Journal of Emerging Trends in Science and Technology
Volume I, Issue I, January 2026

Possibilities Of Developing: An Algae-Based Biofertilizers Enhanced with Biochar for Soil Ph Balancing in Agriculture

C.M.Mohith Kumaran [1], Dr. Farzana Tasneem MI [2], Amrutha Ravi [3]

C.M.Mohith Kumaran,UG Student Dept of Biotechnology,Surana College,Autonomous Bangalore-04

Dr. Farzana Tasneem MI,Associate Professor Dept of Biotechnology,Surana College,Autonomous Bangalore-04

Amrutha Ravi,UG Student Dept of Biotechnology,Surana College,Autonomous Bangalore-04

Soil health is critical to achieving sustainable agriculture and ensuring food security globally. However, soil pH imbalance remains a persistent challenge, significantly affecting crop productivity and environmental sustainability. Acidic soils commonly found in agricultural regions lead to aluminum toxicity and nutrient deficiencies while alkaline soils limit the availability of essential micronutrients, reducing crop yields and soil fertility. Addressing these challenges is essential to promote eco-friendly farming practices and mitigate the negative impacts on agricultural ecosystems. This study investigates the synergistic potential of integrating algae-based biofertilizers and biochar to restore soil health to correct pH imbalances and improve soil fertility. Algae-based biofertilizers enhance soil fertility by fixing atmospheric nitrogen and supporting plant growth, while biochar neutralizes acidic soils and improves nutrient retention through its porous structure. Together, they offer a sustainable solution to major agricultural challenges. The combined application of algae-based biofertilizers and biochar offers a holistic and sustainable solution to multiple agricultural challenges. Algae enhances nitrogen availability, soil aggregation and microbial diversity while biochar improves nutrient retention, balances pH levels and serves as a habitat for beneficial microbes. This integrated approach addresses critical issues such as nutrient deficiencies, soil degradation, and carbon sequestration, significantly boosting crop productivity and environmental sustainability. While the results highlight the potential of this approach key challenges remain including optimizing the application rates and ensuring compatibility between algae a biochar and adapting the strategy to various soil types and climatic conditions. Future research must focus on large-scale field trials, economic feasibility, and the development of customized formulations to meet specific regional needs.In conclusion, integrating algae-based biofertilizers and biochar presents a transformative, eco-friendly strategy to improve soil health, enhance agricultural productivity, and support global sustainability goals.

Key words: Algae-Based Biofertilizers, Biochar, Soil pH Imbalance, Cyanobacteria, Sustainabi

Introduction:A biofertilizer (also bio-fertilizer) is a substance which contains living microorganisms which, when applied to seed, plant surfaces, or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant Substance that contains living microorganisms that, when applied to seed, plant surfaces, or soil, colonize the rhizosphere or the interior of the plant and promote growth by increasing the supply or availability of primary nutrients to the host plant. Bacteria are used to Fix nitrogen, solubilize phosphorus, and mobilize potassium, improve soil structure and microbial activity, reduce dependency on chemical fertilizers, minimizing environmental harm. Types: Nitrogen-fixing, Phosphate-solubilizing, Potassium-mobilizing, PGPR, Blue green Algae (or) Cyanobacteria. "Soil health is the cornerstone of sustainable agriculture, yet soil pH imbalance remains a persistent challenge, threatening crop productivity and environmental sustainability. Acidic soils, prevalent in many agricultural regions, lead to aluminum toxicity and nutrient deficiencies, while alkaline soils restrict the availability of essential micronutrients. Addressing these issues is critical for ensuring food security and promoting eco-friendly farming practices. Biofertilizers particularly those derived from algae (cyanobacteria), have emerged as a sustainable alternative to chemical fertilizers. These microorganisms fix atmospheric nitrogen, enhance soil fertility, and promote plant growth through the production of growth-promoting substances. Among biofertilizers, algae-based formulations stand out due to their ability to thrive in diverse environments and contribute to soil health.

Biochar, a carbon-rich material produced through the pyrolysis of biomass, has gained attention for its ability to balance soil pH and improve nutrient retention. Its alkaline nature helps neutralize acidic soils, while its porous structure enhances water and nutrient- holding capacity. When combined with biofertilizers, biochar could offer a synergistic solution to soil pH imbalance and fertility challenges.

A “porous carbonaceous solid” produced by thermochemical conversion of organic materials in an oxygen depleted atmosphere, which has physiochemical properties suitable for the safe and long-term storage of carbon in the environment.The conversion of biosolids (treated sewage sludge) into biochar presents an innovative solution for waste management. Biosolid-derived biochar enhances organic matter content in soils while mitigating heavy metal contamination. Regulatory frameworks influence its application, with concerns related to sustainability and environmental safety. The study discusses the benefits and challenges associated with biosolid biochar, emphasizing its potential role in circular economy approaches for waste utilization **(Jorge Paz-Ferreiro et al., 2018).** A meta-analysis conducted on 75 studies revealed that biochar application increases soil carbon sequestration by 61%, while its effects on microbial respiration and CO_2 flux remain inconclusive. Higher application rates and specific feedstock types significantly enhance carbon sequestration. The study identifies that lower pyrolysis temperatures favor increased microbial respiration and carbon retention. These findings support the role of biochar in mitigating climate change by reducing CO_2 emissions and improving soil carbon storage **(Madina Bekchanova et al., 2024).**

Soil degradation due to nutrient depletion and erosion is a pressing global concern. Biochar has been found to improve soil fertility by increasing nutrient retention, enhancing water-holding capacity, and moderating soil acidity. The porous structure of biochar facilitates the adsorption of heavy metals, phosphates, and nitrates, making it a valuable soil amendment. The effectiveness of biochar depends on factors such as feedstock composition, pyrolysis temperature, and application rate. Additionally, biochar supports microbial activity, leading to enhanced crop productivity and reduced environmental impact**(YangDingetal.,2016).**

Biochar production typically involves slow pyrolysis at temperatures ranging from 400 to 600°C, resulting in a carbon-rich material with a fixed carbon content of 60–85%. Its application to soil enhances physiochemical properties, increases water retention, and acts as a carbon sequestration agent. Additionally, biochar reduces nitrogen leaching, improves cation exchange capacity, and contributes to sustainable agriculture. This review highlights biochar as a viable alternative to chemical fertilizers, offering long-term benefits for soil health and climate resilience (N. L. Panwar et al., 2019). The effective management of agro-industrial waste plays a crucial role in reducing pollution. Sugarcane bagasse (SB), a major byproduct of the sugar industry, presents opportunities for conversion into biochar through pyrolysis. SB biochar exhibits promising applications in soil remediation, carbon sequestration, and sustainable material development. Thermochemical techniques such as gasification, hydrothermal carbonization, and torrefaction are commonly employed to optimize biochar properties for various applications **(Mohd. Khalid Zafeer et al., 2024).**

Uses of Biochar:

1. Soil pH Balancing:1. Biochar is alkaline nature helps neutralize acidic soils, reducing aluminum toxicity and improving nutrient availability. It acts as a liming agent, raising soil pH and enhancing crop productivity. Nutrient Retention: Biochar’s porous structure increases soil’s cation exchange capacity (CEC), improving nutrient retention and reducing leaching. Environmental Benefits- Carbon Sequestration: Biochar locks carbon in the soil for centuries, reducing greenhouse gas emissions. Waste Management: Converts agricultural and municipal waste into a valuable resource. Water Retention: Improves soil water-holding-capacity and reduce irrigation.

Method of Obtaining: Pyrolysis: Pyrolysis is the most common method for producing biochar. It involves heating biomass at elevated temperatures (typically 400–700°C) in the absence of oxygen. The process has three main stages: 1. Drying: Removal of moisture from the biomass.2. Thermal Decomposition: Breakdown of organic compounds into gases, liquids (bio-oil), and solid char.3.Cooling: Collection and stabilization of the solid biochar. Pyrolysis conditions (temperature, heating rate, and duration) influence biochar's chemical composition and properties.2.2. Chemical Composition: Biochar's chemical composition varies depending on the feedstock and pyrolysis conditions, but it includes:1.Carbon (C): 70–90% of biochar's composition, providing stability and carbon sequestration.2.Ash Content: Minerals like calcium (Ca), magnesium (Mg), potassium (K), and phosphorus (P).3.Volatile Organic Compounds (VOCs): Residual organic matter that can influence soil microbial activity.4.pH: Typically, alkaline (pH 8–10), making it effective for neutralizing acidic soils.3.Possibilities of Combining Algae-Based Biofertilizers with pH-Controlling Biochar: The integration of algae-based biofertilizers with pH-controlling biochar represents a promising advancement in sustainable agricultural practices. Algae, particularly Blue- Green Algae (BGA) and Azolla, are well-documented for their ability to fix atmospheric nitrogen, thereby enriching soil fertility. On the other hand, biochar, a carbonaceous material produced through the pyrolysis of organic biomass, is renowned for its capacity to improve soil structure, enhance nutrient retention, and regulate soil ph. This chapter explores the potential of combining these two components, examining their synergistic effects, merits, demerits, and practical considerations for agricultural applications.

Possibilities of Algae-Biochar Integration:

The combination of algae-based biofertilizers and biochar offers a multifaceted approach to soil management. Algae, such as Blue-Green Algae (BGA) species like Anabaena, Nostoc, and Aulosira, are capable of fixing significant amounts of atmospheric nitrogen, contributing approximately 20–60 kg N/ha under optimal conditions. Similarly, Azolla, a water fern that forms a symbiotic relationship with the nitrogen-fixing cyanobacterium Anabaena azollae, can contribute up to 40–60 kg N/ha per rice cropping season. When paired with biochar, these algae-based biofertilizers can benefit from the alkaline properties of biochar, which help neutralize acidic soils and create a more favorable environment for microbial activity. Biochar, particularly when produced at higher pyrolysis temperatures (500–700°C), exhibits a pH range of 8–11, making it an effective amendment for acidic soils. By raising the soil pH to a near-neutral or slightly alkaline range (6.5–7.5), biochar enhances the survival and activity of nitrogen-fixing algae, which thrive under such conditions. Furthermore, biochar improves soil porosity, water retention, and aeration, all of which are critical for the proliferation of algae and other beneficial microorganisms. The combined application of algae and biochar not only enhances soil fertility but also promotes long- term soil health by increasing organic carbon content and supporting microbial diversity.

1.Merits of Algae-Biochar Combination:

The integration of algae-based biofertilizers with biochar offers numerous advantages, making it a compelling option for sustainable agriculture. One of the primary benefits is cost-effectiveness. Algae cultivation, particularly in waterlogged or wetland environments, requires minimal inputs and can be easily integrated into existing agricultural systems. Biochar production, while initially requiring investment in pyrolysis equipment, can utilize agricultural waste materials, thereby reducing costs and promoting waste recycling.

From an agronomic perspective, the combination significantly improves soil health. Algae contributes to nitrogen fixation, reducing the need for synthetic nitrogen fertilizers, while biochar enhances nutrient availability by adsorbing and slowly releasing essential nutrients such as phosphorus, potassium, and micronutrients. This dual action not only boosts crop productivity but also minimizes nutrient leaching, thereby reducing environmental pollution. Additionally, biochar's ability to regulate soil pH ensures that the soil remains within an optimal range for microbial activity and nutrient uptake.

Environmental benefits are another key advantage of this combination. Biochar serves as a long-term carbon sink, sequestering carbon in the soil for centuries and mitigating climate change. Algae, through photosynthesis, contribute to carbon fixation, enhancing the overall carbon sequestration potential of the soil. Moreover, the reduction in chemical fertilizer uses decreases greenhouse gas emissions associated with fertilizer production and application.

Demerits and Challenges:

Despite its numerous advantages, the integration of algae-based biofertilizers with biochar is not without challenges. One of the primary limitations is the specific cultivation requirements for algae. Blue-Green Algae and Azolla thrive in waterlogged conditions, making them suitable for rice paddies and wetland agriculture but less adaptable to arid or semi-arid regions. Biochar production, while beneficial, requires access to pyrolysis technology, which may not be readily available to smallholder farmers. The initial investment in equipment and the technical knowledge required for biochar production can be barriers to widespread adoption.

Another challenge lies in the survival conditions of algae. These microorganisms are sensitive to environmental factors such as temperature, light, and water availability. Prolonged drought, extreme temperatures, or inadequate sunlight can hinder their growth and nitrogen-fixing capabilities. Similarly, the effectiveness of biochar depends on the feedstock used and the pyrolysis temperature, which can influence its pH, nutrient content, and stability. Variability in these factors can lead to inconsistent results in field applications.

Storage and shelf life are additional concerns. Algae-based biofertilizers have a limited shelf life and require proper storage conditions to maintain microbial viability. Biochar, while stable, must be stored in dry conditions to prevent contamination and ensure its effectiveness. Farmers may also face challenges in determining the optimal application rates and methods, as the performance of the algae-biochar combination can vary depending on soil type, climate, and crop species.

Practical Considerations:

For successful implementation, several practical considerations must be addressed. Algae cultivation, particularly for BGA and Azolla, requires specific environmental conditions. BGA thrives in waterlogged fields with adequate sunlight and nutrient availability, while Azolla requires stagnant water with a pH range of 6.5–7.5. Farmers must ensure that these conditions are met to achieve optimal growth and nitrogen fixation.

Biochar production involves the pyrolysis of organic materials such as crop residues, wood, or manure at temperatures ranging from 350–700°C. The choice of feedstock and pyrolysis temperature significantly influences the properties of biochar, including its pH, nutrient content, and stability. Higher pyrolysis temperatures generally produce biochar with more alkaline properties, making it suitable for acidic soils.

The combination of algae and biochar can be achieved by mixing dried algae biomass with biochar in a 1:1 or 1:2 ratio. This mixture can be applied to the soil before planting or during crop growth. Proper storage is essential to maintain the viability of algae and the effectiveness of biochar. The mixture should be stored in a cool, dry place to prevent contamination and ensure long-term stability.

Why We Need Biofertilizers with Biochar: The integration of **biofertilizers** with **biochar** addresses critical challenges in modern agriculture, offering a sustainable and eco-friendly solution to enhance soil health, improve crop productivity, and mitigate environmental degradation. This combination is particularly relevant in the context of increasing global food demand, soil degradation, and the adverse effects of chemical fertilizers on ecosystems. Below, we discuss the key reasons why this integration is essential:

Addressing Soil pH Imbalance: Soil pH imbalance, particularly in acidic soils, is a major constraint to agricultural productivity. Acidic soils lead to **aluminum toxicity** and **nutrient deficiencies**, while alkaline soils restrict the availability of essential micronutrients. Biochar, with its **alkaline nature**, helps neutralize acidic soils, raising the pH to a near-neutral range (6.5–7.5). This creates a favorable environment for the growth and activity of **nitrogen-fixing algae** (e.g., Blue-Green Algae and Azolla), which thrive in slightly alkaline conditions. By combining biochar with algae-based biofertilizers, we can effectively address soil pH issues while enhancing nutrient availability.

Enhancing Nutrient Availability and Retention: Biofertilizers, particularly algae-based formulations, fix atmospheric nitrogen and solubilize phosphorus, making these essential nutrients available to plants. However, their effectiveness can be limited by nutrient leaching and low soil fertility. Biochar, with its high cation exchange capacity (CEC) and porous structure, improves nutrient retention and reduces leaching. This synergistic effect ensures that nutrients fixed by algae are retained in the soil for longer periods, enhancing their availability to crops Reducing Dependency on Chemical Fertilizers

The overuse of chemical fertilizers has led to **soil degradation**, **water pollution**, and **greenhouse gas emissions**. Algae-based biofertilizers provide a natural alternative by fixing atmospheric nitrogen and solubilizing phosphorus, reducing the need for synthetic fertilizers. When combined with biochar, which enhances nutrient retention and soil fertility, this approach can significantly reduce dependency on chemical inputs, promoting sustainable agricultural practices.

Moreover, the rising cost of chemical fertilizers has become a significant burden for farmers, especially in developing countries. In contrast, algae can be cultivated at minimal or no cost in waterlogged fields, and biochar can be produced from freely available agricultural waste, such as crop residues and wood chips. This makes the combination of algae-based biofertilizers and biochar a cost-effective alternative to expensive chemical fertilizers, reducing input costs for farmers and improving their economic viability.

1. Improving Soil Structure and Microbial Activity:

Biochar improves soil structure by increasing **porosity**, **water retention**, and **aeration**, creating a conducive environment for microbial activity. Algae-based biofertilizers, particularly cyanobacteria, contribute to **soil organic carbon** and support **microbial diversity**. Together, they enhance soil health by promoting the growth of beneficial microorganisms, which play a crucial role in nutrient cycling and plant growth.

2. Mitigating Climate Change:

Biochar is a carbon-negative material that sequesters carbon in the soil for centuries, reducing greenhouse gas emissions. Algae, through photosynthesis, also contribute to carbon fixation. By combining these two components, we can enhance the carbon sequestration potential of agricultural soils, contributing to climate change mitigation.

3. Promoting Environmental Sustainability:

The combination of biofertilizers and biochar aligns with the principles of environmental sustainability. It reduces the environmental footprint of agriculture by minimizing the use of chemical fertilizers, preventing nutrient leaching, and improving soil health. This approach supports eco-friendly farming practices and contributes to the long-term sustainability of agricultural systems.

Conclusion:

The integration of algae-based biofertilizers with biochar presents a transformative and sustainable approach to addressing critical challenges in modern agriculture. This study highlights the synergistic potential of combining these two components to restore soil health, correct pH imbalances, and enhance crop productivity. Algae-based biofertilizers, particularly cyanobacteria and Azolla, contribute significantly to nitrogen fixation, soil aggregation, and microbial diversity, while biochar neutralizes acidic soils, improves nutrient retention, and sequesters carbon. Together, they offer a holistic solution to issues such as nutrient deficiencies, soil degradation, and greenhouse gas emissions.

The findings underscore the cost-effectiveness and environmental benefits of this approach. Algae can be cultivated at minimal cost in waterlogged fields, and biochar can be produced from readily available agricultural waste, reducing dependency on expensive chemical fertilizers. This combination not only improves soil fertility and crop yields but also promotes eco-friendly farming practices, making it particularly valuable for smallholder farmers in developing countries.

However, challenges remain, including optimizing application rates, ensuring compatibility between algae and biochar, and adapting the strategy to diverse soil types and climatic conditions. Future research should focus on large-scale field trials, economic feasibility studies, and the development of customized formulations to meet specific regional needs.

In conclusion, the integration of algae-based biofertilizers with biochar represents a promising pathway toward achieving sustainable agriculture, food security, and environmental conservation. By leveraging the unique properties of these two components, we can create resilient agricultural systems that support both productivity and planetary health. This approach aligns with global sustainability goals and offers a practical solution for farmers worldwide, paving the way for a greener and more sustainable future.

1.Cost-Effectiveness and Accessibility:

Algae-based biofertilizers are relatively inexpensive to produce, especially in waterlogged or wetland environments. Biochar production can utilize agricultural waste (e.g., crop residues, wood chips), making it a cost-effective soil amendment. Together, they offer a low-cost solution for improving soil fertility and crop productivity, particularly for smallholder farmers in developing countries.

2.**Adaptability to Diverse Agroecological Conditions:**

The combination of biofertilizers and biochar is adaptable to a wide range of agroecological conditions. While algae thrive in waterlogged environments (e.g., rice paddies), biochar can be tailored to suit different soil types and climates by adjusting the feedstock and pyrolysis conditions. This adaptability makes the approach suitable for diverse agricultural systems. 1. Long-Term Soil Health Benefits

The combined application of biofertilizers and biochar provides long-term benefits for soil health. Biochar's stability ensures that its effects persist for years, while algae continuously contribute to nitrogen fixation and organic matter accumulation. This long- term impact supports sustainable crop production and reduces the need for frequent soil amendments.

2.**Addressing Global Food Security:**

With the global population projected to reach 9.7 billion by 2050, there is an urgent need to increase agricultural productivity without compromising environmental health. The integration of biofertilizers with biochar offers a sustainable pathway to enhance crop yields, improve soil fertility, and ensure food security for future generations.

References:

1. Jorge Paz-Ferreiro, Aurora Nieto, Ana Méndez, Matthew Peter James Askeland, GabrielGascó. "Biochar from biosolids pyrolysis: A review." International Journal of Environmental Research and Public Health (2018). DOI: 10.3390/ijerph15050956
2. Madina Bekchanova, Tom Kuppens, Ann Cuypers, Marijke Jozefczak, Robert Malina."Biochar's effect on the soil carbon cycle: a rapid review and meta-analysis." Biochar (2024). DOI: 10.1007/s42773-024-00381-8
3. N. L. Panwar, Ashish Pawar, B. L. Salvi. "Comprehensive review on production and utilization of biochar." SN Applied Sciences (2019). DOI: 10.1007/s42452-019-0172-6
4. Mohd. Khalid Zafeer, Rachel Alveera Menezes, H. Venkatachalam, K. Subrahmanya Bhat. "Sugarcane bagasse-based biochar and its potential applications: a review." Emergent Materials (2024). DOI: 10.1007/s42247-023-00603-y

5. United Nations Environment Programme (UNEP). (n.d.). Circularity in sectors: Food and food waste. Retrieved fromhttps://www.unep.org/topics/chemicals-and-pollution-action/circularity-sectors/food-and-food- waste#:text=These%20include%3A, increase%20by%2060%20per%20cent.

6. Zubairu, A. & Ngala, A & Kwari, Samson & Usman, Kachalla & Tela Buba, Muhammad. (2023). Exploring the effect of biochar on soil pH (A review).
7. Government Arts College, Ariyalur. (n.d.). Biofertilizers. Retrieved from https://www.gacariyalur.ac.in/econtent/botany/pg/PG-I-P16BO14.pd
8. ScienceDirect. (n.d.). Scientific research articles and journals. Retrieved from https://www.sciencedirect.co
9. 9.Images: - Freepik. (n.d.). Free vectors, stock photos, and PSD files. Retrieved from https://www.freepik.co
10. 10.Prime Video. (n.d.). Kadaisi Vivasayi. Retrieved from https://www.primevideo.com/detail/Kadaisi-Vivasayi/0QLL52VYUQSL2VBDT9M19RM0FP#:text=Prime%20Video:%20Kadaisi%20Vivasayi,Garudan
11. 11.Sundara Rajan, S. (2014). College Botany-1 (3rd ed.). Mumbai, India: Himalaya Publishing House.
12. 12.Chapter 4: Applied Microbiology – Biofertilizers (p. 42).
13. 13.Chapter 11: Phycology – General Topics – Algal Biofertilizers (Including Cyanobacteria) (p. 287).
14. 14.Image;: iStock. (n.d.). Stock photos, illustrations, and vectors. Retrieved from https://www.istockphoto.com.