**Shodhpith**
**International Multidisciplinary Research Journal**
(International Open Access, Peer-reviewed & Refereed Journal)
(Multidisciplinary, Bimonthly, Multilanguage)
Volume: 1 Issue: 2 March-April 2025

# Role of Plants in Carbon Credit: A Botanical Perspective

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## Abstract:

The escalating challenges of climate change have intensified global focus on carbon mitigation strategies, prominently highlighting the concept of carbon credits. Within this paradigm, plants—particularly higher green plants—emerge as crucial agents in atmospheric carbon sequestration due to their innate photosynthetic capability. This research explores the botanical mechanisms and ecological roles of plants in contributing to carbon credit systems. From carbon dioxide assimilation to biomass accumulation and long-term carbon storage in roots, trunks, and soil, the study examines how various plant types—forests, mangroves, grasslands, and agroforestry systems—serve as effective carbon sinks. The paper further delves into the physiological attributes of plants, such as stomatal conductance, leaf area index, and net primary productivity (NPP), that influence their carbon capture efficiency. Special attention is given to native, fast-growing, and high-biomass-producing species suitable for afforestation and reforestation projects aligned with carbon trading schemes. The study also evaluates how plant diversity and ecosystem integrity contribute to long-term carbon storage and ecological balance. Botanical insights are crucial for enhancing the accuracy of carbon sequestration models, determining carbon offset potentials, and selecting species for climate-resilient carbon credit plantations. Moreover, this paper discusses the role of phytoremediation and carbon farming as emerging practices within sustainable agriculture and environmental policy frameworks. The integration of botanical research into national and international carbon credit mechanisms is proposed as a vital step towards achieving sustainable climate goals under the Paris Agreement. In conclusion, the botanical perspective provides a scientific foundation for optimizing the role of vegetation in carbon credit markets, thereby bridging the gap between plant science and environmental economics. The research advocates for increased interdisciplinary collaboration and policy support to realize the full ecological and commercial potential of plant-based carbon sequestration.

Keywords: Carbon credit, carbon sequestration, photosynthesis, net primary productivity (NPP), afforestation, phytoremediation, botanical carbon sinks.

## Introduction

The increasing concern over climate change and global warming has led to the formulation of various environmental policies and mechanisms at the international level, aimed at reducing greenhouse gas emissions. Among these mechanisms, the concept of carbon credit has emerged as a market-based tool to incentivize reduction in carbon dioxide ($CO_2$) emissions and encourage sustainable practices. In this framework, the role of plant science, especially in terms of the biological process of carbon sequestration, has received significant attention. Plants, through photosynthesis and biomass accumulation, play a vital role in capturing atmospheric carbon and storing it in various parts of their bodies and surrounding ecosystems. This intrinsic botanical function is now being re-evaluated not merely as an ecological service but as an economically quantifiable asset under carbon credit regimes. A carbon credit is a tradable certificate or permit that represents the right to emit one metric tonne of carbon dioxide or an equivalent amount of another greenhouse gas. The idea stems from the "cap-and-trade" system, where a limit is set on the total amount of emissions allowed. If a business or entity emits less than its allotted quota, it can sell the surplus as carbon credits to others that exceed their limits. This economic mechanism encourages emission reductions and promotes cleaner technologies or conservation-based practices.

The Kyoto Protocol (1997) and the Paris Agreement (2015) institutionalized the framework for carbon trading and offset mechanisms. In these contexts, activities that reduce, avoid, or sequester $CO_2$—such as afforestation, reforestation, or conservation of forests—qualify for carbon credits. The clean development mechanism (CDM) under the Kyoto Protocol allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, which can be traded in global markets. Plants, especially in the form of forest cover, are central to such projects because of their unique capacity to absorb and store carbon over long periods. The carbon credit system thus not only aligns ecological functions with economic value but also bridges the domains of environmental science, public policy, and market economics. It rewards actions that contribute to reducing atmospheric carbon levels, particularly those involving land use and vegetative cover changes, making plant science a key stakeholder in this process.

Climate change, primarily driven by the anthropogenic release of greenhouse gases, has become a matter of urgent international concern. Increasing temperatures, rising sea levels, frequent extreme weather events, and ecological disruptions point toward the adverse impacts of unchecked emissions. According to the Intergovernmental Panel on Climate Change (IPCC), the concentration of $CO_2$ in the atmosphere has reached unprecedented levels, necessitating immediate and scalable mitigation strategies. Carbon trading has emerged as a pragmatic approach to address this crisis. It allows nations and corporations to meet emission targets in a cost-effective manner by investing in carbon-saving projects elsewhere. This has led to the emergence of both compliance-based markets (like the European Union Emission Trading Scheme) and voluntary carbon markets where entities participate in carbon trading beyond regulatory obligations.

India, as a signatory to the Paris Agreement, has committed to reduce the emissions intensity of its GDP and increase its carbon sink through forest and tree cover. The Indian government has actively promoted afforestation, conservation, and agroforestry programs to meet these targets. The Green India Mission and the National Afforestation Programme are initiatives that align with carbon credit objectives. In this global and national backdrop, the role of plant-based solutions has gained prominence not only as ecological imperatives but also as tradable and measurable services in the form of carbon offsets.

The science of botany provides the essential knowledge base to understand and enhance the role of plants in carbon sequestration. Through photosynthesis, green plants absorb atmospheric carbon dioxide and convert it into organic compounds, which are stored in plant tissues as biomass. This includes leaves, stems, trunks, and roots. A portion of this carbon is also transferred to the soil through root exudates and decayed organic matter, contributing to long-term carbon storage. Different plant species vary in their capacity for carbon sequestration. Fast-growing trees like Dalbergia sissoo, Tectona grandis, and Eucalyptus species are often preferred in plantation projects due to their high biomass yield and adaptability. Likewise, mangrove forests and grasslands contribute significantly to coastal and terrestrial carbon sinks. The selection of species, understanding of ecological requirements, and estimation of net primary productivity (NPP) are all areas where botanical knowledge becomes crucial.

Botanists play a key role in designing carbon credit projects by identifying suitable species combinations, predicting biomass accumulation rates, and monitoring ecological integrity. Furthermore, innovations in plant biotechnology such as genetically modified high-biomass species and improved agroforestry models hold promise in enhancing the carbon capture potential of vegetation. The relevance of plant science extends to creating carbon inventories, verifying emission reductions, and implementing carbon farming techniques. These approaches require a deep understanding of plant physiology, ecosystem interactions, and climate adaptability—all central to botany as a discipline.

## Role of Plants in Carbon Credit: A Botanical Perspective

The integration of plant biology into carbon credit systems has brought new dimensions to environmental sustainability and climate policy. Plants, through their natural physiological and ecological processes, perform the crucial task of removing carbon dioxide ($CO_2$) from the atmosphere and storing it in various forms. This phenomenon, termed carbon sequestration, forms the scientific and botanical foundation of plant-based carbon offset programs. In this context, understanding the internal plant mechanisms that govern carbon uptake, storage, and interaction with the soil environment becomes essential to quantify and enhance their role in carbon credit systems. Photosynthesis is the most fundamental biochemical process that enables green plants to convert atmospheric carbon dioxide into organic compounds. In this process, plants absorb $CO_2$ through stomata present on leaf surfaces, which, in the presence of sunlight and chlorophyll, is converted into glucose and other carbohydrates. The overall chemical equation of photosynthesis—$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$—summarizes the transformation of inorganic carbon into organic matter that can be stored within plant tissues. This process not only drives plant growth but also serves as the primary gateway through which atmospheric carbon enters terrestrial ecosystems.

In botany, the efficiency of photosynthesis is influenced by factors such as leaf morphology, stomatal conductance, light interception, and chlorophyll content. The carbon fixation pathway differs among plant species. For instance, C3 plants such as wheat and rice dominate temperate regions, while C4 plants like maize and sugarcane are more efficient in carbon fixation under tropical conditions due to reduced photorespiration. CAM (Crassulacean Acid Metabolism) plants, such as certain succulents, optimize carbon uptake in arid conditions by temporally separating carbon fixation.

The carbon fixed during photosynthesis is translocated to different parts of the plant—leaves, stems, branches, and roots—where it is stored as biomass. This stored carbon remains in the plant body for varying durations depending on the growth pattern and life span of the species. Trees, especially those belonging to long-lived hardwood species, store substantial amounts of carbon in their woody tissues. The stem or trunk acts as a long-term carbon reservoir, with heartwood providing the most stable form of carbon storage due to its resistance to decay. Leaves, though transient, serve as active sites of photosynthesis and contribute to carbon input during their lifespan. They eventually fall and decompose, transferring carbon to the soil. Roots also play a dual role—storing carbon belowground and enabling carbon input into the soil through exudation and decay. In fact, belowground biomass is often more stable and less prone to immediate release of carbon into the atmosphere, especially in forest ecosystems.

Botanically, biomass accumulation depends on growth rate, wood density, leaf area index, and climatic adaptability. Plantation programs aiming for carbon sequestration often prioritize fast-growing species such as Eucalyptus, Populus, and Tectona grandis, which provide rapid biomass buildup. However, native species with long-term stability and ecological compatibility are increasingly being recognized for their sustainability and biodiversity co-benefits.

Beyond plant biomass, a significant proportion of sequestered carbon is stored in the soil, especially in the form of soil organic carbon (SOC). This carbon originates from decomposed plant residues, root exudates, and microbial activity in the rhizosphere—the zone of intense biological interaction surrounding plant roots. SOC serves as a long-term carbon pool and plays a critical role in maintaining soil health, fertility, and moisture retention. The rhizosphere is a dynamic interface where roots secrete various organic compounds that nourish beneficial microbes. These microorganisms, in turn, enhance nutrient cycling and contribute to carbon stabilization in the soil matrix. Mycorrhizal associations further facilitate carbon storage by extending root surface area and promoting aggregation of soil particles, which protects organic matter from rapid decomposition. Botanical studies highlight that perennial species and deep-rooted trees contribute more effectively to SOC accumulation compared to annual crops. Agroforestry models, combining trees with crops, are particularly valuable for increasing SOC without compromising productivity. Practices such as mulching, minimal tillage, and green manure incorporation also promote SOC enhancement.

In the context of carbon credit systems, soil carbon is increasingly being recognized as a verifiable and tradable asset. Protocols for measuring and certifying SOC are being developed to include soil-based sequestration in carbon markets. Hence, the understanding of root biology, rhizosphere dynamics, and decomposition pathways becomes essential in optimizing plant contributions to total ecosystem carbon storage.

## Plant Types and Their Carbon Sequestration Potential

The global drive toward carbon neutrality and climate resilience has led to the exploration of nature-based solutions, particularly those rooted in the botanical sciences. One of the most critical aspects of this approach lies in understanding how different plant types contribute to carbon sequestration. Plants are not a homogeneous group when it comes to carbon storage; their capacity to fix and retain carbon varies significantly across structural types—forests, grasses, shrubs, and even aquatic vegetation. These differences are determined by their biomass, root systems, growth rate, life span, and ecological adaptability. Recognizing the distinctive carbon sequestration potential of various plant forms allows for targeted strategies in afforestation, land management, and environmental restoration programs aimed at generating carbon credits. Forests remain the most potent terrestrial carbon sinks due to their extensive above-ground and below-ground biomass. In India and globally, afforestation (planting on non-forested land) and reforestation (replanting on degraded or deforested land) projects have emerged as primary instruments for carbon offset generation. Trees are perennial and accumulate large amounts of carbon in their woody structures over extended periods. The carbon remains stored in trunks, branches, and roots, sometimes for decades or even centuries, depending on the species and local climatic conditions. Among Indian species, Tectona grandis (teak), Dalbergia sissoo (shisham), Eucalyptus spp., and Acacia nilotica have shown significant promise due to their rapid growth, high biomass yield, and adaptability to various climatic zones. Native hardwood species, though slower growing, provide more durable carbon sinks and contribute to biodiversity conservation, making them suitable for long-term sequestration projects.

The role of forests extends beyond biomass. Litterfall, deadwood accumulation, and root decay contribute to soil carbon pools, further enhancing sequestration. Dense canopy cover also influences microclimates and moisture retention, indirectly supporting carbon cycling processes. Well-designed afforestation and reforestation efforts aligned with the Forest Survey of India guidelines and National Afforestation Programme have the potential to significantly contribute to India's Nationally Determined Contributions (NDCs) under the Paris Agreement.

Although often overlooked in comparison to trees, grasses, shrubs, and non-woody plants also contribute meaningfully to carbon sequestration, particularly in grasslands, semi-arid regions, and degraded ecosystems. These plants have high root-to-shoot ratios, meaning a larger proportion of carbon is stored underground, making the carbon pool more stable and less prone to rapid oxidation. Deep-rooted grasses such as Cenchrus ciliaris and Dichanthium annulatum are effective in storing carbon in subsoil layers, particularly under minimal disturbance conditions. Shrubs like Carissa carandas, Calotropis gigantea, and Lantana camara develop woody stems and survive in dryland ecosystems, where they help stabilize soils and contribute to biomass accumulation over time. Though the above-ground biomass is relatively limited, the total sequestration potential, when scaled over vast semi-arid regions, becomes substantial. Non-woody plants, particularly those cultivated under conservation agriculture practices, contribute to short-term carbon fixation. Though their biomass is temporary, crop residues, green manure, and rotational cropping systems build soil organic matter, enriching soil carbon stocks. These systems, when maintained under low-tillage conditions, lead to the gradual buildup of soil carbon and can be integrated into carbon farming projects that are now gaining ground in India.

Aquatic ecosystems are vital players in global carbon dynamics, and within them, aquatic plants and algae perform the crucial function of capturing carbon dioxide dissolved in water. Through photosynthesis, these organisms not only support aquatic food chains but also influence carbon sequestration in sediment layers and water columns. Algae, both micro and macro forms, are especially efficient in carbon fixation due to their rapid growth rates and high photosynthetic efficiency. In Indian aquatic systems, species such as Hydrilla verticillata, Eichhornia crassipes (water hyacinth), and Lemna minor (duckweed) have been noted for their carbon assimilation potential. While some, like water hyacinth, pose ecological concerns due to invasiveness, their controlled cultivation in wastewater treatment and biomass-based carbon projects is being explored. These plants can be harvested periodically, and their biomass can be used for bioenergy, thereby locking the carbon temporarily while providing renewable energy alternatives. Marine macroalgae, especially those cultivated along India's coastal regions such as Gracilaria, Ulva, and Sargassum, are gaining recognition under blue carbon initiatives. These algae sequester carbon not only through growth but also by contributing to deep-sea carbon burial when dead material sinks to ocean beds. While quantifying this sequestration remains a research challenge, preliminary studies indicate that aquatic plants and algae could complement terrestrial sequestration programs in carbon credit frameworks.

## Urban Greenery and Plantation Drives

As global urbanization accelerates, the ecological footprint of cities continues to expand, resulting in increased carbon emissions, loss of green cover, and environmental degradation. In this context, urban greenery and plantation drives have emerged as critical components of sustainable urban planning and climate mitigation strategies. From a botanical perspective, the integration of plant life into cityscapes serves not only aesthetic and recreational purposes but also performs vital environmental functions such as air purification, temperature regulation, and carbon sequestration. Urban forestry refers to the management of trees and vegetation within urban and peri-urban environments for ecological and social benefits. In recent years, the scientific community and policymakers have acknowledged the significant carbon sequestration potential of urban green belts, avenues, parks, and institutional campuses. While individual trees in cities may not sequester as much carbon as forest trees, their cumulative impact over expansive urban areas is substantial.

Trees in urban environments contribute to carbon capture by fixing atmospheric carbon dioxide through photosynthesis and storing it in biomass. In Indian cities, commonly planted species such as Azadirachta indica (neem), Polyalthia longifolia, Ficus religiosa (peepal), and Delonix regia are known for their adaptability and moderate to high biomass potential. These species are often selected for urban planting due to their tolerance to pollution and minimal water requirements. Urban green belts also serve as buffers that reduce vehicular and industrial emissions by acting as physical barriers and biofilters. Studies conducted by the Indian Institute of Forest Management and state pollution control boards reveal that well-maintained urban forests can sequester 2.5–4 tonnes of $CO_2$ per hectare annually, depending on canopy density and species composition. Municipalities across India, including Delhi, Hyderabad, and Pune, have initiated extensive tree plantation programs as part of their climate action plans. These efforts not only increase local carbon sinks but also contribute to city-level participation in carbon offset schemes under India's Intended Nationally Determined Contributions (INDCs).

In land-scarce urban environments, innovative greening techniques like rooftop gardens and vertical plantations are gaining popularity as viable alternatives to traditional ground-level greenery. These approaches not only optimize space usage but also enhance the city's microclimate and carbon assimilation capacity. Rooftop gardens, often established on residential and commercial buildings, contribute to carbon sequestration by supporting herbaceous plants, shrubs, and small trees. Their soil substrates act as additional carbon reservoirs, and the evapotranspiration process helps mitigate the urban heat island effect. Vertical gardens—constructed along building facades and walls using hydroponic or soil-based systems—are becoming increasingly prevalent in smart city designs. These installations allow for high-density planting in constrained spaces and contribute significantly to air purification, temperature regulation, and carbon uptake. Plant species commonly used in such settings include Money plant (Epipremnum aureum), Areca palm, Ficus benjamina, and various ferns, all of which have proven tolerance to urban pollutants and compact growing conditions. Botanically, the efficiency of rooftop and vertical plantations in carbon sequestration depends on factors such as plant density, leaf area index, and maintenance practices. While the individual carbon sequestration capacity of these systems may be low compared to forests, their aggregated impact across urban infrastructure is notable, especially when linked to carbon offset calculations under decentralized carbon credit projects.

Botanical gardens and academic institutions serve as custodians of plant diversity and act as knowledge hubs for sustainable practices. Their role in climate change mitigation extends beyond plant conservation to active engagement in public education, demonstration of best practices, and scientific research on carbon sequestration. Indian botanical gardens such as the Acharya Jagadish Chandra Bose Indian Botanical Garden (Howrah), Lalbagh Botanical Garden (Bengaluru), and Tropical Botanic Garden and Research Institute (Thiruvananthapuram) maintain diverse plant collections and serve as live laboratories for studying carbon dynamics in controlled environments. These institutions often collaborate with municipal bodies, schools, and NGOs to conduct plantation drives, awareness programs, and exhibitions focusing on green urban living and the role of plants in combating climate change. Many of these gardens have initiated tree-mapping and carbon inventory programs to measure the ecological contribution of their flora. Educational outreach through guided tours, workshops, and green festivals helps bridge the gap between scientific research and community action. Furthermore, botanical researchers contribute to the development of species selection guidelines for urban greening based on factors like drought resistance, pollution tolerance, and carbon fixation rate. By integrating traditional knowledge systems with modern ecological practices, these institutions foster a culture of responsible urban environmental stewardship.

## Conclusion

In the face of an escalating climate crisis, plants have emerged not just as passive components of ecosystems but as active agents in global carbon management. The scientific, ecological, and economic potential of plants to capture, store, and stabilize atmospheric carbon dioxide forms the foundation of nature-based solutions and carbon credit mechanisms. Under the broader theme of "Role of Plants in Carbon Credit: A Botanical Perspective", this study has explored how various botanical processes, plant types, scientific tools, and policy frameworks converge to position vegetation as a measurable and tradable carbon sink. As the global community pursues carbon neutrality, recognizing and strengthening the botanical dimensions of carbon sequestration is more critical than ever. To fully leverage plant-based systems in carbon credit markets, there is an urgent need to align policies, practices, and scientific innovations. First and foremost, government programs at both central and state levels should actively promote species selection based on regional ecological compatibility and carbon sequestration potential. Indigenous, fast-growing, and climate-resilient species should be prioritized, and agro-climatic mapping can help match plants with their optimal zones. Secondly, agroforestry and afforestation programs should be integrated into India's agricultural extension services to reach rural stakeholders. Incentive structures like payment for ecosystem services (PES) and community carbon credit funds can motivate farmers and tribal communities to maintain green cover. Clear legal rights over planted trees, simplified harvesting permissions, and secure carbon ownership need to be ensured to make plant-based projects feasible and economically attractive. The role of biodiversity in enhancing ecosystem resilience and carbon stability should be investigated further. Research into polyculture systems, native species restoration, and interspecies interactions can reveal how ecological diversity enhances long-term carbon sinks. Furthermore, with climate variability increasing, the development of heat-tolerant, drought-resistant, and salinity-adapted plant varieties through traditional breeding and biotechnology must be accelerated. On the technological front, integrating Artificial Intelligence (AI) and Machine

Learning (ML) with remote sensing can vastly improve predictive modeling of carbon storage. Mobile-based field data collection tools, blockchain for carbon tracking, and open-source MRV platforms will democratize participation in carbon markets and enhance trust. In summary, plants lie at the heart of carbon sequestration strategies due to their inherent biological properties. As this paper has emphasized, the effective deployment of plants in carbon credit systems requires scientific rigor, technological support, institutional backing, and grassroots participation. Through continued research, supportive policy frameworks, and robust implementation, India and the world can move towards a greener, more carbon-neutral future—rooted quite literally in the wisdom of plants.

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## Cite this Article-

'Dr. Ramesh R. Nair', ' Role of Plants in Carbon Credit: A Botanical Perspective', Shodhpith International Multidisciplinary Research Journal, ISSN: 3049-3331 (Online), Volume:1, Issue:02, March-April 2025.

Journal URL- https://www.shodhpith.com/index.html

Published Date- 04 March 2025

DOI-10.64127/Shodhpith.2025v1i2003