Chapter 7

Climate Change Impacts on Soil Ecosystems

S.L. Yadav
Department of Soil Science
RVSKVV
Gwalior, Madhya Pradesh, India.
syadav1551@gmail.com

A. Bhargava
Department of Soil Science
RVSKVV
Gwalior, Madhya Pradesh, India.

Arham Tater
Division of Soil Science and
Agricultural Chemistry
ICAR-Indian Agricultural
Research Institute
New Delhi, India.

Abstract

The relationship between soil systems and conservation tactics in relation to the effects of climate change is addressed in climate change and soil interaction, introducing modern research facilities on plants, soil carbonization, and soil biodiversity studies. A useful tool for maintaining the different relationships necessary for environmental sustainability, it includes information on soil remediation techniques, microbiological reactions to climate change, and soil health. Restoring soil system vitality under changing climatic circumstances requires an understanding of soil systems, including diverse physical, chemical, and biological interactions. This chapter discusses how numerous positive interactions in soil systems are impacted by changing climatic circumstances and offers suitable solutions to maintain these interactions. Researchers studying agriculture, ecology, and the environment can better comprehend cultivation by consulting Climate and Soil Interactions, which offers current, reliable, and novel data on how diverse soil interactions are affected by

changing climatic circumstances. It will provide insights with pertinent information regarding environmental science, climate change, and biodiversity.

Keywords: Climate change, soil health, biodiversity, sustainability, ecology.

I. INTRODUCTION

An essential resource for sustaining plant development, soil is a dynamic natural organism on Earth's surface. It gives the developing plants the nutrition they need and is made up of minerals, organic components, and living things. Water is both a cause of soil erosion and a transporter of nutrients. Degradation of the land and environment due to poor management and careless usage of water and soil resources can have grave consequences for both humans and animals. Soil and water conservation as well as wise management are necessary to achieve sustained production and environmental advantages.

In addition to holding the nutrients necessary for plant growth, soil gives roots a place to take hold. In addition to controlling the outflow of surplus rainwater and preventing flooding, the floor filters rainfall. In addition, it safeguards groundwater purity and guards against pollution. Large amounts of organic carbon may be stored in soil. It is the planet's greatest carbon reservoir. Generally speaking, soil has around twice as much carbon as the atmosphere and roughly three times as much organic carbon as plants. This is particularly crucial for attempts to slow down climate change. Soil stores carbon that escapes from the atmosphere and contributes to the rebalancing of the global carbon budget.

In numerous aspects of life, such as agriculture, urban usage, environmental management, wildlife preservation, and landscape architecture, soil functions are fundamental soil capabilities.

India is a country characterized by rivers and the monsoon, with a variety of fertile soil types produced by intricate geomorphological processes as well as natural phenomena including rainfall, weathering, and temperature. But as of late, this natural resource finds itself in a dire condition. In many places, soil erosion is a major hazard to civilization as a whole. The adverse effects of such rapid erosion were due to both natural and anthropogenic events (Sidle *et al.*, 2006). Many scientists and international organizations, such as the Food and Agriculture Foundation (FAO), the United States Department of Agriculture (USDA), and the Commonwealth Scientific and Industrial Research Organization (CSIRO), have conducted soil studies to establish educational taxonomies. Many soil scientists have also used influential geographic factors that are most relevant to their models to identify the main sources of soil erosion

(Rodrigo-Comino *et al.*, 2018). Data collected from representative concentration pathways (RCPs) show a positive association between climate change and soil erosion processes (Ganasari and Ramesh 2016).

II. CLIMATE CHANGE IMPACTS ON SOILS

Global climate change is an ongoing phenomenon that has existed from the beginning of time. Over the past ten years, climate change has emerged as a significant scientific and political concern. The past 150–200 years have seen comparatively quick global observations of the cold and warm cycles that have characterized Earth's climatic history. Given the limited resources of soil, an increasing global population that depends on it for food and fiber appears to make soil more vital than ever for modern human cultures. Food security is at risk globally due to climate change. Due to their tropical environment and the poor ability of small, marginalized farmers to adapt, nations like India are particularly vulnerable. Agriculture is predicted to be significantly impacted by climate change, both directly and indirectly, through effects on crops, soils, cattle, and pests. Although the effects of climate change are gradual and include only little variations in temperature and precipitation over extended periods of time, they have a significant impact on many soil processes, especially those that are connected to soil fertility. provide It is anticipated that the primary causes of climate change's effects on soil would be elevated CO_2 levels, temperature rises, and modifications to soil moisture content. Different effects of global climate change are anticipated on soil processes and qualities that are crucial for replenishing soil fertility and production. Warmer temperatures and more CO_2 emissions are predicted to be the main effects of climate change.

1. Soil Formation

Many variables, including meteorological ones like temperature and precipitation, influence the development of soil. By supplying biomass and weathering conditions, these environmental elements have a direct impact on the development of soil. The total active temperature and the ratio of precipitation to evaporation are the two most significant meteorological characteristics that have a direct impact on soil formation. They calculate the energy required for the production of soil, the equilibrium of water in soil, the processes underlying organo-mineral interactions, the conversion of organic and mineral materials, and the movement of soil solutions. The mineral matrix of soil undergoes permanent changes as a result of steady global warming. Temperature and precipitation variations in the exterior soil formation factors cause changes in the interior soil formation factors (energetic, hydrological, and biological). Because of the buildup of weathering minerals, climate change intensifies the energy of soil mineral degradation, simplifying the mineral matrix. As a result, the soil becomes less able to retain its fertility and becomes more reliant on mineral fertilizers.

2. Soil Development

There are three primary elements affecting soil growth. This article takes into account elements such as vegetation type, parent plant, and climate. It is anticipated that variations in soil moisture conditions, as well as rises in soil temperature and CO_2 levels, would be the primary drivers of climate change's impact on soil fertility. Through direct climatic events (precipitation, temperature impacts on evaporation), changes in vegetation caused by the climate, plant growth rates, soil water extraction rates, and the influence of rising CO_2 levels on plant transpiration, soil moisture levels will be impacted by climate change. Variations in soil water fluxes have a correlation with climate as well; in fact, they may exacerbate drought conditions by raising air temperatures, changing circulation patterns, and reducing available moisture. Among the many variables influencing the process of soil formation, climate is a critical component in the weathering of rocks and minerals.

The many phases of rock weathering are influenced by climate change elements, including temperature and rainfall, which permits free use, distribution, and non-commercial building on your work. The fact that the bulk of the cultivated land, which is rainfed, is heavily dependent on monsoon uncertainty illustrates how weather affects agriculture. By maintaining the integrity of the food chain, climate change directly affects food security. In two important ways, agriculture contributes to food security: first, it employs 36% of the global workforce as their major source of income. In heavily populated Asia and the Pacific, this percentage ranges from 40–50%, but in sub-Saharan Africa, 67% of working age people still make their livelihood from agriculture. Agriculture is both a cause and an effect of climate change. Due to its substantial greenhouse gas emissions and the minerals (parent material) that induce chemical and mineralogical changes in the soil that eventually become rocks, agriculture is both a source and a sufferer of climate change. Because chemical weathering depends heavily on water, an increase in rainfall speeds up the process. Various secondary minerals arise from the same source mineral types under various weathering circumstances. Thus, various soil profiles might result from same rock types eroding in different climates.

3. Soil Fertility and Productivity

Moisture, temperature, and CO_2 are a few examples of climate change elements that are predicted to have diverse effects on different soil processes and attributes that directly affect soil fertility and production. However, as one component might affect the other and have difficult consequences as a result, the effects of the climate change variables cannot be taken into account independently. Depending on soil properties, temperature circumstances, and the extent of climate change, all of these effects will be quite local. Nine of the world's twelve soil orders and fifteen agroclimatic zones—each with its own distinct seasons, crops, and agricultural seasons—are found in India. Climate change is a fact that will affect the livelihoods of millions of people in the region by having direct and indirect effects on agricultural production qualities and soil regeneration processes. In order to understand the link between climate change variables and various soil characteristics and to develop suitable mitigation methods, the influence of climate change factors—specifically, temperature, CO_2 and rainfall—on various soil properties are being constantly discussed and researched.

4. Plant Nutrient Availability and Acquisition

The chemical composition of the soil, the location of an ion in relation to the root surface, and the distance a nutrient must travel through the soil before reaching the root surface all affect how readily available nutrients are in the soil. Temperature increases and variations in precipitation significantly impact the temperature and moisture content of the root zone. It is fair to predict that process results will reflect the new climate since it is widely known that soil moisture and temperature are the key regulators of nutrient availability and root growth and development, and that carbon allocation to roots affects nutrient uptake. The location and soil conditions will determine the kind and degree of these two factors. It's been proposed that direct effects on root surface area and inflow rate are the main ways that climatic change affects nutrient utilization efficiency. (Pendall *et al.*, 2004)

5. Nutrient Transformation in Soil

Nutrients must be in solution in order to be absorbed by plants, which take up nutrients from the soil solution pool. Global climate change can therefore have a significant impact on both the concentrations of n and s in solutions. While increased CO_2 concentrations may not directly affect n mineralization per se, they can lead to increased concentrations of n in the solution phase. Moisture and temperature play a major role in the biological transformation between organic and inorganic pools. By modifying the ionic strength of the soil solution, variations in soil moisture can also modify reactions (Pendall *et al.*, 2004).

6. Soil Carbon Dynamics

It is widely acknowledged that changes in CO_2 concentrations both qualitatively and quantitatively affect the way chemicals produced from roots develop. When plants are subjected to high CO_2, they allocate more c-rich metabolites and less n-rich metabolites to their root exudates. (Tarnawski *et al.,* 2006) Increased microbial activity leads to increased CO_2 generation, which may be detrimental to soil accumulation and hence soil sequestration. Due to increased microbial activity in soil with increasing atmospheric CO_2 concentrations, the priming effect reduces the potential for soil sequestration and has a considerable detrimental impact on processes related to global change. Numerous research employing c isotope tracers have mentioned high CO_2 plant growth conditions.

The stimulation of CO_2 respiration in the rhizosphere may be much higher than the enhancement of root biomass. (Cheng *et al.*, 1998) demonstrated that although plants produced only 15–26% more biomass under elevated CO_2, rhizosphere respired C increased by 56–74% as compared to ambient CO_2 treatments.

7. Response to Mycorrhizal Association

Enhanced mycorrhizal colonization is frequently a result of elevated plant demand for nutrients, assimilation rates, and enhanced c assimilation rates, which are all caused by high atmospheric CO_2 concentrations on the structure of the soil microbial community. Because plant needs for N and P will rise in tandem with rates of C absorption, and because plants will devote more hotosynthates belowground to the roots and mycorrhizal fungi, CO_2 enrichment can enhance mycorrhizal biomass. Increased p absorption in mycorrhizal plants growing in increasing CO_2 concentrations is attributed to both a larger fine root mass and mycorrhizal infection. Mycorrhizal biomass would increase at higher CO_2 levels as soil nutrients become more limiting to plant development and carbon becomes less limiting. (Drigo *et al.*, 2008) nevertheless, the information available in the literature isn't always accurate.

8. Soil Biological Activities

Due to the very different patterns of plant C allocation in different plant–soil systems, soil microorganisms' response to changes in plant growth under elevated CO_2 is highly variable. Under high CO_2, a high degree of variability is observed in microbial biomass, gross n mineralization, microbial immobilization, and net N mineralization. However, rates of soil and microbial respiration are generally higher under elevated CO_2, suggesting that increased plant growth under elevated CO_2 increases the amount of C entering the soil, thereby stimulating soil microbial activity. Since soil microorganisms are often C-limited, increased c availability promotes microbial growth and activity. It is generally assumed that the CO_2 induced increases in soil c availability would increase fungal biomass more than bacterial biomass. It is due to increased concentrations of dissolved organic c in the rhizosphere and to increases in soil water dissolved organic nitrogen.

Changes in fungal populations may have a significant effect on soil functioning since fungi are essential for the breakdown of organic matter, the cycling of nutrients, plant nutrition, and the creation of soil aggregates. Furthermore, since fungi typically have a greater C:N ratio than bacteria and have a lower requirement for nitrogen than bacteria do, decreased N availability at increasing CO_2 levels may help to partially explain these increases in fungus (Hu *et al.,* 2001). The first consumers of soil organic matter, bacteria and fungus, serve as substrates for a wide variety of microscopic grazers and predators that make up the soil food web, such as protozoa, nematodes, and arthropods. Thus, an increase in grazing may occur after an increase in bacterial growth brought on by an increase in C allocation at rising atmospheric CO_2 levels, which would raise the turnover of the microbial biomass. As a result, increased grazing, hastens the process of recycling nutrients from microbial biomass, thereby increasing the flow of nutrients to the plant.

III. ADAPTATION AND MITIGATION STRATEGIES

Using farm management techniques that reduce the adverse impacts of temperature fluctuations, variations in rainfall, and other extreme weather events, agriculture can adjust to climate change. Numerous management-level adaptation strategies are available to lessen the effects of climate change on crop productivity. These include wider agronomic management approaches (e.g., irrigated crops) as well as zero tillage, crop residue retention, expanding fallows, increasing production diversity, and adjusting the amounts and timing of external inputs (e.g., water, fertilizers), adjusting the timing, row spacing, and planting density; adding novel germplasm resistant to drought or heat stress. By using plant-based technologies that lower greenhouse gas emissions (carbon dioxide, nitrous oxide, and methane) and enhance soil carbon sequestration, agriculture can help mitigate the effects of climate change. By using energy more wisely and consuming less biomass, carbon dioxide emissions may be decreased. Better farm management techniques, such as better handling of animal waste and water in rice fields, can lower methane emissions. Improved soil management (preventing soil compaction) and fertilizer management, including the proper amount, rate, and application technique, can lower nitrous oxide emissions. Different farm management techniques can increase soil carbon reserves and enhance soil quality. The most successful approaches include conservation agriculture (minimal soil disturbance, cover crops, and legume rotations), soil conservation (composting, for example), and soil rehabilitation (composting, for example). By creating an environment that supports rapid plant development and a protective layer of soil, contour farming and nutrient replenishment techniques can help rebuild soil organic matter. In some circumstances, nevertheless, a change of the agricultural production system could be necessary. The growth of agroforestry techniques or ley farming is taking the role of continuous grain cultivation. The worldwide soil carbon pool is four to five times larger than the biomass pools, excluding the fact that recent soil deterioration has resulted in losses of between 30 and 75 percent of its antecedent soil organic carbon. Consequently, an increase in soil carbon has a major worldwide mitigation benefit. The process of storing carbon in a stable solid state is known as sequestration. Both direct and indirect fixation of atmospheric CO_2 is the cause of it. Direct soil carbon sequestration occurs when CO_2 is converted by inorganic chemical processes into soil inorganic carbon molecules like calcium and magnesium carbonates. Direct plant carbon sequestration happens during breakdown processes when plants photosynthesize ambient CO_2 into plant biomass; a portion of this biomass is subsequently indirectly stored as soil organic carbon (SOC). The long-term link between carbon absorption and release mechanisms is reflected in the quantity of carbon delivered at a place. Incorporating various agronomic, forest, and conservation activities along with optimum management methods leads to a positive net increase in soil carbon fixation. Through biotic carbon sequestration in soils and plants, agro-ecosystems may significantly contribute to the reduction of CO_2 emissions. The estimated 41 to 55 kt of previous carbon losses have provided the soils with a source of carbon storage. Soil carbon sequestration capability is influenced by several factors such as temperature, plant type, parent material composition, soil drainage, edaphic environment, soil organic matter (SOM), and its decomposition ability. Soil carbon sequestration may be greatly increased by better management of agro-ecosystems. Net carbon sequestration occurs in soils when management techniques or technological advancements improve carbon input to the soil, decrease carbon loss, or do both. The selection of high biomass producing crops, application of organic materials (e.g., animal manure, compost, sludge, green manure, etc.), adoption of agro forestry systems, intensification of agriculture through improved nutrient and water management practices, reduction of summer or winter fallow, conversion from monoculture to rotation cropping, and switching from annual crops to perennial vegetation are some of the methods that can be used to increase carbon input in agro-ecosystems. Reduced tillage intensity, the use of low-quality organic inputs, conservation agriculture, and reducing soil disturbance can all help to reduce the amount of carbon lost from the soil. Effective methods for sequestering soil carbon in Indian agro-ecosystems include integrated nutrient management and maturation, crop residue assimilation, mulch farming and/or conservation agriculture, agro-forestry techniques, grazing management, and agricultural intensification. Integrated nutrient management, which combines the use of organic manures and composts with inorganic fertilizers, improves soil aggregation. (Benbi and Senapati, 2009).

IV. CONCLUSION

The climate change has emerged as an ultimate truth of the 21st century. The phenomenon of climate has made every aspect of scientific community to reconsider their interventions and dwell deeper into the environmental sustainability. Agriculture being a direct beneficiary of the climate needs special consideration in this regard. Soil and its dynamics is affected to a greater extent from climate change. Reduction in organic matter, disturb in nutrient dynamics, disturbance in soil microbial communities and alterations of soil moisture relations are most vulnerable aspects of climate change. Adoption of agro-forestry systems, addition of organic matter, minimum soil disturbance, water harvesting strategies could play a key role in combating climate change anomalities.

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