BioScientific Review (BSR)
Volume 7 Issue 2, 2025
ISSN$_{(P)}$: 2663-4198, ISSN$_{(E)}$: 2663-4201
Homepage: https://journals.umt.edu.pk/index.php/bsr

Article QR

Title: **Ecosystem Architects: The Vital Role of Plants in Nature's Balance**

Author (s): Rabia Shahdin and Ayesha Siddiqa

Affiliation (s): University of the Punjab, Lahore, Pakistan

DOI: https://doi.org/10.32350/bsr.72.05

History: Received: October 11, 2024, Revised: January 21, 2025, Accepted: March 21, 2025, Published: April 29, 2025

Citation: Shahdin R, Siddiqa A. Ecosystem architects: the vital role of plants in nature's balance. *BioSci Rev.* 2025;7(2):54-72. https://doi.org/10.32350/bsr.72.05

Conflict of Interest: Author(s) declared no conflict of interest

A publication of
The Department of Life Sciences, School of Science
University of Management and Technology, Lahore, Pakistan

Ecosystem Architects: The Vital Role of Plants in Nature's Balance

Rabia Shahdin, and Ayesha Siddiqa*

Institute of Microbiology and Molecular Genetics, University of the Punjab, Lahore, Pakistan

ABSTRACT

Background. Plants as primary producers transform solar energy into biochemical energy, and are the foundation of terrestrial ecosystems. In advance, plants hold the ability to interact with soil, other biotic factors, and their communities to drive nutrient cycles and preserve the ecosystem homeostasis.

Methodology. This review aimed to compile the available studies on plant ecosystem interaction while observing the links with other species, photosynthesis, plant soil dynamics, and biogeochemical cycling. Various human impacts, such as deforestation and climate change were evaluated to determine how they affect the balance of ecosystem.

Results. Primary production and nutrient cycling particularly nitrogen, phosphorous, and carbon cycles contribute to the stability of ecosystems. The plant animal interaction fosters biodiversity and the plant soil and microorganisms are collectively involved in improving fertility. However, these processes are distributed by human activity which results in instability in ecosystem.

Conclusion. To support nutrition and energy flows, plants are essential to preserve the integrity of ecosystems. Considering the growing environmental problems, this assessment shows the interconnectedness of plant systems and the need for protection and sustainable utilization.

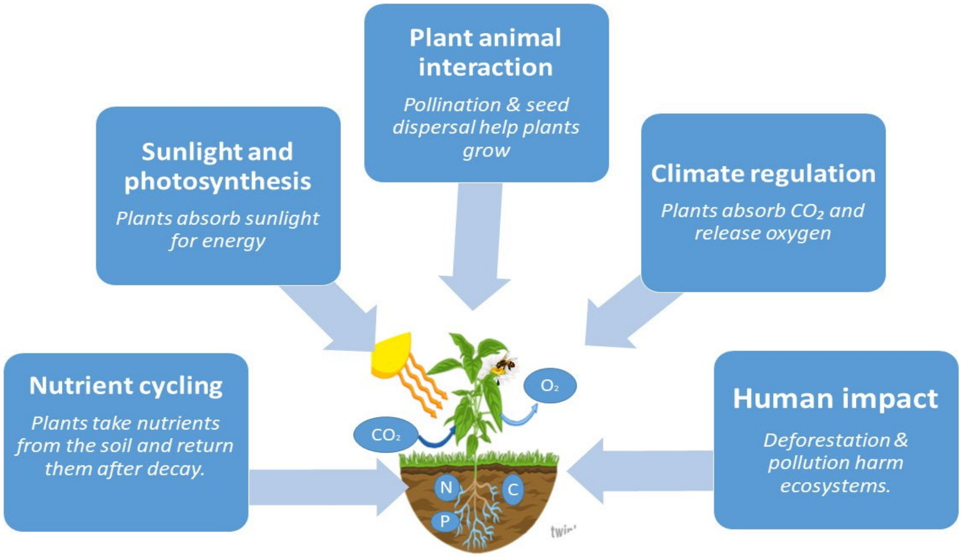
Keywords: biogeochemical cycles, climate change, ecosystem, photosynthesis, plant-soil interaction

Highlights

- For the conversion of solar radiation into chemical energy, plants favor intricate food webs and serve as the foundation for ecologic trophic systems which, in turn, drives primary production effectively.
- Through various biogeochemical cycles, such as nitrogen, phosphorous, and carbon cycle, vegetation arbitrates vital nutrient fluxes that helps to maintain balance and atmospheric gas exchange in ecosystem.
- The symbiotic relationships between plant root systems and soil microbes enhance soil structure, nutrient uptake, and resilience of ecosystem in general.

*Corresponding Author: ayesha.mmg@pu.edu.pk

GRAPHICAL ABSTRACT



1. INTRODUCTION

The biotic components in a particular place interact with each other and with other abiotic components facilitating the exchange of matter and energy constituting the ecosystem [1]. The abiotic components include sunlight, water, air, pH, temperature, salinity, altitude, humidity, nutrients, minerals, and wind, while flora, fauna, and microbes are the biotic components that form the ecosystem [2]. Since biodiversity is known to be essential to ecosystem functioning, it may have a positive impact on the delivery of services by ecosystems that benefit society [3]. Plants are vital to the ecosystem's functioning since they are the first trophic level. In terrestrial ecosystems, plants are crucial for both structural and functional reasons. They comprise both food webs and basic food chains. Due to the fact that plants have roots, the soil over Earth's layers that are mellowing (composting) is held down by the roots, which network and enrich the habitat. Organic substrates are created when microbes and small animals settle there. These organisms then alter the parent substrate to produce nutrients that green plants may absorb [4].

The majority of terrestrial ecosystems are found on the Earth's major landmasses and are dominated by plants. Despite making up a very small portion of the planet's surface, plants play a crucial role in biology because they are able to absorb, process, and store solar energy [5]. Over 255 thousand plant species have been described to date. Out of these, over 20,000000 are flowering plants, 10,000 ferns, over 25,000 mosses, and roughly 18,000 algae [6]. The main concerns of ecology include plant diversity, richness, abundance, and distribution of species in a local or regional environment during various spatiotemporal scales [7]. In order to forecast ecosystem function and to predict future ecological dynamics and human-induced disturbances (e.g., habitat loss, biological invasions), knowledge of the biosphere also necessitates an understanding of, or the prediction of, the structuring processes of plant diversity [8].

Terrestrial plants are essential to the remaining carbon and energy flows in the system. This is because they serve as the principal designers and builders of the vast, durable features of the earth's surface. Plants are essential for controlling the movement of gases, nutrients, and heat at the surface of the earth in secular time [9]. Furthermore, plants have a crucial role in adjusting the productivity of ecosystems during times of relief. They have a cumulative influence on the abiotic environment and, consequently, on terrestrial ecosystems due to their need to reclaim the energy they have previously collected. In this capacity, plants aid in the determination of fundamental terrestrial characteristics including temperature, humidity, and gas composition [10].

Plants also aid in the determination of other atmospheric characteristics, such as wind and patterns of aerial precipitation. By all of this, they continue to be important to the soil, the climate, and the delicate balance of complex webs of life including the terrestrial landscape, the animals, and plants they coexist with, as well as humanity [11]. Due to the fact that they employ photosynthesis to absorb solar energy and convert it into organic molecules that nourish a wide variety of different organisms, plants are at the base of the food chain. In addition to giving the plants themselves nourishment, these organic compounds are the main source of energy and nutrition for a wide variety of heterotrophic creatures, such as herbivores, detritivores, and decomposers [12]. By studying the position of plants in the terrestrial ecosystems and the complex relationships between plants and their surrounding world, it may be possible to discover more important functions of plants for the life that depends on them.

1.1. Photosynthesis and Primary Production

Photosynthesis employs inorganic oxidized carbon molecules with low energy, such as CO_2 or H_2O and light energy in the synthesis of carbohydrates, for instance, glucose and oxygen. This is an activity done by green plants and algae as well as by some bacteria. It is the fundamental process by which chemical energy is created and stored as glucose, in the form of triphosphate. This process results in the storage of chemical energy in the form of glucose, a precursor for organic compounds like nucleotides and lipids. By mitochondrial respiration, this stored energy is used to produce cellular energy carrier the adenosine triphosphate (ATP) [13]. This stored chemical energy is requisite for the existence of all living organisms, including consumers of energy-rich plant compounds, such as bullocks, humans, and other herbivorous animals [14]. The process of photosynthesis also enables the better understanding of bioenergetics in living systems.

About 10% of photosynthesis worldwide is produced by terrestrial plants, the bulk of which are found in aquatic habitats including lakes, ponds, and oceans. While stems and other green sections of terrestrial plants may also undertake photosynthesis, leaves are the main organs responsible for this process [15]. The primary photosynthetic pigment, chlorophyll, transmits and reflects green light by absorbing light energy mostly in the visible spectrum's blue and red portions [16]. Chlorophyll is found in chloroplasts in chlorenchymatous cells, which have a high concentration of chloroplasts and are specialized for photosynthesis. The pigment-protein complexes that make up photosystems I and II are found in every chloroplast. These photosystems absorb light energy and route it towards electron acceptors, where redox processes result in the synthesis of ATP and NADPH. After that, these energy molecules are employed in the chloroplast stroma, which has the enzymes required for the synthesis of carbohydrates, for carbon fixation, and other metabolic processes [17]. In photosystem II (PSII), photosynthesis starts when photons are absorbed. This excites the electrons in chlorophyll and causes water molecules to break (photolysis), which releases protons and oxygen. Protons are subsequently pumped into the thylakoid lumen by protein complexes, for instance, the cytochrome B6f complex, which allows electrons to enter the Electron Transport Chain (ETC) and create a proton gradient. ATP synthase, which is propelled by this gradient to promote ATP synthesis through chemiosmotic photophosphorylation, returns protons to the stroma [18]. Absorbing photons in photosystem I re-excite electrons, which are subsequently transported to ferredoxin and NADP+ reductase, resulting in the production of NADPH [19]. The Calvin cycle uses the produced ATP and NADPH to fix carbon. Light availability, thylakoid membrane organization, and regulatory proteins all play a role in controlling the efficiency of light-dependent reactions (Figure 1). This results in the best possible energy conversion and defense against photo damage via processes including non-photochemical quenching [20].

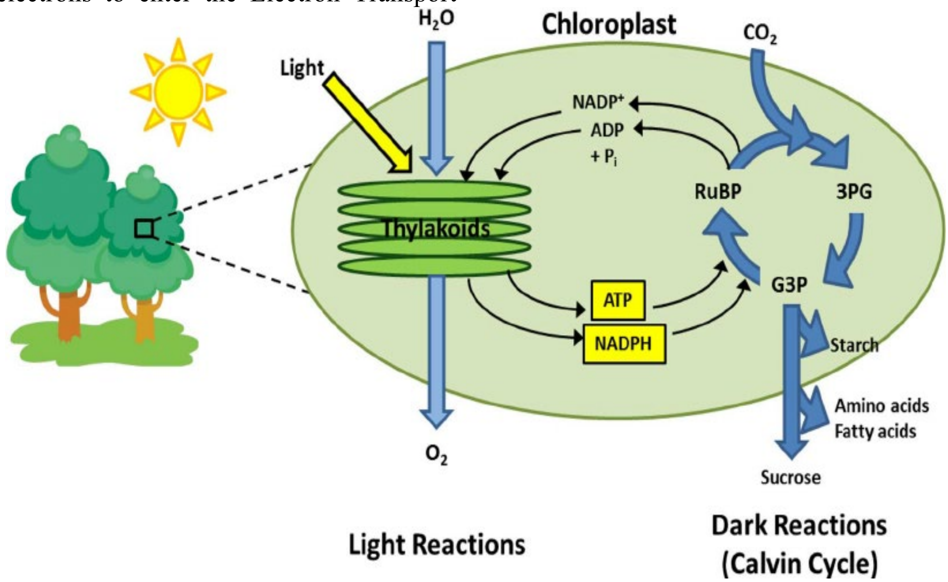


Figure 1. The Pathway of Photosynthesis Following Light and Dark Reactions [21]

2. NUTRIENT CYCLING

Nutrients fall into two basic categories: (1) inorganic substances, which autotrophic animals require for metabolism and photosynthesis, and (2) organic substances, which heterotrophic creatures devour [22]. Plants take up a wide variety of inorganic nutrients from their environment, most of which are simple molecules. Carbon, for instance, comes from the environment to most plants as gaseous carbon dioxide (CO_2); nitrogen comes from ions (charged molecules) as ammonium ($NH^{4+)}$ or nitrate (NO^{-3}); phosphorus comes from phosphate (PO_4^{-3}); and calcium and magnesium come from simple ions (Ca^{2+} and Mg^{2+}) (Figure 2). Plant roots take up ions from the soil water as they break down. Plants need these various resources for photosynthesis and other metabolic activities to produce all the biochemicals needed for growth and reproduction [23].

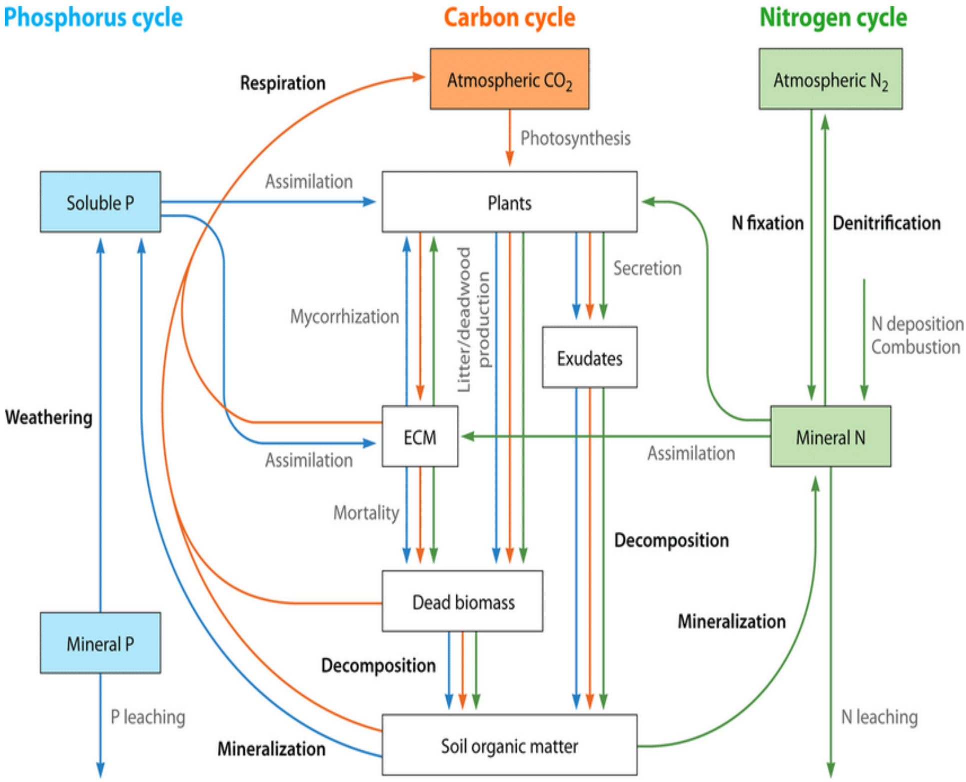


Figure 2. Diagrammatic View of Nutrient Cycling Involving Plants Activity in Phosphorous, Carbon, and Nitrogen [24]

Despite making up over 80% of the earth's atmosphere, nitrogen gas (N_2) is the nutrient that impedes primary production in many ecosystems. Since nitrogen gas cannot be utilized by plants or animals in that state, it is a very stable molecule that requires considerable energy to break due to the strength of triple bond that connects the nitrogen atoms to one another [25]. Before nitrogen can be utilized as a constituent in proteins, DNA, and other compounds that are essential to biological activities, it must first undergo a chemical transformation. The process of converting nitrogen into nitrogen that is absorbed by living things is known as nitrogen fixation [26]. Leguminous plants in symbiosis with nitrogen fixing bacteria, for instance, Rhizobium mostly perform this function. In addition to giving the host plants the necessary nitrogen, this process enriches the soil with nitrogen molecules, which benefits the nearby vegetation and improves soil fertility overall. In advance to fixing nitrogen, plants also affect the nitrogen cycle by absorbing it, assimilating it, and breaking down trash [27]. Through their roots, plants take up inorganic nitrogen forms from the soil, such as nitrate (NO_3^-) and ammonium (NH_4^+). Following their assimilation, these substances form organic molecules that are necessary for the growth and development of plants, such as proteins and amino acids. The organic nitrogen in plant tissues returns to the earth as litter when a plant dies or sheds its leaves. This organic nitrogen is broken down by bacteria into inorganic forms, completing the nitrogen cycle and allowing subsequent plants to absorb it. Through these processes, plants act as both sinks and sources of nitrogen, maintaining the balance and flow of this essential nutrient within ecosystems [28].

Two different mechanisms through w hich plant species affect the nitrogen cycle in ecosystems have been suggested. Initially, variations in the efficiency of nitrogen usage may result in favorable feedbacks on the nitrogen cycle rate [29]. Despite being abundant, most of the nitrogen in the atmosphere is in the inert form nitrogen (N_2), which is not directly used by plants. Thus, the most common nutrient that inhibits plant growth is nitrogen. More recently, it has also been shown that plants can take up nitrogen in a range of organic forms. Plants may absorb and grow from a wide range of dissolved organic nitrogen forms, ranging from simple, low molecular weight compounds (like amino acids, oligopeptides, nucleotides, and urea) to more complicated polymeric components (like proteins) [30]. As an alternative, plant species can regulate the amount of nitrogen that enters and leaves ecosystems. The microbial biomass absorbs the nitrogen that is released by the organic materials in the soil.

Numerous studies have demonstrated how different plant species affect nitrogen inputs and losses, such as atmospheric deposition, losses caused by fire, nitrogen leaching, and nitrogen fixation which is accomplished by plants providing nitrogen fixers with carbon. The nitrogen is reincorporated into the soil's organic matter after they die [31].

Additionally, it has been demonstrated that plants have a range of coping strategies to deal with nitrogen limitation, such as reorganizing and recruiting microbial communities that cycle nitrogen. Variations in nitrification, denitrification, and trace nitrogen gas losses could arise from these techniques. By means of biological nitrogen fixation, a diverse array of bacteria may transform atmospheric nitrogen into ammonia [32]. Different plants create mutualistic connections to use this function. In order to accomplish this, they release signals in the form of secondary metabolites, which liberate living bacteria that fix nitrogen and enable them to enter roots. The mutualism causes nodules, a new organ on the root of the plant, to form. The bacteria inside the nodules receive photosynthetically-fixed carbon from the plants, and in exchange, the bacteria provide the host plant with fixed nitrogen. Plant species may also influence the behavior of herbivores, which could result in the animal-facilitated transfer of nitrogen between ecosystems [33].

The phosphorus cycle is the least accessible macronutrient in the majority of natural terrestrial ecosystems. This is because the main forms of phosphorus in soils have very poor solubility and are quickly removed by chemical immobilization mechanisms. Moreover, this is one of the slowest biogeochemical cycles on the planet, which cycles from rocks to terrestrial and aquatic systems, ocean sediments, and back again during geologic aeons. It plays a crucial role in the construction of phospholipid membranes, energy-carrying molecules, for instance, adenosine triphosphate, and several biological macromolecules [34]. It is also necessary to feed crops. It is constantly cycled in ecosystems in a number of ways. However, the availability of soil phosphorus to plants is negatively impacted by soil phosphorus pools (dissolved organic, inorganic, and microbial biomass phosphorus) that are outside the range of plant detection and absorption. Additionally, certain intrinsic soil elements (pH, Al, Fe, and Ca oxides/hydroxides) might play a role in the synthesis of strong phosphorous sorption compounds and, thus, lower the phosphorous content available to plants [35]. Recently, there has been a considerable focus on the role played by plants in the acquisition of nutrients and the necessity of an integrated approach to study phosphorous cycling. In many natural terrestrial ecosystems, plant development is restricted by low phosphorus availability, especially when input sources are insufficient to meet the high phosphorus requirements of biomass from living plants. It is a well-known fact that a root's interactions with its immediate soil environment are influenced by the characteristics of the plants that are in close proximity [36]. The compounds released by roots represent a significant "internal" phosphorus loss component in some ecosystems. The broad differences in the make-up and rates of exudation of roots lend credence to the concept that root-mediated processes are tightly controlled by plants [37].

Plants absorb CO_2 from the atmosphere through photosynthesis and incorporate it into their biomass as organic matter. This process, apart from contributing to soil organic matter formation by the decomposition of dead plants, further decreases the atmospheric concentration of one of the most potent greenhouse gases, CO_2 [38]. Since they absorb more CO_2 than they emit, forests, grasslands, and other terrestrial ecosystems are important carbon sinks. Photosynthesis, respiration, and carbon sequestration processes in plants and soils are crucial to stabilize global climate systems. This reduces the effects of anthropogenic carbondioxide emissions from the combustion of fossil fuels and deforestation [39].

3. PLANT SOIL INTERACTIONS

Plants are influenced by abiotic factors, such as the composition of soil, the availability of water, temperature, and gases in the atmosphere, all of which determine ecosystems. Various plant species have adapted to live in unique environmental conditions [40]. Legumes enrich the fertility of soil by fixing atmospheric nitrogen, and acid-resistant plants, such as pines grow well in poor soil. Desert plants, such as succulents, store water within their tissues, while rainforest plants possess large leaves to allow for the collection of most sunlight in dense canopies. Vegetation impacts local climates; forests control temperature and humidity, whereas grasslands avert soil erosion and desertification [41].

Plants have been playing a pivotal in the development of ecosystems for millions of years. The first land plant life, including ferns and mosses, helped form soil by decomposing rocks and capturing organic particles. Furthermore, plants developed deeper roots over time to anchor soil, reserve water, and enhance nutrient uptake [42]. Most contemporary plant species have evolved symbiotic relationships with microbes, for instance, nitrogen-fixing bacteria, to increase soil fertility [43]. Plants have also evolved to suit various environmental conditions—for instance, drought-tolerant plants including cacti have evolved water-storing tissues, while mangroves have evolved specialized root systems to thrive in salt environments. These evolutionary changes allow plants to promote ecological balance, control climate, and support biodiversity [44].

The accumulative properties of soil are influenced by both natural biota, such as plants and larger animals. Many aspects of the soil that are essential to plant growth and survival are influenced by plants. Since the physical and chemical properties of the soil change across the succession, plants are affected by these changes, particularly in the primary succession. Plants have the power to alter soil pH, microbiological populations, and nutrient availability, particularly for phosphate and nitrogen [45]. These interactions are necessary for both plant development and ecological production. The diversity and make-up of plant communities can be influenced by the effects that various plant species have on the soil. Due to their shared evolutionary past, plants and soil organisms have evolved mutual adaptations that improve nutrient uptake and efficiency. These evolutionary processes shape the capabilities and composition of ecosystems across time. Specific plant species are capable to alter the chemistry of soil and have an impact on microbial activity which, in turn, may affect plant health and nutrient intake. They can also release different organic chemicals into the soil through their roots. Furthermore, plant litter and root turnover influence soil fertility and plant growth via cycling nutrients within ecosystems [46].

Global biogeochemical and hydrological cycles are centered on plant-soil interactions. Additionally, land use and climate change have the potential to significantly affect how these interactions affect the feedback of greenhouse gases between the biosphere and atmosphere. Plant fitness greatly depends on the ability of roots to anchor land plants in the soil and to efficiently absorb water and mineral nutrients [47]. The root system is composed of both embryonic and postembryonic roots. Plant resource accessibility is largely determined by the Root System Architecture (RSA), which is the general spatial arrangement of the various parts of the root system. RSA) is highly flexible in terms of genetics and environment. Resultantly, depending on the current soil conditions, different species or ecotypes have evolved distinct RSA. This is because short-term environmental signals, such as variations in the availability of water, nutrients, and oxygen, or pests and diseases, can affect the rate at which individual parts of the root system develop and grow. Significantly different RSA may also be adopted within the same genotype and even within the life span of a single plant [48]. Plants are unable to relocate from undesirable locations, in contrast to mammals. Therefore, they need complex sensing and signaling mechanisms to respond to changing soil conditions since they influence growth and development. Although, considerable research has been conducted on the processes governing RSA responses to specific nutrients, particularly nitrogen (N) and phosphorus (P), little is known about the interactions between various nutritional signals and the advantages of RSA responses under specific conditions [48].

The vast majority of terrestrial plants have evolved different mutualistic connections, which involve the physical integration of symbiotic partners into specialized root structures, with the assistance of fungus and bacteria (Figure 3). With 70–90% of all living species, arbuscular mycorrhizal fungi belonging to the phylum Glomeromycota are involved in the oldest and most common kind of plant symbiosis. It is estimated that the start of this kind of symbiosis occurred 460 million years ago. Fungal mycelia make-up to 20% of the carbon obtained from photosynthetic processes. This is because they can develop up to 100 m of hyphae per cubic centimeter of soil and may pierce soil pores that are inaccessible to plant roots. Microbial community structure and plant performance are strongly influenced by interactions between plants and microbes, whether they occur above or below the ground. Numerous soil microbial symbionts form associations with plants that enhance their nourishment [49].

Since over 90% of terrestrial plants generate mycorrhizae—associations between soil fungus and plant roots—mycorrhizal symbiosis is the most common type of association. Water and mineral nutrients that the fungal companion has gathered from the soil are given to the plant in a mycorrhiza. Plant roots create tight relationships with symbiotic microbes, such as bacteria and fungi, which improve nutrient uptake, growth, and resistance to environmental stressors [50]. By creating hyphal networks, mycorrhizal fungi help plants grow longer roots, which increases the surface area available to absorb nutrients and water, especially phosphorus. The plants provide the fungal glucose and other organic chemicals in exchange. Mycorrhizal fungi provide their host with protective properties that stem from enhanced nutrition as well as more specialized interactions [51].

Research on the metabolic processes associated with nitrogen as well as the ways in which plants absorb, transport, and utilize this nutrient has long been of interest. Nitrogen also affects the soil microbiota since microorganisms take part in the nitrogen cycle, particularly when it comes to the biological application of nitrogen. The impact of the microbiota on the plant's nitrogen metabolism, therefore, needs to be investigated after the discovery of nitrogen fixing microbes. Additionally, symbiotic microbes may strengthen plant defenses against infections [52]. As an example, certain beneficial bacteria and fungi have the ability to create antimicrobial chemicals or cause plants to develop systemic resistance, both of which have protective effects. These symbiotic connections have wider ecological ramifications that support plant diversity and ecosystem stability. Symbiotic microbes are essential to the health and productivity of plant communities as well as the habitats they live in as they enhance plant health and productivity [53].

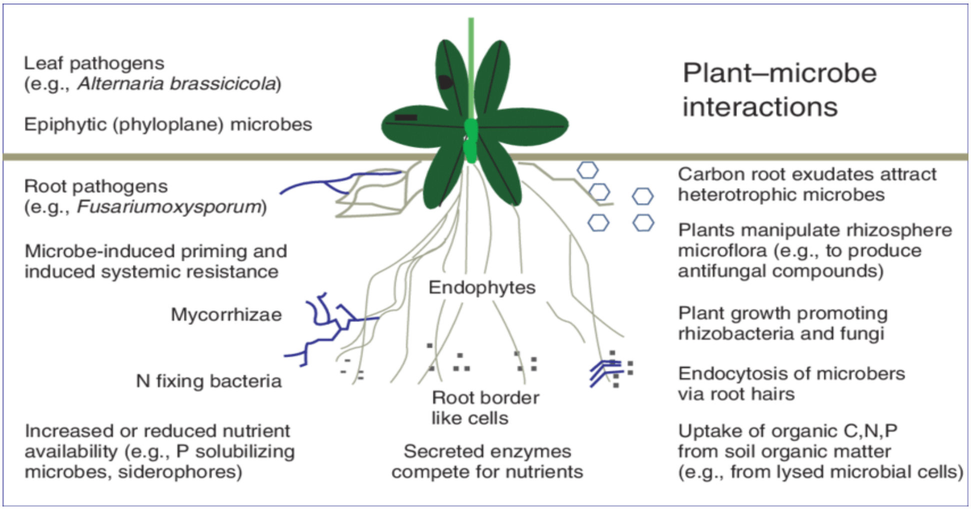


Figure 3. Scheme of Plant Microbe Interaction [49]

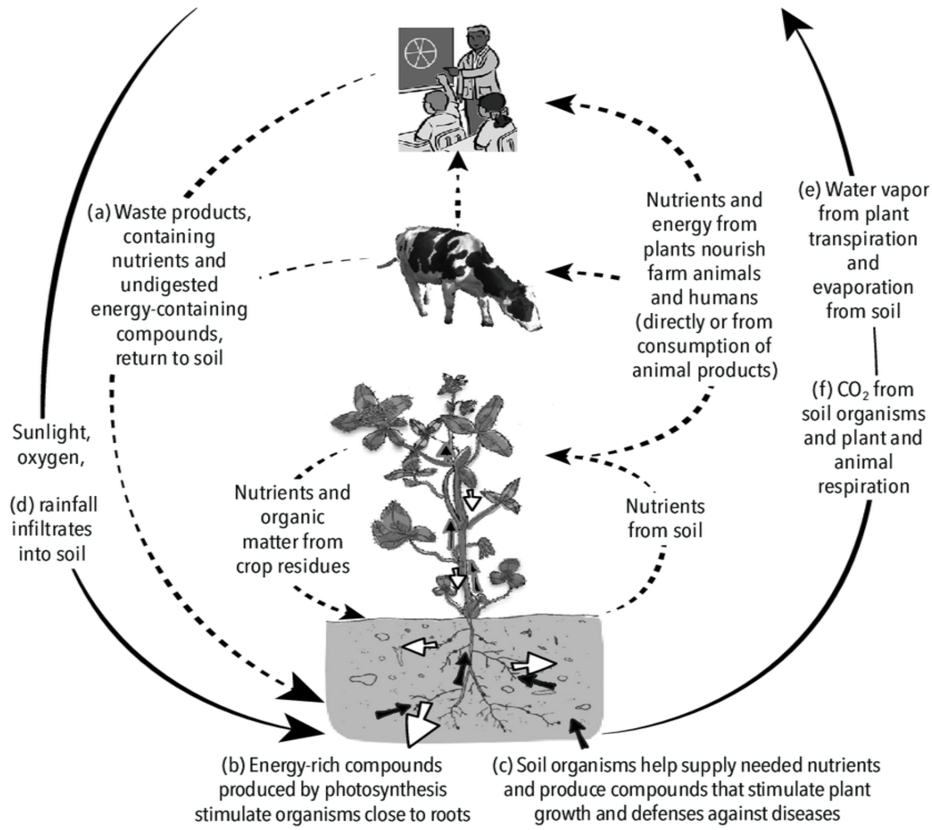


FIGURE 4. Interaction of Plants, Animals, and Soil Components [52]

4. PLANT-ANIMAL INTERACTIONS

The intricate relationship between plant resource competition and herbivory determines how these two factors impact plant biomass and growth. Herbivory and competition have mutually reinforced effects that may either intensify or lessen their effects on plants. Significant roles are played in these interactions by the geographical scales of plant community heterogeneity and herbivore behavior, which impact plant performance and community dynamics (Figure 4). This detailed knowledge makes it easier to forecast how plants would react in different ecological situations [54]. Focusing on mutualistic relationships, such as seed dispersal and pollination, the complex web of interactions between plants and animals revealed that these interactions form network structures that may be classified into various patterns, such as nested, modular, and compartmentalized structures. The stability and functionality of ecosystems depend heavily on these patterns. The way these interaction networks are structured could have a considerable impact on ecological processes [55].

5. PLANT-PLANT INTERACTIONS

Plant-plant interaction is one of the key mechanisms that control how different plant species and communities react to these drivers. It is central to understanding how plant communities' function and evolve. The interactions between plants are typically divided into two broad categories: competition and facilitation [56]. Two or more plants compete for the same resources, such as light, water, or nutrients. For instance, in a dense forest, bigger trees might shade out small plants and, therefore, only be able to thrive at one or a few light regimes. Conversely, facilitation is typified by an interaction wherein one plant species benefits the other; stress often defines these interactions; for instance, some provide shade, shelter, or alter the soil to suit the living conditions of neighbors [57]. Other mechanisms related to plant-plant interactions, such as facilitation and evolutionary processes, are also being acknowledged as critical elements to assess the effects of environmental change. Plant-plant interactions, however, are not the only factors influencing how species and communities react to drivers of environmental change. Their activity needs to be understood in the context of many different factors that control ecosystems, communities, and species. Plants are not passive organisms; they actively acquire and respond to environmental information. Moreover, they have evolved mechanisms to detect environmental cues, for instance, light and chemical signals. These systems help plants make decisions about resource allocation, growth, and defense. Besides this, light quality and quantity are crucial for plant growth. Plants can detect changes in light caused by the presence of neighboring plants, for instance, through phytochromes. Shade avoidance responses are triggered by detecting reduced red to far-red light ratios. Plants release and detect volatile organic compounds (VOCs and root exudates). These chemicals can signal the presence of other plants, triggering defensive or competitive responses [58]. Plants can alter their growth patterns (e.g., stem elongation, leaf angle) in response to detected signals. These morphological changes may enhance light capture or reduce competition. The interactions between plants are dynamic and influenced by the information acquired from the environment. Plants use the acquired information to optimize resource use and minimize the negative impacts of competition. Information-acquiring systems play a critical role in these interactions by providing the necessary data for adaptive responses. Information-acquiring systems are integral to plant life, affecting interactions with neighboring plants and overall ecological outcomes [59].

In some way, tropical alpine environments are characterized by harsh conditions, such as high radiation, cold temperatures, and nutrient-poor soils. These conditions create unique challenges for plant interactions. In stressful environments, such as tropical alpine regions, facilitative interactions (where one plant benefits another) are often more prevalent than competitive interactions. Facilitation might include shading, wind shelter, and nutrient enrichment. A nurse plant is one that provides conditions for the colonization and growth of other species. They often create microhabitats that reduce hostile environmental conditions. The structure of communities and species richness can be strongly affected by the presence of nurse plants. Positive interactions, which include mutualism and commensalism, prevail in tropical alpine habitats [60]. Such interactions may lead to the formation of plant clusters or communities where species live together and help each other.

With plant ontogeny, the relative levels of facilitation and competition may also alter. This is because seedlings may be more susceptible to abiotic stress during the early ontogenetic phases, facilitation may be especially crucial. Given that larger plants have deeper root systems and more carbon stored in their storage organs, which enable them to withstand periods of environmental stress, competition may rise with plant size [61]. On the other hand, when adverse environmental occurrences, smaller seedlings are correspondingly more sensitive. All plant communities may be experiencing both competition and facilitation, however, each may mask the relative strengths of the other. Consequently, the result of plant interactions could be the culmination of competition for scarce resources as well as facilitation brought about by improved microclimate. Similarly, competitive release could be the reason behind a neighbor removal's beneficial impact on a single plant's performance.

6. HUMAN IMPACTS ON PLANT-ECOSYSTEM INTERACTIONS

Plant, ecosystem, and human health is intricately connected—a framework termed as ‘One Health’. Plants control atmospheric gases, reducing air pollution and climate change, which affects human respiratory health directly. Forests and green areas also promote mental health and yield medicinal compounds vital for medicine. Plant ecosystem destruction by deforestation and urbanization upsets ecological balance, raising the likelihood of zoonotic diseases, loss of biodiversity, and food insecurity [62]. Encouraging sustainable agriculture, reforestation, and conservation policy is in harmony with the One Health approach to ensure environmental, human, and animal health. The appreciation of the critical importance of plants to planetary health may inform more successful conservation efforts, which are to the benefit of nature and society [63].

Human-induced global changes in climate, nutrient cycling, and species invasions are altering terrestrial plant community composition and dynamics with cascading effects on ecosystems (Figure 5). While broad changes in aboveground plant community composition have been documented at large spatial scales, impacts on plant composition and growth patterns would likely be more pronounced at local scales. Recent research has demonstrated that organic amendments and the presence of native insects greatly alter plant community composition, growth, and productivity at a local scale. These strong interactive effects of land use and insect presence on community-level properties suggest that previously-landscaped and insect-free systems may experience a further reduction in productivity due to an increase in nutrients and invasive. This, in turn, would initiate feedback between plant community dynamics and ecosystem functioning [59]. Such feedback effects between aboveground plant communities and belowground nutrient cycling, however, still demand rigorous testing. Beyond this conceptual framework to understand plant-community-landscape-system dynamics, recent advances in the understanding of plant interactions with herbivores, pathogens, and microbes, as well as biophysical effects on communities, may lead to a more complete picture of plant interactions within ecosystems [60]. As a result of human activities on ecosystems, deforestation and climate change are closely-related effects that exacerbate one another and jeopardize the stability of the environment globally. Large areas of forest land are lost due to deforestation, which is mostly caused by logging, urbanization, and agriculture. This drastically lowers the earth's ability to store carbon [61]. By absorbing CO_2 from the atmosphere during photosynthesis, forests function as carbon sinks. Destroyed trees not only lose their capacity to absorb carbon but also release the carbon they had previously stored back into the atmosphere, increasing greenhouse gas concentrations. Resultantly, both global warming and climate change get worse [62].

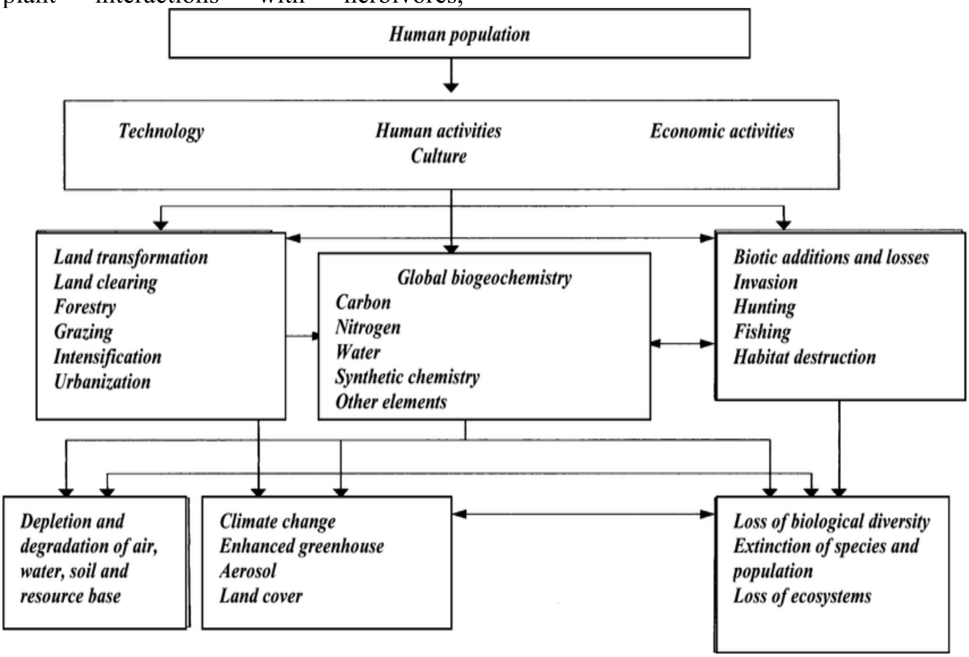


Figure 5. Human Impact on Natural Systems [63]

It is important to adopt sustainable management and conservation practices, such as ecological restoration, agroforestry, and conservation planning, for the preservation of plant ecosystems. These strategies help in reintegrating the original biodiversity, nutrient cycles, and the services provided by the ecosystems, while the public involvement maximizes the success of the conservation strategies that are put in place.

7. CONCLUSION

The current study concluded that plants are present in every terrestrial ecosystem and they aid other biotic and abiotic components to interact with one another in intricate ways. For instance, they harness the light energy from sun through photosynthesis for the chemical energy required in primary production which, in turn, fuels the food chain. This is because they are involved in nutrient cycling, especially in the case of gases, for instance, N, P, and C, which further their role in balancing the biosphere and global changes including the mitigation of climate change. To add on this, how plants interact with their pollinators, herbivores, soil microbes, and even other plants create interactions, ensuring that ecosystems remain stable and diverse. Nevertheless, such interactions between plants and ecosystems are under serious threat due to human activities, such as deforestation, climate change, and invasive species. Changes in any of these interactions would have a chain of negative implications on biodiversity, climate stability, and the provision of ecosystem services. Therefore, the conservation and management of the environment in which we live would not be adequate without understanding and appreciating the role of plants in ecosystems. By promoting restoration ecology and respect for the environment, these impacts can be reduced and it may be ensured that plants continue to live while supporting the very intricate biological systems that depend on them.

CONFLICT OF INTEREST

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

DATA AVAILABILITY STATEMENT

The data associated with this study will be provided by the corresponding author upon request.

FUNDING DETAILS

No funding has been received for this research.

REFERENCES

1. Verma, AK. Necessity of ecological balance for widespread biodiversity. *Ind J Biol*. 2017;4(2):158–160.

2. Kumar KA, Karthika KS. Abiotic and biotic factors influencing soil health and/or soil degradation. In: Giri B, Varma A, eds. *Soil Health.* Springer; 2020:145–161.

3. Quijas S, Schmid B, Balvanera P. Plant diversity enhances provision of ecosystem services: a new synthesis. *Basic Appl Ecol.* 2010;11(7):582–593. https://doi.org/10.1016/j.baae.2010.06.009

4. Chen Y, Huang X, Lang X, et al. Effects of plant diversity, soil microbial diversity, and network complexity on ecosystem multifunctionality in a tropical rainforest. *Front Plant Sci.* 2023;14:e1238056. https://doi.org/10.3389/fpls.2023.1238056

5. Liao Z, Zhou B, Zhu J, Jia H, Fei X. A critical review of methods, principles

and progress for estimating the gross primary productivity of terrestrial ecosystems. *Front Environ Sci.* 2023;11:e1093095. https://doi.org/10.3389/fenvs.2023.1093095

6. Christenhusz MJ, Byng JW. The number of known plants species in the world and its annual increase. *Phytotaxa*. 2016;261(3):201–217. https://doi.org/10.11646/phytotaxa.261.3.1
7. Tilman D, Isbell F, Cowles JM. Biodiversity and ecosystem functioning. *Ann Rev Ecol Evol Syst.* 2014;45(1):471–493. https://doi.org/10.1146/annurev-ecolsys-120213-091917
8. Newbold T, Hudson L, Hill S, et al. Global effects of land use on local terrestrial biodiversity. *Nature*. 2015;520:45–50. https://doi.org/10.1038/nature14324
9. Keller CK. Carbon exports from terrestrial ecosystems: a critical-zone framework. *Ecosystems*. 2019;22(8):1691–1705. https://doi.org/10.1007/s10021-019-00375-9
10. Piao S, Yue C, Ding J, et al. Perspectives on the role of terrestrial ecosystems in the 'carbon neutrality' strategy. Sci. *China Earth Sci.* 2022;65:1178–1186. https://doi.org/10.1007/s11430-022-9926-6
11. Kanta C, Kumar A, Chauhan A, Singh H, Sharma IP. The interplay between plant functional traits and climate change. In: Kumar N, Singh H, eds. *Plant Functional Traits for Improving Productivity*. Springer; 2024:41–58.
12. Yao Z, Xin Y, Yang L, Zhao L, Ali A. Precipitation and temperature regulate species diversity, plant coverage and aboveground biomass through opposing mechanisms in large-scale grasslands. *Front Plant Sci.* 2022;13:e999636. https://doi.org/10.3389/fpls.2022.999636
13. Suresh G, Sharma P, Kumari A. Fundamentals of crop photosynthesis. *Crop Physiol: Collab Insights*. 2023:1:1–29.
14. Sharkey TD. Emerging research in plant photosynthesis. *Emerg Topics Life Sci*. 2020;4(2):137–150. https://doi.org/10.1042/ETLS20200035
15. Matthews ML. Engineering photosynthesis, nature's carbon capture machine. *PLoS Biol.* 2023;11;21(7):e3002183. https://doi.org/10.1371/journal.pbio.3002183
16. Shevela D, Bjorn LO. *Photosynthesis: Solar Energy For Life*. World Scientific Publishing; 2018.
17. Taiz L, Zeiger E. *Plant Physiology*. Sinauer Associates, Inc; 2006.
18. Orr L, Govindjee. Photosynthesis web resources. *Photosynth Res.* 2013;115:179–214. https://doi.org/10.1007/s11120-013-9840-3
19. Alberts B, Heald R, Johnson A, et al. *Molecular Biology of the Cell: Seventh International Student Edition with Registration Card*. WW Norton & Company; 2022.
20. Mandal R, Dutta G. From photosynthesis to biosensing: chlorophyll proves to be a versatile molecule. *Sens Int*. 2020;1:e100058. https://doi.org/10.1016/j.sintl.2020.100058
21. Rasmussen M, Minteer SD. Photobioelectrochemistry: solar energy conversion and biofuel

production with photosynthetic catalysts. *J Electrochem Soc*. 2014;161(10):eH647. https://doi.org/10.1149/2.0651410jes

22. BassiriRad H, ed. *Nutrient Acquisition By Plants: An Ecological Perspective*. Springer; 2005.
23. Paul EA. Soil microbiology, ecology, and biochemistry: an exciting present and great future built on basic knowledge and unifying concepts. *Soil Microbiol Ecol Biochem*. 2014;14:1–3.
24. Lladó S, López-Mondéjar R, Baldrian P. Forest soil bacteria: diversity, involvement in ecosystem processes, and response to global change. *Microbiol Mol Biol Rev*. 2017;81(2):e00063-16. https://doi.org/10.1128/mmbr.00063-16
25. Hopkins W, Hiiner NPA. *Introduction to Plant Physiology*. John Wiley and Sons; 1999.
26. Kramer SB. *Nitrogen, Microbes and the Human Predicament: The Ecology and Relevance Of Nitrogen Recycling* (dissertation). Stanford: Stanford University; 2006.
27. Finan TM, ed. *Nitrogen Fixation: Global Perspectives: Proceedings of the 13th International Congress on Nitrogen Fixation, Hamilton, Ontario, Canada. 2001*. CABI; 2002.
28. Kim HT. *Principles of Soil Chemistry*. CRC Press; 2010.
29. Cain ML, Bowman WD, Hacker SD. *Ecologia*. Artmed Editora; 2017.
30. Schepers JS, Raun W, eds. *Nitrogen in Agricultural Systems*. Asa-CSSA-Sssa; 2008.
31. Chapin FS, Mcguire AD, Randerson J, et al. Arctic and boreal ecosystems of western North America as components of the climate system. *Glob Change Biol*. 2000:211–23. https://doi.org/10.1046/j.1365-2486.2000.06022.x
32. de Bruijn FJ. "Biological Nitrogen Fixation" book summary. *Adv Microbiol*, 2016;6(6):e66453. https://doi.org/10.4236/aim.2016.66040
33. Mus F, Crook MB, Garcia K, et al. Symbiotic nitrogen fixation and the challenges to its extension to nonlegumes. *Appl Environ Microbiol*. 2016;82(13):3698–3710. https://doi.org/10.1128/AEM.01055-16
34. Bünemann EK, Oberson A, Frossard E, eds. *Phosphorus in Action: Biological Processes in Soil Phosphorus Cycling*. Springer; 2010.
35. Lal R, Stewart BA. *Soil Phosphorus*. CRC Press; 2016.
36. Sims JT, Sharpley AN. *Phosphorus: Agriculture And The Environment*. American Society of Agronomy; 2005.
37. Valsami-Jones E. *Phosphorus in Environmental Technology*. IWA Publishing; 2004.
38. Dessaux Y, Hinsinger P, Lemanceau P. *Rhizosphere: Achievements and Challenges*. Springer; 2010.
39. Narula N, Kothe E, Behl RK. Role of root exudates in plant-microbe interactions. *J Appl Botany Food Qual*. 2012;82(2):122–130.
40. Gavrilescu M. Water, soil, and plants interactions in a threatened environment. *Water*. 2021;13(19):e2746. https://doi.org/10.3390/w13192746
41. Hailu F. Climate change as a trigger for desertification and possible alternatives to reduce biodiversity loss.

J Selva Andina Biosphere. 2023;11(1):94–111.

42. Gregory PJ. RUSSELL REVIEW are plant roots only "in" soil or are they "of" it? Roots, soil formation and function. *Eur J Soil Sci*. 2022;73(1):e13219. https://doi.org/10.1111/ejss.13219
43. Sharma P, Sangwan S, Kaur H, Patra A, Anamika, Mehta S. Diversity and evolution of nitrogen fixing bacteria. In: Singh NK, Chattopadhyay A, Lichtfouse E, eds. *Sustainable Agriculture Reviews 60: Microbial Processes In Agriculture*. Springer Nature; 2023:95–120.
44. Muluneh MG. Impact of climate change on biodiversity and food security: a global perspective—a review article. *Agricul Food Sec*. 2021;10(1):e36. https://doi.org/10.1186/s40066-021-00318-5
45. Cardon ZG, Whitbeck JL, eds. *The Rhizosphere: An Ecological Perspective*. Elsevier; 2011.
46. Field CB, Fung IY. The not-so-big US carbon sink. *Science*. 1999;285(5427):544–545. https://doi.org/10.1126/science.285.5427.544
47. Lenton TM, Pichler PP, Weisz H. Revolutions in energy input and material cycling in Earth history and human history. *Earth Syst Dynam*. 2016;7(2):353–370. https://doi.org/10.5194/esd-7-353-2016
48. van Breemen N, Finzi AC. Plant-soil interactions: ecological aspects and evolutionary implications. *Biogeochemistry*. 1998;42:1–19. https://doi.org/10.1023/A:1005996009413
49. Gruber BD, Giehl RF, Friedel S, von Wirén N. Plasticity of the Arabidopsis root system under nutrient deficiencies. *Plant Physiol*. 2013;163(1):161–179. https://doi.org/10.1104/pp.113.218453
50. Smith SE, Read DJ. *Mycorrhizal Symbiosis*. Academic Press; 2010.
51. Carvalhais LC, Dennis PG, Tyson GW, Schenk PM. Rhizosphere metatranscriptomics: challenges and opportunities. *Mol Microbial Ecol Rhizosph*. 2013;1:1137–1144. https://doi.org/10.1002/9781118297674.ch109
52. Hambäck PA, Beckerman AP. Herbivory and plant resource competition: a review of two interacting interactions. *Oikos*. 2003;101(1):26–37.
53. Lampo A, Palazzi MJ, Borge-Holthoefer J, Solé-Ribalta A. Structural dynamics of plant–pollinator mutualistic networks. *PNAS Nexus*. 2024;3(6):epgae29 https://doi.org/10.1093/pnasnexus/pgae209
54. Magdoff F. Harmony and ecological civilization. *Monthly Rev*. 2012;64(2):1–9.
55. Callaway RM, Pugnaire FI. Facilitation in plant communities. In: Pugnaire F, Valladares F, eds. *Functional Plant Ecology*, CRC Press, 2007:435–456.
56. Callaway RM. *Positive Interactions and Interdependence in Plant Communities*. Dordrecht: Springer; 2007.
57. Bruno J, Stachowicz J, Bertness M. Inclusion of facilitation into ecological theory. *Trends Ecol Evol*. 2003;18:119–125.

58. Aphalo PJ, Ballare CL. On the importance of information-acquiring systems in plant-plant interactions. *Function Ecol*. 1995;9(1):5–14. https://doi.org/10.2307/2390084

59. Ballaré CL, Pierik R. The shade-avoidance syndrome: multiple signals and ecological consequences. *Plant Cell Environ*. 2017;40(11):2530–2543. https://doi.org/10.1111/pce.12914

Gómez-Aparicio L. The role of plant interactions in the restoration of degraded ecosystems: A meta-analysis across life-forms and ecosystems. *J Ecol*, 2009:97:1202–1214. https://doi.org/10.1111/j.1365-2745.2009.01573.x

61. Parmesan C. Ecological and evolutionary responses to recent climate change. *Annual Rev Ecol Evol Syst*. 2006;37:637–669. https://doi.org/10.1146/annurev.ecolsys.37.091305.110100

62. Gao D, Shen J, Gao Y, Zhang Z. The beneficial elements in forest environment based on human health and well-being perspective. *Forests*. 2024;15(9):e1604. https://doi.org/10.3390/f15091604

63. Varanasi U. Focusing attention on reciprocity between nature and humans can be the key to reinvigorating planetary health. *Ecopsychology*. 2020;12(3):188–194. https://doi.org/10.1089/eco.2020.0011