https://doi.org/ 10.37939/jhcc.v4i1.17

Influence of Climate Change on Soil Nutrient Cycling: Consequences for Ecosystem Sustainability and Agricultural Production

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Abstract

Climate change impacts soil nutrient cycle, major process for maintaining ecosystem health and yield. Rising temperature amplify microbial activities, increase the decomposition of organic matter and change the availability of nutrients. These changes disrupt the basic cycle, like carbon and nitrogen and harm the soil functioning. Variations in moisture, droughts, extreme rainfall events intensify the soil erosion, nutrient leaching and soil compaction. These changes further damage the soil fertility, poses risk to food safety and ecosystem facilities. To lessen these harmful effects, practices like minimum tillage, improved water management and addition of organic amendments can help under climate change.

Keywords: Climate change, Soil, Nutrient, Sustainability, Production.

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Received Oct 20, 2024; accepted Jan 28, 2025

1. Introduction

Soils are essential components of the land ecosystem, contributing significantly to nutrient cycling, water retention, and carbon storage. They also support plant growth and development, impacts the water flow, and maintain biodiversity. However, climate change is starting to disrupt several essential processes. Increasing global temperature, changing rainfall patterns, and higher frequency of extreme weather events are altering soil characteristics and processes, which have substantial implications for nutrient dynamics. [1,2,6]

Soil nutrient cycling also involves in the conversion and transportation of important elements like carbon (C), nitrogen (N), and phosphorus (P) through biological, chemical, and physical processes. Climate change has a direct impact on these cycles by altering the soil temperature and moisture as well as indirectly by impacting vegetation patterns and microbial communities. The higher temperatures may boost microbial activity leading to the rapid decomposition of organic matter while changes in rainfall may impact nutrient leaching and availability. [1-5]

2. Soil Properties and Climate Change

Climate change directly impacts soil conditions such as temperature, moisture, and organic matter content. The increase in temperature enhances microbial activity, causing organic matter decomposition faster and nutrient availability changes. On the other hand, the change in rainfall can contribute to soil erosion, compaction, and change in soil moisture level which further affects nutrient cycling [2,5,8]

3. Soil Structure and Erosion

Climate-related weather events may affect soil structure, which causes erosion and nutrient loss. Heavy rain can compact the soil, reducing water infiltration and limiting plant nutrient uptake[9-11]. Soil degradation caused by erosion can decrease soil fertility and productivity, posing a risk to food security.

4. Impact on Nutrient Cycling Processes

4.1. Effect on Carbon cycling

Climate change has a significant impact on the carbon cycle. Higher temperatures can lead to soil emission of more CO_2 and reduce the amount of organic carbon stored in the soil. This reduction in soil organic carbon can make the climate change worse. Changes in plant productivity caused by climate stress can also affect the amount of organic matter returned to the soil, impacting carbon dynamics. [3,7,8]

4.2. Effect on Nitrogen cycling

Climate change also has a significant impact on the nitrogen cycle. The change in temperature and moisture can all have an impact on nitrogen mineralization and nitrification processes. The warmer conditions may speed up the breakdown of nitrogen, potentially leading to higher nutrient leaching and decreased nitrogen availability for plants. Changes in the types of microbes in the soil caused by climate stress can impact nitrogen cycling, which affects soil fertility [5,8]

5. Soil Microbial Dynamics in Nutrient Cycling

Soil microorganisms are crucial for nutrient cycling because they helps in the alteration of nutrients through numerous biochemical mechanisms. Climate change may alter the makeup and function of soil microbial communities, affecting their ability to cycle nutrients effectively i.e., drought can shift microbial communities toward drought-resistant species, which may have different nutrient cycling capacities compared to the original ones. [3,4,8]

5.1 Changes in Microbial Communities

Microbial communities' responses to climate change differ depending on temperature and moisture conditions. The changes in moisture levels can stress microbes and reduce their ability to cycle nutrients efficiently. [10-13]

5.2 Microbial Feedback Mechanisms

Microbial processes also play an important role in feedback mechanisms for soil carbon and nitrogen cycles. Changes in the composition of microbial communities can impact nitrogen fixation rates, with implications for plant nutrient availability. Furthermore, some microbial groups may become more dominant as climate condition changes, which can impact the efficiency of nutrient cycling processes [11,12]

6. Implications for Food Security and Ecosystem Services

Climate change impacts global food security by altering nutrient cycling mechanisms. Crop productivity can be decreased by decreased soil fertility and nutrients availability, while environmental degradation can result from increasing nutrient losses. Soil management and climate adaptation strategies are essential for reducing these impacts and promoting sustainable agriculture. [3,9,11]

7. Impacts of Extreme Weather Events

Extreme weather like droughts, floods, and storms can seriously disrupt the way nutrients move and cycle in soil. They can break the natural nutrient flow and even cause nutrients to be lost. Drought can significantly reduce the microbial activity which may lead less availability of nutrients. Prolonged dry conditions slow down decomposition and lower nitrogen levels, which can negatively impact plant growth and the overall health of the ecosystem, on the other hand, heavy rainfall and flooding can wash nutrients like nitrogen and phosphorus into water bodies. This can cause eutrophication, which harms and degrades aquatic ecosystems. [1,2,11]

Conclusion

Climate change significantly disrupts nutrient cycling in soils, impacting the health of ecosystems and agricultural productivity and global food security. Changes in temperature and rainfall affect microbial activity, intensify soil erosion, and nutrient leaching. Soil Compaction also affects the nutrient availability and soil microbial activities. These changes comprise soil fertility and efficiency of carbon and nitrogen cycle, exacerbate environmental degradation and climate change. Effective soil management and adaptation strategies are crucial to address these issues. Future research should explore how climate change interacts with soil properties and microbial communities to improve the resilience of nutrient cycling. The synopsis is also presented in Figure 1.

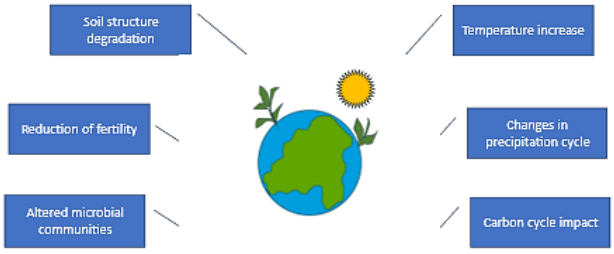

Figure 1: Climate change and soil nutrient cycle

References

1. Koltz AM, Gough L, McLaren JR. Herbivores in Arctic ecosystems: effects of climate change and implications for carbon and nutrient cycling. Ann N Y Acad Sci. 2022;1516(1):28-47.
2. Maharajan T, Ceasar SA, Krishna TP, Ignacimuthu S. Management of phosphorus nutrient amid climate change for sustainable agriculture. Journal of Environmental Quality. 2021 Nov;50(6):1303-24.
3. Herzfeld T, Heinke J, Rolinski S, Müller C. Soil organic carbon dynamics from agricultural management practices under climate change. Earth System Dynamics. 2021 Oct 22;12(4):1037-55.
4. Broadbent AA, Newbold LK, Pritchard WJ, Michas A, Goodall T, Cordero I, et al. Climate change disrupts the seasonal coupling of plant and soil microbial nutrient cycling in an alpine ecosystem. Glob Change Biol. 2024;30(3):e17245.
5. Li Z, Peng Q, Dong Y, Guo Y. The influence of increased precipitation and nitrogen deposition on the litter decomposition and soil microbial community structure in a semiarid grassland. Science of the Total Environment. 2022 Oct 20;844:157115
6. Lin J, Hui D, Kumar A, Yu Z, Huang Y. Climate change and/or pollution on the carbon cycle in terrestrial ecosystems. Front Environ Sci. 2023;11:1253172.

7. Navarro-Pedreño J, Almendro-Candel MB, Zorpas AA. The increase of soil organic matter reduces global warming, myth or reality?. Sci. 2021 Mar 8;3(1):18.
8. Toor MD, Basit A, Okorie B, Nath D, Din MMU, Kumar Verma P, et al. Earthworms as catalysts for climate-resilient agriculture: enhancing food security and water management in the face of climate change. Water Air Soil Pollut. 2024;235(12):779.
9. Srivastav AL, Dhyani R, Ranjan M, Madhav S, Sillanpää M. Climate-resilient strategies for sustainable management of water resources and agriculture. Environmental Science and Pollution Research. 2021 Aug;28(31):41576-95.
10. Naylor D, Sadler N, Bhattacharjee A, Graham EB, Anderton CR, McClure R, et al. Soil microbiomes under climate change and implications for carbon cycling. Annu Rev Environ Resour. 2020;45(1):29-59.
11. Jiang C, Li J, Hu Y, Yao Y, Li H. Construction of water-soil-plant system for rainfall vertical connection in the concept of sponge city: a review. Journal of Hydrology. 2022 Feb 1;605:127327.
12. Dai Z, Xiong X, Zhu H, Xu H, Leng P, Li J, Tang C, Xu J. Association of biochar properties with changes in soil bacterial, fungal and fauna communities and nutrient cycling processes. Biochar. 2021 Sep;3:239-54.
13. D'Alò F, Odriozola I, Baldrian P, Zucconi L, Ripa C, Cannone N, Malfasi F, Brancaleoni L, Onofri S. Microbial activity in alpine soils under climate change. Science of the Total Environment. 2021 Aug 20;783:147012.