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Review

Exploring Diverse Biological Fertilizers (Micronutrients) for Sustainable Soil Fertility: A Review

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Abstract: Attaining sustained soil fertility is essential for guaranteeing global food security and environmental well-being. Traditional farming methods that depend extensively on synthetic fertilizers have resulted in soil deterioration and environmental contamination. Biological fertilizers fortified with micronutrients have emerged as viable alternatives. This analysis examines many types of biological fertilizers and their contribution to improving soil fertility via micronutrient enhancement. Multiple sources of micronutrient-enriched biological fertilizers, such as microbial inoculants, compost, and organic amendments, are evaluated for their effectiveness in enhancing plant growth, increasing nutrient availability, and boosting soil health. Moreover, the effects of these fertilizers on agricultural productivity, soil microbial populations, and ecological sustainability are examined. Green manuring is a reasonable and ecofriendly scientific approach to enhancing robust and sustainable food production in agricultural systems. The integration of green manure improves soil quality by augmenting its chemical, physical, and biological properties, including the availability of organic matter, potassium, nitrogen, and phosphorus, while also enhancing soil structure by reducing erosion and improving water retention capacity. Green manure serves as a natural fertilizer, releasing nutrients into the soil during decomposition, so enhancing nutrient content and fostering plant growth and development. The results highlight the potential of biological fertilizers as sustainable solutions for improving soil fertility and decreasing reliance on synthetic inputs, hence promoting long-term agricultural output and ecosystem resilience.

Keywords: sustainable; biological; fertilizers; micronutrients; soil fertility; microbial inoculants; soil health; green manure; organic matter; agriculture productivity

1. Introduction

Enhancing agricultural output by safeguarding the environment as major priority for the scientific community (Murata et al., 2021). In recent decades, agriculture production has accelerated meet to increasing food demand, but it has also significantly harmed the global environment (Alvarez et al., 2021). The overuse of chemical fertilisers is a dominant strategy for enhancing crop yields and augmenting the profitability of the agricultural sector (Osorio-Reyes et al., 2023). This method results in considerable environmental problems, including emissions of gas from greenhouse, deprivation of water and soil quality, and loss of biodiversity (Řezbová et al., 2023). Moreover, improper use of chemical fertilisers may pose significant risks to human health (Ward, 2009).

The insistent use of chemical fertilisers may result in the accumulation of detrimental heavy metals and nitrates in the soil (Rashid et al., 2023). This pollution jeopardises soil quality and leads to the bioaccumulation of dangerous substances in food crops, fruits, and vegetables, heightening concerns over potential health risks for consumers (Yousefi and Douna, 2023).

In the next 30 years, the global population is projected to exceed 10 billion. Consequently, food supply must augment by 60% to satisfy anticipated demand in 2050 (Kinge et al. 2022). Food distribution and manufacturing need more efficient and sustainable management to prevent supply shortages. Farmers use organic fertilisers produced from recycled resources such as manure, agricultural waste, and municipal sewage, including human excrement (Ju et al. 2005). The excessive use of pesticides and inorganic fertilisers has led to agricultural land degradation, diminished crop yields, and a rise in serious health issues (Bedair et al. 2022). Consequently, biofertilization requires investigation to ensure the provision of healthy food (Ammar 2022).

Inorganic fertilisers, herbicides, and insecticides have profoundly adversely affected the soil ecosystem. This kind of soil alteration will negatively impact future crop production. To guarantee adequate nutrient absorption, crop output, and resilience to abiotic stress, the use of natural plant biostimulants is advocated as an innovative solution to the issues of sustainable agriculture (Povero et al. 2016). Fertilisers are essential for promoting the growth of high-yield crops. N, P, Ca, Mg, K, Fe, Zn, and Some important elements that most crops need in substantial quantities across various soils (White and Brown 2010).

Researchers have focused on using biofertilizers, which provide several advantages over traditional fertilisers, to alleviate the adverse impacts of chemical fertilisers. Biofertilizers provide a more economical and ecologically sustainable use for chemical fertilisers, as they augment soil fertility, enhance nutrient availability, foster sustainable plant development, and alleviate the adverse environmental effects associated with excessive chemical application (Kumar et al., 2022). Kumar et al. (2022) say that biofertilizers improve soil health, stimulate beneficial microbial activity, and boost sustainable agricultural methods. Formulations originating from photosynthetic organisms, especially microalgae, have garnered considerable interest among various biofertilizers available commercially owing to their exceptional capacity to improve soil fertility and stimulate plant development (Çakirsoy et al., 2022).

In permaculture, plants are often used to enhance soil fertility. Specific plant residues, such as those from *Musa paradisiaca*, *Coffea arabica*, and *Lathyrus oleraceus*, may be used as soil fertilisers (Singh et al. 2013). Biological fertilizers, which are substances containing microorganisms, enhance soil fertility and stimulate plant development when applied to the soil. Biofertilization is a sustainable agriculture technology that enhances soil nutrient content and, therefore, production. Research indicates that soil microflora may enhance biomass output and soil fertility. It is acknowledged as an appropriate, environmentally sustainable bio-based fertiliser that may be used in agriculture to mitigate pollution. The majority of cyanobacteria has the capability to fix atmospheric nitrogen. Extracts from live organisms may be used as biofertilizers in three distinct methods: foliar application, soil incorporation, or seed imbibition. (Figure 1).

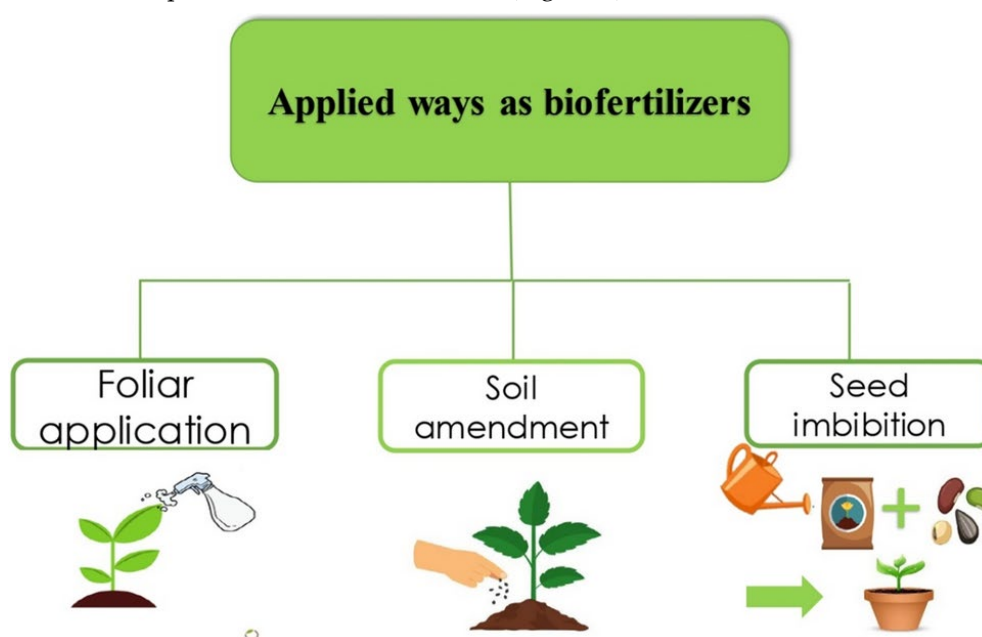


Figure 1. Way of applying biofertilizer on plants.

2. Bacteria as Biofertilizer

Bacterial biofertilizers boost plant growth in several ways (Kumar et al. 2022). This includes the production of plant nutrients or phytohormones for plant absorption, soil chemical mobilisation for nutrient uptake, and plant defence against environmental stress. These processes minimise plant illnesses or death by reducing stresses and increasing pathogen resistance. Multiple plant growth-promoting rhizobacteria (PGPR) have been employed as biofertilizers worldwide for years. They increase agricultural production and soil fertility, perhaps promoting sustainable forestry and agriculture.

Bacterial biofertilizers are growing in popularity as bacterial inoculant technologies improve (Garcia-Gonzalez and Sommerfeld 2016). Study Azotobacter in labs and fields as a biological fertilizer for over an era. Azotobacter fixes nitrogen endophytically in rice rhizospheres and roots, aiding growth. As an endophyte in rice, Azotobacter fixes atmospheric nitrogen in the rhizosphere and produces phytohormones and growth stimulants. Tables 2.1 and 2.2 show that these bacteria fix nitrogen, breakdown insoluble phosphate, and boost plant development (Daniel et al. 2022).

Table 2.1. Bacteria that fix nitrogen: biological fertilizer.

Bacteria	Examples	Crops	Impact	References
Free-living Bacteria	<i>Azotobacter</i>	<i>Oryza sativa</i>	Endorse plant development	Dar et al., 2021
Symbiotic	<i>Anabaena azollae</i>	<i>Oryza sativa</i>	Increase soil fertility by mounting the microbial pollution in soil	Abd El-Aal, 2022
Associative symbiotic	<i>Azospirillum</i>	<i>Triticum aestivum</i>	Mitigation of abiotic stresses	Raffi and Charyulu. 2021

Table 2.2. Microorganisms that solubilize phosphate as a biofertilizer.

PGPR	Plants	Impacts	References
<i>Azotobacter chroococcum</i>	<i>Triticum aestivum</i>	Improved results using mutants that solubilize phosphate	Nosheen et al. (2021)
<i>Bacillus megaterium</i>	<i>Saccharum officinarum</i>	When sugarcane is grown in pots, yield and yield-related factors are encouraged.	Chungopast et al. (2021)
<i>Bradyrhizobium japonicum</i>	<i>Glycine max</i>	lessens the detrimental effects of drought stress on soybean plants' ability to grow	Sheteiwiy et al. (2021)
<i>Pantoea agglomerans</i>	<i>Solanum lycopersicum</i>	Growth improved	Mei et al. (2021)
<i>Pseudomonas fluorescens</i>	<i>Ipomoea batatas</i>	Higher yield	Santana-Fernández et al. (2021)
<i>Rhizobium leguminosarum</i>	<i>Vicia faba</i>	Increased yield of faba beans	Fikadu (2022)

Conversely, cyanobacteria, which comprise a diverse array of creatures, are the most ancient and prolific prokaryote group on the planet. The biomass or extracts of cyanobacteria significantly improved the soil's chemical and physical characteristics. It is also commonly known that cyanobacteria may produce biologically active chemicals that can be used in phytoremediation of industrial effluent and as an efficient defense against plant diseases (Bedair et al. 2022). As a result, they enhance plant growth and productivity and play a major role in nutrient cycling, phosphorus

accessibility, nitrogen-fixation, preservation of the environment, and disease control as natural biofertilizers. Cyanobacteria also convert radiation energy into chemical energy. These biological systems create oxygen through photosynthesis. These species provide us with energy, food, secondary compounds, cosmetics, and medications. Multiple high-value products may be created by growing cyanobacteria on a big scale in an ecologically friendly manner, hence decreasing CO₂ levels (Gören-Sağlam, 2021).

Therefore, biofertilizers containing cyanobacteria may eventually replace chemical fertilizers (Bhuyan et al. 2022). Nitrogen-fixing heterocystous filamentous cyanobacterium *Anabaena azollae* lives in the leaf cavities of the eukaryotic water fern *Azolla pinnata*. *Anabaena azollae* is grown on synthetic medium like BG-110. *Azollae* is a valuable bioresource for agriculture, industry, and medicine. Indole acetic acid, gibberellic acid, fatty acids, polysaccharides, and phenolic compounds were extracted from *A. azollae*. The compounds were microbicidal *in vivo* and *in vitro*. Strong nitrogenase activity is a confirmed biofertilization indication for *A. azollae*. boosted microbial populations boosted dehydrogenase activity and polysaccharide excretion, enhancing soil fertility (Adhikari et al. 2020) (Figure 2).

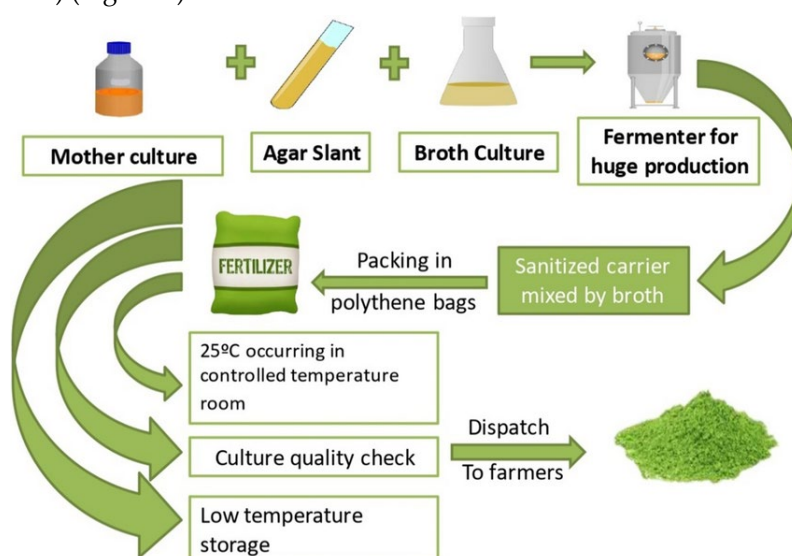


Figure 2. Cyanobacteria cultivation for use in biofertilization.

3. Algae as Biofertilizers

Biofertilizers represent the most effective alternatives to synthetic fertilizers. Chatterjee et al. (2017) indicate that algae species possess significant potential for biofertilizer technology, particularly regarding cost-effectiveness and environmental sustainability. The algal process generates substantial byproducts, and its physicochemical properties render it an effective biofertilizer that enhances soil health. Due to its advantages for the environment, technology, and business, algae represent a highly favorable and sought-after bioresource of the twenty-first century (Mahapatra et al. 2018) (Figure 3).

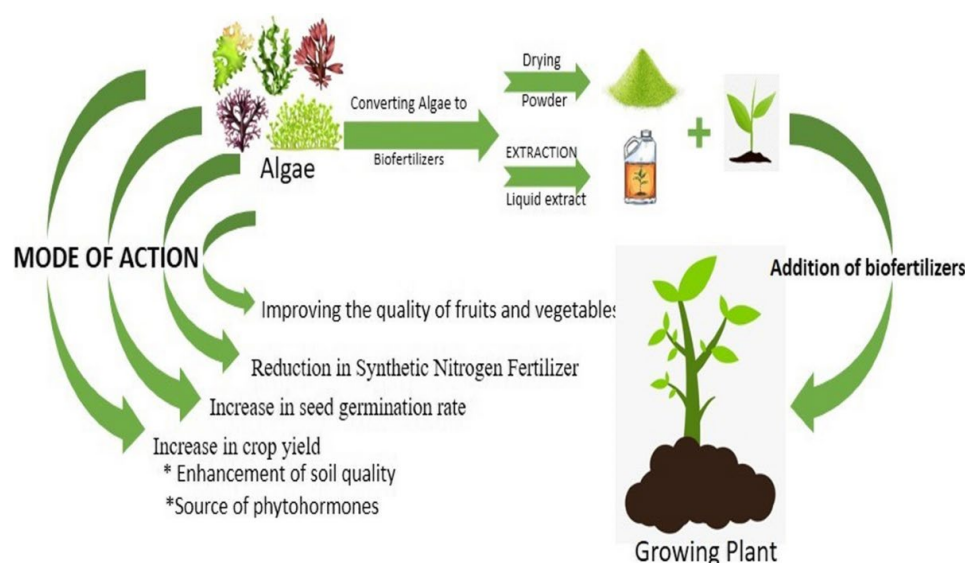


Figure 3. Algae as biological fertilizer.

4. Microalgae as Biofertilizer

According to Fernandes et al. (2023), microalgae are a varied category of tiny, single-celled creatures that include both eukaryotic and prokaryotic microorganisms. Microalgae are seen to be prospective cell factories because of their ability to photosynthesise, which allows them to effectively convert CO₂ into biomass and a variety of products, such as nutrients, biofuels, and numerous high-value chemicals (Sun et al., 2023). Because of these qualities, microalgae are widely used as a valuable biological resource in a variety of industries, such as the food business, the manufacturing of biofuel, the wastewater treatment industry, the cosmetics industry, and the pharmaceutical industry (Khaligh & Asoodeh, 2022). Microalgae are becoming more and more popular in agriculture as biofertilizers because of their high concentration of macro- and micronutrients, bioactive and phytohormones compounds. These interactions between crops and the soil microbiome have a positive biochemical impact on the soil ecosystem (Osorio-Reyes et al., 2023).

Additionally, even in situations with low nutrients, microalgae can thrive and efficiently absorb nitrogen and phosphorus due to their exceptional skills in nutrient recovery for their metabolic activities (De et al., 2019). Conversely, this amazing assemblage of species enriches the soil with organic materials. Microalgae improve the structure, ability to hold onto moisture, and general fertility of the soil by releasing organic chemicals and adding biomass. Furthermore, the development of agricultural products may profit from their ability to create metabolites like phytohormones, polysaccharides, and so on (Guo et al., 2020). Because of their capacity to successfully inhibit or limit the growth of diseases, such as bacteria, nematodes, and fungus, microalgae are often referred to as biocontrol agents or biopesticides (Osorio-Reyes et al., 2023). This is accomplished by producing hydrolytic enzymes and biocidal substances such as majusculic and benzoic acids (Renuka et al., 2018).

Microalgae have a lot of promise for application in agriculture, but their broad usage in these contexts is still hampered by a lack of understanding and scattered knowledge about how they affect soil and plants under a variety of situations (Alvarez et al., 2021). This book highlights recent developments and uses of these microorganisms in the agricultural sector, offering a thorough overview of how microalgae might improve crop output in a sustainable manner.

Common examples of photosynthetic microalgae are bacterial blue algae and eukaryotic green algae. Their potential application in contemporary agriculture is considerable, given their ability to enhance soil nutrient levels and increase the absorption of both macro- and micronutrients. In addition to improving soil fertility and quality, microalgae can generate metabolites and hormones that promote plant growth (Guo et al. 2020). Microalgae serve as an essential source of biofertilizers for agricultural practices (Dineshkumar et al. 2019). The classification of extracts generated by microalgae, encompassing bioactive and high-value products, is dependent on their physicochemical

properties and biological functions. Microalgae display a variety of beneficial traits. Their use in agriculture has attracted considerable interest because of the bioactive compounds that improve plant production (Bello et al. 2021). Microalgal biofertilizers present a renewable and cost-effective solution for farmers aiming to cultivate nutritious organic crops. They promote an environment free from harmful chemicals, positioning themselves as a viable alternative to traditional chemical fertilisers (Dineshkumar et al. 2020). Cyanobacteria play a significant role in enhancing soil organic matter, acting as a potent biofertilizer with the capability to substitute chemical fertilisers. Crop yield and plant growth are enhanced while also promoting soil health (Maqubela et al. 2009). Additionally, algal biomass contains a wealth of metabolites (Jamal Uddin et al. 2019).

5. Fungi as Biofertilizer

Most important taxonomic groups of heterotrophic and eukaryotic living things on Earth are the fungi family, which also includes puffballs, yeast, mildew, and mold. They have benefits for plant development, agricultural yield, and crop protection (Ahmad et al. 2022).

Biofertilizers are composed of biologically active bacterial and fungal strains that improve, increase, change nutrients from an unusable state to useful form (Rastegari et al. 2020). In addition to their intended variety of traits that promote plant development, beneficial fungi help the plant by generating cell wall lysing enzymes such as glycosidase and cellulases, siderophores, gluconase antagonists, and antibiotics. Auxin, gibberellins, cytokinin, zinc, and potassium are also generated together with the solubilization of micronutrients (phosphorus, potassium, and zinc) (Ahmad et al. 2022).

6. Plant Residues as Biological Fertilizers

Similar to other living things, plants may be utilized as biological fertilizers by processing their leftover components, or plant residues, to create environmentally beneficial, biodegradable fertilizers. Banana peels are among the plant leftovers that are utilized as soil biological fertilizers. Because of its flavor and nutritional benefits, bananas are a widely consumed fruit. Large amounts of by-products generated from banana peels are the end result. Research has demonstrated that the macro- and micronutrient-rich peel and bloom of bananas, as well as their anti-inflammatory and anti-oxidative stress qualities, all contribute to excellent health. Due to its advantages, such as improving soil fertility, research is being done on turning banana peels into novel, handcrafted products (Kraithong and Issara 2021). The worldwide biochar project (2012) defines banana peel biochar as “a solid compound generated through the thermo-chemical conversion of biomass in an oxygen-constrained environment” (Comino et al. 2020). Biochar from banana peels is a carbon-rich product. Recent studies have focused a lot of attention on banana peel biochar because of its unique property that improves soil quality (Islam et al. 2019) (Table 6.1).

Table 6.1. Higher plant as biological fertilizer.

Applied Plant	Form of Biofertilizer	Treated Plants	Effect	References
Banana Peels	Biochar	<i>Ipomoea aquatica</i>	Increase the amount of K added to the soil, yet plant growth is not much increased	Islam et al., 2019
<i>Musa paradisiaca</i> L.	Powder	<i>Abelmoschus esculentus</i>	Elevate K and see a noteworthy rise in fruit count, fresh and dry weight per fruit, root length, leaf area, height, and chlorophyll content.	el Barnossi et al., 2021

Coffee	Spent coffee ground	Brassica sp.	increases soil fertility, organic matter, seed emergence, and minerals (N, K, P, and Cu).	Chrysargyris et al., 2021
Peas (pulses food)	Intercropping	Cereal crops	Symbiotic interactions between nodules and rhizobia fix atmospheric nitrogen to replenish soil nitrogen. Pulses reduce greenhouse gas emissions, boost soil organic carbon and water retention, and disrupt cereal disease and weed cycles.	Powers and Thavarajah, 2019
Pomegranate peel	Water extract	<i>Salvia officinalis</i> L	Increased nutritional value, fresh and dry mass, essential oils, carbs, flavonoids, phenolic compounds, and reduction of free radical scavenging compared to plants treated with chemical fertilizers.	Abd-Rabbu et al., 2021

7. Soil Amendment with Compost and Manure

Manure has been used as a fertiliser and trash disposal on farms for millennia (Kumar et al., 2013). Manure was the main source of nutrients for agricultural soil development before chemical fertilisers (Kumar et al., 2013). Cattle dung has been utilised to increase soil fertility by adding organic matter and improving its physical, chemical, and biological qualities (Indraratne et al., 2009).

Manure enhances soil structure and adsorption by lowering volumetric density, increasing porosity, infiltration rate, hydraulic conductivity, and aggregate stability (Abbott et al., 2018). Manure improves soil structure and increases nutrient retention, organic matter content, and water retention by adding nutrients such organic nitrogen or ammonia (Mosebi et al., 2015).

The main benefits of manure application on agricultural land are its ability to improve soil qualities such plant nutrient availability, pH, cation-exchange capacity, and water retention. Bicarbonates, organic anions, and basic cations like Ca²⁺ or Mg²⁺ in manure may neutralise soil acidity (Abbott et al., 2018). Manure application increases soil organic matter and carbon, which increases soil cation-exchange capacity (CEC) (Abbott et al., 2018). Due to its high organic matter concentration, manure helps regenerate organic matter in damaged regions and releases nutrients gradually (Mosebi et al., 2015). Adding this waste to the soil may increase species richness, abundance, and variety (Abbott et al., 2018). Soil biodiversity reduces pathogen and insect populations, releases allelochemicals, raises pH, and increases soil microbial antagonists like Actinobacteria (Abbott et al., 2018).

Generally, manure compost may enhance the physical, chemical, and biological characteristics of soil, similar to other compost varieties. We identify the three categories of attributes that may be referenced (Lazcano et al., 2008):

- The physical qualities of manure compost might fluctuate based on the particular combination of organic components used in the composting process. Nonetheless, manure compost has many physical features, including texture, colour, odour, and moisture content.
- The chemical characteristics of manure compost significantly influence its efficacy as a fertiliser. The principal chemical features of manure compost are nutritional composition, organic matter, pH level, salinity, and heavy metal concentration.

- The biological features of manure compost pertain to microorganisms, including bacteria, fungus, and protozoa, that facilitate the decomposition of organic materials and the release of nutrients. These bacteria may also inhibit plant diseases and enhance soil structure.
- Furthermore, regarding the biological qualities of manure, it is noteworthy that manure compost may attract helpful insects, including earthworms, which contribute to enhancing soil structure and fostering healthy plant development.
- When used correctly, manure serves as a significant source of plant nutrients and enhances soil quality and production (Lazcano et al., 2008).

The increase in plant output due to manure application is due to the nutrients supplied to the soil, the organic matter, the improved water retention capacity, and the general enhancement of the soil's physico-chemical properties (Schlegel et al., 2017). The use of organic nitrogen sources, such as bovine manure, has arisen as a strategy to alleviate reductions in crop yield while concurrently improving soil quality (Hariadi et al., 2016). Soils enriched with manure often demonstrate raised pH levels and improved productivity owing to the augmented availability of nitrogen, phosphate, potassium, calcium, and magnesium for vegetation (Abbott et al., 2018). This organic waste contains essential nutrients necessary for plant growth, and its extended use may benefit plants, even at low application rates (Liu et al., 2018).

Compost enhances soil structure, facilitates physical properties such as water retention and aeration, and enriches chemical features by supplying nutrients and modifying soil pH. Compost enhances the biological characteristics of soil by fostering beneficial microbes and increasing soil fertility (Pergola et al., 2018).

The incorporation of compost into soil enhances its characteristics, including organic matter, retention of water and nutrients, penetration, drainage, compacted opposition, durability against erosion, and tolerance to soil-borne pathogens (Xu et al., 2017). Compost derived from manure offers substantial advantages when integrated into the soil, as the organic matter serves as a nutrient reservoirs, improves the nutrient cycle, boosts cation-exchange capacity (CEC) and pH, and improves the physical properties of the soil, including accumulation, flexibility, volume, pores, root penetration, water-holding capacity, and drainage (Rowen et al., 2019).

Compost promotes the proliferation of soil macrofauna, essential for enhancing soil quality. Moreover, compost gradually releases nutrients that plants can absorb, hence enhancing agricultural output (Xu et al., 2017). Compost comprises vital macronutrients (primarily nitrogen, phosphorus, and potassium) and micronutrients required for plant development, hence enhancing soil fertility (Pergola et al., 2018). Compost enhances microbial activity, hence improving nutrient availability for plants and generating hormone-like substances that may promote crop development (Pergola et al., 2018).

Completed compost comprises highly active microbial communities that can enhance soil biota and microbial community structure, potentially modifying the functions of microorganisms engaged in the biogeochemical cycle, suppressing diseases, promoting plant growth, augmenting nutrient availability, and improving fertiliser use efficiency and plant yield (Abbott et al., 2018). In contrast to chemical fertilisers, manure-based fertilisers may diminish insect proliferation by enhancing the micronutrient composition in plant tissues and/or by augmenting the synthesis of defensive secondary metabolites (Rowen et al., 2019). Establishing appropriate cow manure treatment rates is essential for providing essential nutrients to plants and enhancing soil characteristics (Schlegel et al., 2017).

8. Green Manure

Green manuring is a classic agricultural practice that involves introducing green plant cells into the soil. As a consequence, it boosts soil fertility, promotes biological activity, improves soil health via nutrient mineralization, and lowers agricultural crop production costs. (Asghar, Kataoka, 2022). Furthermore, it improves organic matter and total soil nitrogen concentrations, potentially improving soil physical conditions (Mandal et al., 2003). Increasing the quantity of green manure in the soil boosts natural carbon, while nitrogen may help rice grow more efficiently. As a consequence, green

manure may improve soil fertility, increase crop output, and lower the risk of nitrogen loss (Hu et al., 2022).

8.1. Impact of Green Manure on Crop Growth

Green manuring is a sustainable agriculture approach influences plant morphological characteristics. It efficiently enhances growth parameters by providing enough nutrient levels for crop development (Meng et al., 2019). Decomposed sesbania biomass converts inaccessible nutrients into available forms via soil microorganisms in green manure fields, which shows the impact on growth parameters compared to non-green manure fields and creates sustainable soil conditions for increased crop yield (Sandhya et al., 2022). Significantly, green manure soil fertility and provides a chemical fertilizer substitute. Field tests evaluate its effects on soil physio-chemical characteristics and uptake of nitrogen by crops. It also boosts plant productivity for N fertilizer and increases availability of total organic carbon and nitrogen (Song et al., 2022). It generates an extensive root system, which helps in nutrient uptake, resulting in improved plant growth, a higher leaf area index, and more than the conventional method (application of approved fertilizer dosages alone) (Karmakar et al., 2011). Because of the increased biomass and maximum nutrient absorption in rice crops, it also shows a positive influence on plant growth attributes such as plant height, number of tillers, and dry matter accumulation (Puli et al., 2016) (**Table 8.1**). It also promotes nutrient absorption in plants and influences rice development indices such as plant height, tiller number, and leaf area index due to its residual actions compared to other methods (Parmar et al., 2020).

Table 8.1. Effect of green manure on the growth attributes of different crops.

Crop	Growth parameters	Without Green Manure	With Green Manure	References
Rice	Plant Height	103.16 cm	107.91 cm	Parmar et al. (2020)
	Leaf area index	4.21/m ²	4.39/m ²	
Wheat	Tillers	261/m ²	293/m ²	Sajjad et al. (2018)
Maize	Plant Height	193.2 cm	222.2 cm	Sandhya et al. (2022)
	Cob length	15.3 cm	16.2 cm	
Soyabean	Leaf area	96.4 cm ²	126.4 cm ²	Egbe et al. (2022)
	Number of branches	8	8.3	
	Plant Height	59.2 cm	60.2 cm	
	Length of root	31.3 cm	35.06 cm	
	Leaf number	31.6	33.2s	

Furthermore, green manuring-treated plots exhibit greater biomass (17.89 tons/ha) and a 7.6 percent rise in fertile tillers in wheat crops compared to non-green manuring fields, as soil moisture availability improves, which is a key component in sustainability (Sajjad et al., 2018). However, they also observed that green manure serves the function of increasing enzyme activity, which makes nutrients more accessible, as well as enhancing soil texture, moisture, and other nutrients. Due to an increase in enzyme activity that releases nutrients into the crop, which influence on crop growth attributes such as plant height, number of branches, collar diameter, length of root, number of leaves, and leaf area than other control plots in the cropping system (Egbe et al., 2022).

9. Conclusion

Biofertilizers are one example of a new eco-friendly technology that will be integral to sustainable farming. Biofertilizers improve soil fertility and crop yields due to their higher nutritional content. Biofertilizers may be derived from a wide range of sources. Bacteria (including Nitrobacter, Azotobacter, and Cyanobacter), microalgae and microfungi (including Glomus spp.) are all components of this category. Another option for biofertilizers is the byproducts of microorganisms, such as plants, fungus, or algae. Supporting the principles of sustainable development, microbes and

macro-organism leftovers may boost soil fertility without adding toxins, which is great news for the environment and ecosystems. Plus, they're biodegradable. Green manure is a farming method that has several environmental and agronomic benefits. It is proven to be an effective way to increase crop productivity while reducing the environmental impact of intensive agriculture techniques. It restores soil fertility and increases production potential and sustainability in agricultural systems. Therefore, it is concluded that the incorporation of green manure improves the physical, chemical, and biological properties of the soil. These improvements have an advantageous effect on crop growth and development and ultimately contribute to ensuring long-term sustainable agricultural production for farming communities.

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