regulates temperature, and prevents soil degradation.
- **Reforestation and grassland management** - Restoring vegetation reduces erosion, improves water retention, and sequesters carbon.
- **Efficient water management** - Using drip irrigation and rainwater harvesting conserves water and reduces drought impact.

Conclusion

Soil plays a vital role in regulating the earth's climate, but climate change is increasingly threatening its health and productivity. Rising temperatures, erratic rainfall, and extreme weather events accelerate soil degradation, leading to erosion, reduced fertility, and increased carbon emissions. However, adopting sustainable soil management practices such as conservation tillage, cover cropping, and efficient water use can help mitigate these effects and enhance soil resilience. Protecting soil is essential for food security, environmental sustainability, and climate change mitigation, making it crucial for policymakers, farmers, and individuals to take action in preserving this valuable resource.

References

- Allen, D.E., Singh, B.P., and Dalal, R.C. 2011. Soil health indicators under climate change: a review of current knowledge. In: Singh, B.P., Cowie, A.L., and Yagi, K. (eds), *Soil health and climate change*. Springer International Publishing, Berlin, pp. 25-45.
- Birkas, M., Dexter, A., and Szemók, A. 2009. Tillage-induced soil compaction, as a climate threat increasing stressor. *Cereal Res. Commun.* 37: 379-382.
- Castro, H.F., Classen, A.T., Austin, E.E., Norby, R.J., and Schadt, C.W. 2010. Soil microbial community responses to multiple

- experimental climate change drivers. *Appl. Environ. Microbiol.* 76(4): 999-1007.
- Davidson, E.A. and Janssens, I.A. 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature* 440(7081): 165-173.
- Guo, Q., Wang, Y., Ma, Z., Guo, T., Che, Z., Huang, Z., and Nan, L. 2011. Effect of vegetation types on soil salt ion transfer and accumulation in soil profile. *Scientia Agricola Sin.* 44: 2711-2720.
- Reich, P.B., Hobbie, S.E., Lee, T., Ellsworth, D.S., West, J.B., Tilman, D., Knops, J.M., Naeem, S., and Trost, J. 2006. Nitrogen limitation constrains sustainability of ecosystem response to CO₂. *Nature* 440(7086): 922-925.
- Reynolds, W.D., Drury, C.F., Tan, C.S., Fox, C.A., and Yang, X.M. 2009. Use of indicators and pore volume-function characteristics to quantify soil physical quality. *Geoderma* 152(3-4): 252-263.
- Strong, D.T. and Fillery, I.R.P. 2002. Denitrification response to nitrate concentrations in sandy soils. *Soil Biol. Biochem.* 34(7): 945-954.
- Weil, R.R. and Magdoff, F. 2004. Significance of soil organic matter to soil quality and health. In: Weil, R.R. and Magdoff, F. (eds), *Soil organic matter in sustainable agriculture*. CRC Press, London, pp.1-43.
