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Research Application Summary

Biogeochemical processes in forest ecosystems: A review

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Abstract

Biogeochemical processes are the biological, geological, and chemical characteristics of a forest ecosystem, whereas biogeochemical cycles are the pathways by which vital elements of a living matter are transported through biotic and abiotic compartments of Earth. Forest canopy element transformations, hydrology, soil organic matter dynamics, nitrogen cycling, geochemical weathering, and chemical equilibrium reactions are all examples of significant biogeochemical processes. Atmospheric deposition, hydrology, weathering or mineral weathering, and soil chemical reactions (example, cation exchange and), and biological transfers (example, vegetation element uptake, element mineralization, and nitrification are the key biogeochemical processes that regulate the acid-base condition of soil and water. Ecosystem services are becoming increasingly essential and a cause to promote the use of natural resources in a sustainable manner. Carbon (C) sequestration and nutrient cycling are two of the many significant ecosystem services provided by forests. Forests are a major carbon sink, and they play a vital role in climate change. The nutritional substance is exchanged cyclically between living organisms and their non-living environment is called biogeochemical cycle. All living things require a healthy ecosystem and well-functioning biogeochemical processes to survive and thrive. More extensive and comparative studies will be necessary to predict the future of the environment, increasing forest cover and lowering deforestation and nutrient loss, as well as to identify the factors affected by global change in a wide range of ecosystems.

Key words: Biogeochemical cycle, ecosystem, hydrology, weathering, carbon sequestration

Résumé

Les processus biogéochimiques sont les caractéristiques biologiques, géologiques et chimiques d'un écosystème forestier, tandis que les cycles biogéochimiques sont les voies par lesquelles les éléments vitaux d'une matière vivante sont transportés à travers les compartiments biotiques et abiotiques de la Terre. Les transformations des éléments de la canopée forestière, l'hydrologie, la dynamique de la matière organique du sol, le cycle de l'azote, l'altération géochimique et les réactions d'équilibre chimique sont tous des exemples de processus biogéochimiques importants. Les dépôts atmosphériques, l'hydrologie, la météorisation ou encore l'altération minérale, les réactions chimiques du sol (par exemple, l'échange de cations) et les transferts biologiques (par exemple, l'absorption d'éléments par la végétation, la minéralisation des éléments et la nitrification) sont les principaux processus biogéochimiques qui régulent l'état acide-base du sol et de l'eau. Les services d'écosystèmes sont de plus en plus essentiels et constituent une cause pour promouvoir l'utilisation des ressources naturelles de manière durable. La séquestration du carbone (C) et le cycle des nutriments sont deux des nombreux services d'écosystèmes importants fournis par les forêts. Les forêts constituent un puits de carbone majeur et jouent un rôle essentiel dans le changement climatique. L'échange cyclique de substances nutritives entre les organismes vivants et leur environnement non vivant est appelé cycle biogéochimique. Pour survivre et se développer, tous les êtres vivants ont besoin d'un écosystème sain et de processus biogéochimiques qui fonctionnent bien. Des études plus approfondies et comparatives seront nécessaires pour prédire l'avenir de l'environnement, l'augmentation de la couverture forestière et la diminution de la déforestation et de la perte de nutriments, ainsi que pour identifier les facteurs affectés par le changement global dans un large éventail d'écosystèmes.

Mots clés : Cycle biogéochimique, écosystème, hydrologie, altération, séquestration du carbone

Introduction

Ecosystem producers rely on non-living sources for a variety of fundamental inorganic nutrients. These resources are turned into the producers' biomass. Then they are consumed by the general public in the environment and eventually returned to it through the usage of reducers or decomposers (Villa and Bernal, 2018). Ecosystem services are becoming increasingly essential and a cause to promote the use of natural resources in a sustainable manner. Carbon (C) sequestration and nutrient cycling are two of the many significant ecosystem services provided by forests. Forests are a significant carbon sink and play a critical role in climate change mitigation (Villa and Blanca, 2018). The biogeochemical cycle is the cyclic exchange of nutritional material between living organisms and their non-living surroundings. Nutrients circulate via life (bio) and through the earth (geo), as defined by their nomenclatures (cycle). The biogeochemical (material or nutrient) cycles help to conserve the environment's finite supply of raw materials (Gbondo- Tugbawa *et al.*, 2001).

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Forest canopy element transformations, hydrology, soil organic matter dynamics, nitrogen cycling, geochemical weathering, and chemical equilibrium reactions involving solid and solution phases are all examples of significant biogeochemical processes (Sodhi and Ehrlich, 2010). Atmospheric deposition, hydrology, weathering or mineral weathering, soil chemical processes (for example, cation exchange), and biological transfers (for example, vegetation element uptake, element mineralization, and nitrification) are the major biogeochemical processes that regulate the acid-base status of soil and water (Gbondo- Tugbawa *et al.*, 2001). The major or principal chemical elements used by living creatures in structural tissues, replication, energy-harvesting activities, and photosynthesis are carbon, hydrogen, nitrogen, oxygen, phosphorus, sulfur, calcium, and iron. The oceans, atmosphere, and crustal rocks all contain these elements in substantial amounts.

In processes known as biogeochemical cycles, the functions and operating systems of live creatures mix with chemical, physical, and geological factors to continually reallocate these elements between living and nonliving reserves (Summons,1993). As previously said, biogeochemical cycles are important to the existence of life, converting energy and materials into useful forms to enable ecosystem functioning. These cycles between Earth's principal reservoirs—the atmosphere, terrestrial biosphere, seas, and geosphere (soil, sediments, and rocks)—describe the movement of matter (Brusseau, 2019).

Literature Review

Forest canopy elements. The forest canopy is a distinct subsystem of the forest in which numerous forest processes, such as photosynthesis, flowering, and fruiting, take place. At the canopy level, the forest and the atmosphere interact, and the canopy is also a unique environment for many forest residents (Bongers, 2001). Forest canopy structure is the result of combining forest texture (the qualitative and quantitative composition of the vegetation as it relates to various morphological features) with forest structure (the spatial arrangement of these elements). The importance of scale cannot be overstated. Forest types such as broadleaf and coniferous forest can be separated at a regional scale. The canopy structure is mostly determined at the local scale by the distribution, size, and shape of tree crowns, as well as the spatial distribution of leaves and branches within three crowns (Bongers, 2001).

The quantity, spatiotemporal patterning, chemical concentration, character, and constituency of precipitation to soils are all controlled by the exchange between rainfall pattern and forest canopy elements (bark, leaves, and epiphytes) (Van Stan and Pypker, 2015). Because of their diverse morphological characteristics and nutrient uptake, canopy epiphytes have a variety of hydrological and biogeochemical consequences. Gap dynamics refers to the process in which one or more trees in a forest die, leaving a hole in the canopy and making light and nutrient resources available to seedlings and saplings (Grebner *et al*., 2012). Individual tree death can be caused by strong winds, climate extremes (temperature and precipitation), and other phenomena (for example, lightning). Because of their diverse morphological characteristics and nutrient acquisition strategies, canopy epiphytes have a variety of hydrological and biogeochemical consequences. The chemical change of net precipitation fluxes and epiphyte interactions with precipitation partitioning (into interception loss, throughfall, and stemflow) are shown below (throughfall and stemflow). Epiphytes, on the whole, decrease throughfall and stemflow and increase interception loss.

Forest soil microorganisms. In temperate and boreal forest soils, where saprotrophic and mycorrhizal fungal species are abundant and diverse, fungi are the most well-known microorganisms. Fungi are thought to play a critical part in forest decomposition due to their ability to synthesize a wide spectrum of extracellular enzymes that allow them to successfully digest the resistant fraction of dead plant material (Llado *et al*., 2017). Mycorrhizal fungi, on the other hand, play an essential role in the mobilization and sequestration of nitrogen and phosphorus in forest soils, as well as considerable carbon transfer.

Even though there hasn't been much research on it, the bacterial community is an essential aspect of the microbial community in forest soils. Recent results, for example, show that bacteria frequently carry genes for plant cell wall-degrading enzymes and play a key role in organic matter decomposition (Llado *et al.,* 2017). Bacteria are the primary natural mediators in forest ecosystems, where they are responsible for nitrogen fixation as well as other ecosystem processes such as mineral weathering, which results in the release of inorganic nutrients.

Bacteria can be found in a variety of habitats in forest ecosystems, including soil, plant tissues and surfaces, streams, and rocks, among others. However, bacteria appear to be most prevalent on the forest floor, in soil, litter, deadwood, and around plant roots (Llado *et al.*, 2017).

Mycorrhizae, rhizobia bacteria and Frankia communities in soil nutrient cycling

Rhizobia bacteria. In forest soils, they are a member of the microbial community. Recent research (Iyer and Rajkumar, 2019) shows that rhizobia bacteria frequently carry genes for plant cell wall-degrading enzymes and contribute significantly to organic matter decomposition. Furthermore, bacteria are the primary natural agents responsible for nitrogen (N) fixation in forest ecosystems as well as other ecosystem processes such as mineral weathering and inorganic nutrient release. *Leucaena leucocephala*, *Sesbania grandiflora*, and *Grilicidia sepium* are the most common legume trees.

Mycorrhizae. Plant roots and fungi have a symbiotic relationship. Their main function is to increase the host plant's nutrition and water intake by utilizing a wider volume of soil than roots alone can. The distribution of these forms in ecosystems is linked to the distribution of host plants as well as climatic and soil conditions (Orta, 2019). *Calliandra calothyrsus*, *Sesbania sesbana*, *Mucuna stans*, and other tree species have been found to contain it. The potential of mycorrhizae to promote host plant nutrition and water intake, as well as aid in root pathogen and root grazing defense, can affect host plant performance. It also contributes to soil nutrient cycling by enhancing plant nitrogen intake; increased nitrogen in the plant is more likely to lead to enhanced microbial development via increased root exudation (Orta, 2019).

Frankia. It is a heterotrophic and filamentous bacteria found in soil or in conjunction with plant root nodules. These bacteria can establish a symbiotic relationship with actinorhizal plants. Soil stabilization, land reclamation, crop protection, and timber and fuel wood production are all key ecological and economic functions of the Frankia-actinorhizal plant symbiosis (Zhong *et al.*, 2019). Frankia transforms ambient dinitrogen into ammonia (NH_3), which the plant absorbs. Actinorhizal plants provide carbon and energy to the bacteria in exchange. Some actinorhizal plants excrete excess nitrogen, improving soil fertility, and Frankia is thus employed as an inoculum to increase plant performance in degraded situations (Zhong *et al.*, 2019).

Tree foliage qualities/characteristics that are optimal for nutrient recycling in an agricultural landscape include:

- Choosing trees that can help the soil, as well as choosing species or clones that can fix or absorb significant amounts of nitrogen (and other elements, particularly P) and then return it to the soil.
- If they can actively fix nitrogen and so considerably contribute to improving the nitrogen status of the soil, nitrogen-fixing tree species are usually the best choice.
- Trees that encourage beneficial species like earthworms to reproduce.
- It should be necessary to employ nitrogen-fixing species, provenances, and/or clones that are appropriate to the site conditions.
- The ability to expand quickly
- Tress must be able to establish deep roots in order to avoid competition.

The density and depth of root channels, as well as organic residue integrated into the soil, are the key components of a hydrologic model that can be related to carbon and nutrient cycle. Solar radiation, temperature, vapor pressure deficits, precipitation, and wind speed are the five meteorological variables that drive the hydrologic model (Gbondo-Tugbawa *et al.*, 2001).

The hydrological cycle of the earth is the sum total of all processes in which water moves from the land and ocean surface to the atmosphere and back in form of precipitation. The hydrological cycle is influenced by a variety of variables, including oceans and land surfaces (Narasimhan, 2009). Plants are essential to the hydrological cycle's functioning because they dominate energy, water vapor, and carbon exchange activities (Balasubramanian and Nagaraju, 2015).

Natural Dynamic of Carbon in the Forest. In 2005, forests covered an estimated 3,952 million hectares, or about 30% of the world's geographical surface (FAO, 2006). The ecosystem, C is constantly entering and leaving forest ecosystems due to natural processes. The C budget of a forest ecosystem is influenced by natural habitat characteristics such as temperature, moisture availability, and disturbance frequency. The boreal, temperate, and tropical forest biomes are the three major global forest biomes. Climate, life-forms, and ecophysiology define biomes, which are broad vegetation kinds (Lorenz and Lal, 2010).

Carbon is found in all forms of life on Earth. Plants convert atmospheric CO_2 into reduced sugars through photosynthesis, which starts the carbon cycle in forest environments (Gbondo-Tugbawa *et al.*, 2001). The balance between absorption, storage, and losses in forest ecosystems is represented by carbon exchange. The amount of photosynthetically active sunlight absorbed by the entire canopy determines the upper limits of photosynthesis (Gbondo- Tugbawa *et al.*, 2001).

Soil organic matter dynamics. Forest ecosystems rely heavily on soil organic matter. Organic matter concentration has a substantial influence on important soil qualities like moisture holding capacity, aeration, and cation retention, and it normally increases with it. Organic matter also serves as a primary source of nutrients and fixed carbon in forests, fueling microbial processes and supporting diverse soil and forest communities (Nadelhoffer *et al.*, 2004).

Soils store up to three times as much carbon as vegetation above ground, mostly in the form of soil organic matter (SOM) (Halliday, 1984). Under the expected global climate change, carbon sinks could become carbon sources (Bernstein, 2008). Because of greater plant allocation of photosynthetic C to roots and symbiotic fungi, some climate models predict higher C storage in temperate forest soils (Lori *et al.*, 2013). Soil organic matter affects ecosystem cycles of C, N, Al, Fe, and other main and trace elements, as well as soil characteristics (Ussiri and Johnson, 2003).

Nitrogen cycling in a forest ecosystem. The nitrogen cycle is a biogeochemical process in which nitrogen is changed into various forms by moving from the atmosphere to the soil, where it is assimilated by diverse organisms, and then returned to the atmosphere in the form of gas (Fig. 6). (Deluca *et al.*, 2018). Nitrogen fixation, nitrification, nitrification, assimilation, denitrification, degradation, and putrefaction are only a few of the processes involved. Both organic and inorganic forms of nitrogen gas exist. Organic nitrogen is found in living species, and live organisms must devour other living organisms in order to progress via the food chain. The inorganic forms of nitrogen originate in large quantities in the atmosphere.

Most crop plants' nitrogen requirements are second only to their photosynthetic requirements.

Because soil N deficiency is common in many areas of crop production and in land areas that are now considered marginal, N supply, N management, and N-use efficiency are important factors in crop production, as well as the availability of fossil fuel reserves for future fertilizer N production (Maheshwari, 2010).

For decades, scientists have known about the interactions between plant roots and soil microbes. Ethicocorrhizal fungus, nitrogen-fixing bacteria like Actinobacteria, Azotobacter, and Bacillus, soil-borne pathogenic fungi, and other microorganisms have all been studied extensively.

Conclusion

In light of global change, biogeochemical processes in forest ecosystems are undeniably vital for global C balance. The significance of biogeochemical cycles in the ecosystem has revealed that it is still unclear whether these biomes will continue to be a significant carbon sink for anthropogenic emissions. Despite the importance of fungi in forest soils, bacteria play a variety of critical ecosystem roles in the forest environment, including organic matter decomposition, mycorrhizal symbiosis management, and engagement in N cycle processes, as well as climate modification. Ecosystem materials and nutrient cycles are self-sufficient and self-regulating. This indicates that it is a functional system in a balanced state, as well as an open nutrient system in a forest environment. All living organisms in the universe require a balanced ecosystem and well-functioning biogeochemical processes in order to survive and thrive.

Recommendations

1. To anticipate the future of the environment, more complicated and comparable research will be required to examine the factors affected by global change across a wide range of ecosystems.
2. Increase forest cover expansion as a means of reducing climate change and boosting carbon sequestration
3. Harvesting and renewing trees, enhancing forest health via good management, reduces nutrient loss while boosting carbon in a forest ecosystem.
4. Intensify Climate Change Enhancement Deforestation reduction and mitigation measures

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