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EMPTY FRUIT BUNCH COMPOST AND OIL PALM YIELD IMPROVEMENT: A SYSTEMATIC REVIEW OF AGRONOMIC PERFORMANCE AND SOIL HEALTH OUTCOMES

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Abstract

Empty Fruit Bunch (EFB) is a significant solid biomass residue produced by the palm oil industry, which could potentially be recycled as organic compost. More and more people are promoting the use of EFB compost to improve oil palm productivity, soil quality, and assist in sustainable plantation management. A systematic analysis was conducted to evaluate the impact of EFB compost on oil palm agronomic performance and soil health outcomes. An SLR was conducted in accordance with the PRISMA 2020 guidelines. Scopus, Web of Science, and ScienceDirect were used to identify articles published between 2021 and 2026 that met specific eligibility criteria. EFB compost has been found to have a positive impact on fresh fruit bunch yield, nutrient use efficiency, soil organic carbon, chemical exchange capacity, and microbial activity in the literature reviewed. Depending on the plantation age, compost maturity, application rate, soil type, and environmental conditions, the effectiveness of compost application can vary. The agronomic and environmental benefits are most consistent when EFB compost is integrated with inorganic fertilizers.

Keywords: Empty Fruit Bunch compost, oil palm, soil health, sustainable agriculture, systematic literature review.

INTRODUCTION

Despite occupying only a small portion of cultivated agricultural land, the oil palm (Elaeis guineensis Jacq.) is the world's most productive vegetable oil crop and accounts for over one-third of global vegetable oilseed production (Corley & Tinker, 2016; Murphy et al, 2021). Despite this, the palm oil industry is an important driver for national economic development and employment as well as global food security, since Indonesia has always been the leading producer and exporter of crude palm (CPO) [FAOSTAT, 2025; Murphy et al, 2020]. The palm. The palm oil industry is confronted with a major issue in maintaining high productivity while minimizing environmental impacts due to the increasing international demands for sustainable production systems (Murphy et al, 2021; RSPO, 2020).

In addition to genetic potential and crop management, soil fertility and soil health are important factors for long-term oil palm productivity (Lehmann et al, 2020; Bossio & Co.: 2020). Despite the fact that continuous farming and the application of inorganic fertilizers have resulted significantly in increased production, over-reliance on mineral fertilizer can lead to degradation of soil organic matter, soil structure damage, microbial diversity, and poor nutrient use efficiency (Hoffland's et al, 2020; Sánchez-Monedero & Co.:2021).

At the same time, palm oil mills produce significant amounts of biomass waste during their operating processes. Among these wastes, Empty Fruit Bunches (EFB) constitute one of the largest categories of solid waste, representing roughly 20 to 23 percent of the fresh fruit bunches that are processed (Chiew et al., 2011; Rosenani et al., 2004). Given the annual output of palm oil in Indonesia, millions of tonnes of EFB are produced each year (Murphy et al., 2021). If not managed properly, the buildup of EFB could lead to environmental issues such as emissions of greenhouse gases, problems with waste disposal, and ineffective use of resources (De Corato, 2020; Gebremikael et al., 2020). As a result, transforming EFB into beneficial agricultural materials has become a key method in promoting sustainable palm oil practices and initiatives within the circular bioeconomy (De Corato, 2020).

Composting is recognized as one of the most successful methods for turning EFB into a valuable organic amendment for soil. During the composting process, microbial breakdown stabilizes organic matter, reduces the carbon-to-nitrogen (C/N) ratio, and generates mature compost, which is abundant in organic carbon and vital nutrients for plants, including nitrogen, phosphorus, potassium, calcium, and magnesium (Rosenani et al., 2004; Sharma et al., 2021). In addition to providing nutrients, EFB compost enhances the physical, chemical, and biological characteristics of soil, thus improving the soil's functionality, which is crucial for sustainable crop cultivation (Sánchez-Monedero et al., 2021; Gebremikael et al., 2020). Many experimental investigations have shown that applying EFB compost leads to increased soil organic carbon levels, better aggregate stability, higher cation exchange capacity (CEC), improved moisture retention in soil, boosted microbial activity, and enhanced nutrient cycling (Bakar et al., 2011; Comte et al., 2013). These enhancements often result in improved plant growth, better nutrient absorption, greater efficiency in fertilizer use, and ultimately a higher yield of fresh fruit bunches (Bakar et al., 2011; Goh et al., 2003). Additionally, the combination of EFB compost with inorganic fertilizers has been found to lower the reliance on chemical fertilizers while either maintaining or enhancing crop yields, promoting environmentally sustainable nutrient management practices (Comte et al., 2013; Sánchez-Monedero et al., 2021).

Simultaneously, palm oil mills generate a lot of biomass waste during their running operations. Among these garbage, Empty Fruit Bunches (EFB), which make up around 20 to 23% of the processed fresh fruit bunches, are among the biggest types of solid waste (Rosenani et al., 2004; Chiew et al., 2011). Given Indonesia's yearly palm oil output, millions of tonnes of EFB are generated every year (Murphy et al., 2021). If not handled appropriately, the accumulation of EFB may cause environmental problems like greenhouse gas emissions, garbage disposal problems, and inefficient use of resources (De Corato, 2020; Gebremikael et al., 2020). Consequently, a major strategy in advancing sustainable palm oil practices and projects inside the circular bioeconomy is so to convert EFB into useful agricultural resources (De Corato, 2020).

One of the most effective ways to convert EFB into a useful organic soil amendment is composting, according to experts. During composting, microbial decomposition stabilizes organic materials, lowers the carbon-to-nitrogen (C/N) ratio, and creates mature compost, which is rich in organic carbon and essential nutrients for plants including nitrogen, phosphorus, potassium, calcium, and magnesium (Rosenani et al., 2004; Sharma et al., 2021). Apart from their nutritional value, EFB compost improves the physical, chemical, and biological qualities of soil, therefore enhancing the usefulness of soil—which is essential for sustainable crop production (Sánchez-Monedero et al., 2021; Gebremikael et al., 2020).

Many experimental studies have revealed that using EFB compost helps to increase soil organic carbon levels, improve aggregate stability, raise cation exchange capacity (CEC), better moisture retention in soil, stimulate microbial activity, and enhance nutrient cycling (Bakar et al., 2011; Comte et al., 2013). These improvements usually increase fertilizer utilization efficiency, better nutrient absorption, and ultimately fresh fruit bunches (Bakar et al., 2011; Goh et al., 2003) and hence enhance plant development. Furthermore, using EFB compost with inorganic fertilizers helps to reduce reliance on chemical fertilizers while either preserving or improving crop yields, therefore supporting environmentally friendly nutrient management strategies (Comte et al., 2013; Sánchez-Monedero et al., 2021).

LITERATURE REVIEW

Empty Fruit Bunch Compost in Oil Palm Plantations

The fast growth of the oil palm sector has significantly raised biomass residue production, especially Empty Fruit Bunches (EFB), which make up around 20–23% of the fresh fruit bunches (FFB) handled in palm oil factories (Chiew et al., 2011; Rosenani et al., 2004). The great amount of EFB generated yearly offers possibilities for resource recovery and environmental problems as well (De Corato, 2020). If not handled correctly, EFB builds up at factories or plantations and causes greenhouse gas emissions and poor waste management (Gebremikael et al., 2020). On the other hand, transforming EFB into compost helps to support circular bioeconomy ideas in the palm oil sector by recycling nutrients and enhancing soil quality (De Corato, 2020; Sánchez-Monedero et al., 2021).

Composting converts lignocellulosic biomass into a steady organic fertilizer by regulated environmental circumstances microbic breakdown (Sharma et al., 2021; Singh et al., 2021). Microbes lower the carbon-to-nitrogen (C/N) ratio, stabilize organic matter, and boost nutrient availability during this process (Rosenani et al., 2004). Usually, mature EFB compost has significant amounts of organic carbon, nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients that support crop development (Sharma et al., 2021). Several elements—including feedstock composition, moisture level, aeration, temperature, microbiological inoculants, and composting period—affect compost quality (Singh et al., 2021). Improving nutritional stabilization and speeding decomposition, maximizing these elements helps (Sharma et al., 2021).

Emphasizing the use of agricultural leftovers as renewable resources rather than garbage items, circular agriculture seeks Recycling EFB compost within oil palm plantations helps to lower environmental consequences and waste disposal costs while also lowering reliance on synthetic fertilizers (Gebremikael et al., 2020; Sánchez-

Monedero et al., 2021). Therefore, EFB composting is now a crucial part of sustainable plantation management and integrated nutrition recycling programs (De Corato, 2020).

Agronomic Effects of EFB Compost

Many studies on how organic amendments made from EFB influence oil palm development and productivity have been done (Bakar et al., 2011; Comte et al., 2013). Improved nutrition availability, stronger root development, and more soil moisture retention (Bakar et al., 2011; Goh et al., 2003) have all been found in previous research to enhance vegetative development by applying compost. Particularly under nutrient-deficient or degraded soil conditions, improved root development helps oil palms to absorb nutrients more effectively (Comte et al., 2013).

The good effects of EFB compost come from better fertilizer usage efficiency as well as from nutrition supply (Goh et al., 2003). Organic matter helps to retain nutrients in the root zone by acting as a slow-release source and therefore reduces losses via leaching (Sánchez-Monedero et al., 2021). Therefore, using compost and synthetic fertilizers together usually results in more effective nutrient absorption than using mineral fertilizers by themselves (Bakar et al., 2011; Comte et al., 2013).

Several experimental studies have revealed increases in fresh fruit bunch (FFB) yield following repeated EFB compost application (Bakar et al., 2011). Still, Combe et al., 2013; Sharma et al., 2021; Combe et al., 2013; Sharma et al., 2021; Combe et al., 2013; Combe et al., 2013; Sharma et al., 2021), yield responses differ greatly amongst plantations as many elements including application rate, plantation age, soil texture, rainfall, nutritional status, and management techniques affect agronomic performance. These differences help to explain why consistent recommendations for EFB compost use are still scarce in various production settings (Sánchez-Monedero et al., 2021).

Effects of EFB Compost on Soil Health

Because it combines physical, chemical, and biological activities that define long-term soil production, soil health is becoming more and more accepted as a major indicator of agricultural sustainability (Lehmann et al., 2020; Bossio et al., 2020). Unlike conventional fertility tests that just consider nutrition levels, soil health looks at how well soil can support plant growth, control water, support biodiversity, and preserve ecosystem processes (Karlen et al., 2001).

Reducing bulk density, enhancing aggregate stability, raising permeability, and improving water-holding capacity (Comte et al., 2013; Pagliai et al., 2020), EFB compost helps to improve soil physical characteristics. Particularly in very weathered tropical soils, improvements in soil structure help roots to penetrate, boost aeration, and lower erosion risk—Pagliai et al., 2020.

Chemically, EFB compost significantly adds organic carbon, raises cation exchange capacity (CEC), buffers soil acidity, and boosts nutrient availability (Bakar et al., 2011; Hoffland et al., 2020). Higher organic matter helps nutrients stay in the soil and lowers fertilizer losses, so improving nutrient cycling and long-term soil fertility (Gebremikael et al., 2020). Waste compost in oil palm farms improves soil quality both physically and chemically (Hamdani et all., 2023).

Biologically, EFB compost gives easily decomposable organic materials that spur microbial biomass and enzymatic activity (Pankhurst et al., 2020). Improved microbial activity speeds up nutrient mineralization and helps to create a more resilient soil environment (Gebremikael et al., 2020). Recent research also point to increases in microbial diversity after recurrent organic additions, therefore implying more general ecological advantages outside only nutrition supply (Bossio et al., 2020). Likewise, the increase in the population of soil microbes, especially P-solvent microbes. The population of large fauna in the plant environment treated with EFB compost was higher than in the non-compost environment. Of the 225 macrofauna populations, the earthworm (Lumbicina) is the most species of macrofauna (Hamdani et all., 2022).

Factors Influencing the Effectiveness of EFB Compost

Many studies show favorable responses, but the effectiveness of EFB compost varies greatly depending on the location (Comte et al., 2013). One of the most important elements is compost maturity as immature compost may momentarily bind nitrogen and impede plant development (Sharma et al., 2021). Good compost stabilization helps to minimize phytotoxic effects and guarantee balanced nutrient release (Singh et al., 2021).

The rate of application significantly affects agricultural results as well (Bakar et al., 2011). Not enough compost doesn't help much; too much might throw off nutrients or raise running expenses without enough yield benefits (Comte et al., 2013). Moreover, plantation age affects nutrient need and root architecture, which causes mature and immature palms to respond differently (Goh et al., 2003).

Environmental elements such precipitation, soil type, drainage, and temperature also impact decomposition rates and nutritional availability following field application (Comte et al., 2013). Due to their low organic content and restricted nutrition retention capacity, highly weathered Ultisols and Oxisols usually respond more to organic additions (Hoffland et al., 2020). Therefore, rather than using general compost application rates (Sánchez-Monedero et al., 2021), management recommendations should reflect local soil and climate factors.

Research Gap

Though many studies suggest positive reactions, the efficacy of EFB compost differs significantly depending on the site (Comte et al., 2013). One of the most crucial ingredients is compost maturity as immature compost can temporarily bind nitrogen and slow down plant growth (Sharma et al., 2021). Good compost stabilization helps to reduce phytotoxic effects and guarantee balanced nutrition release (Singh et al., 2021).

The agriculture outcomes are also much influenced by the application rate (Bakar et al., 2011). Not enough compost doesn't help much; too much might throw off nutrients or raise running expenses without enough yield benefits (Comte et al., 2013). Furthermore, plantation age influences root architecture and nutritional requirements, therefore causing adult and young palms to react differently (Goh et al., 2003).

Decomposition rates and nutritional availability following field application are also affected by environmental elements include precipitation, soil type, drainage, and temperature (Comte et al., 2013). Highly weathered Ultisols and Oxisols often respond more to organic additions (Hoffland et al., 2020) because of their low organic content and limited ability to retain nutrients. Therefore, management recommendations should consider local soil and climate conditions instead of depending on general compost application rates (Sánchez-Monedero et al., 2021).

METHOD

Study Design

To combine scientific data on the results of Empty Fruit Bunch (EFB) compost use on oil palm output and soil quality, this study made use of a Systematic Literature Review (SLR). To guarantee openness, reproducibility, and methodical rigor all during the review process, the review was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines.

Five consecutive steps made up the review process: review question formulation, methodical literature search, study selection based on predetermined eligibility criteria, (4) quality evaluation and data extraction, and qualitative evidence synthesis.

Research Questions

The review addressed the following research questions:
RQ1: What are the effects of EFB compost application on oil palm agronomic performance?
RQ2: How does EFB compost influence soil physical, chemical, and biological properties?
RQ3: What factors determine the effectiveness of EFB compost under different plantation conditions?
RQ4: What research gaps remain regarding EFB compost utilization in sustainable oil palm production?

Literature Search Strategy

Using three main scientific databases, a thorough literature search was done: Scopus, Scientific Core Collections on Web of Science, Science Direct. These databases were chosen as they feature excellent peer-reviewed work in soil science, environmental science, agriculture, and plantation management. Using keyword combinations linked with Boolean operators, the search was carried out in July 2026.

Search String

("empty fruit bunch" OR EFB OR "oil palm empty fruit bunch") AND (compost OR composting OR "organic fertilizer") AND ("oil palm" OR Elaeis guineensis) AND (yield OR productivity OR growth OR "soil health" OR "soil quality").

Additional manual searches were performed by examining the reference lists of eligible articles to identify potentially relevant studies not retrieved during the initial database search. To guarantee transparency, consistency, and methodological rigour, study selection was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework with figure 1, below :

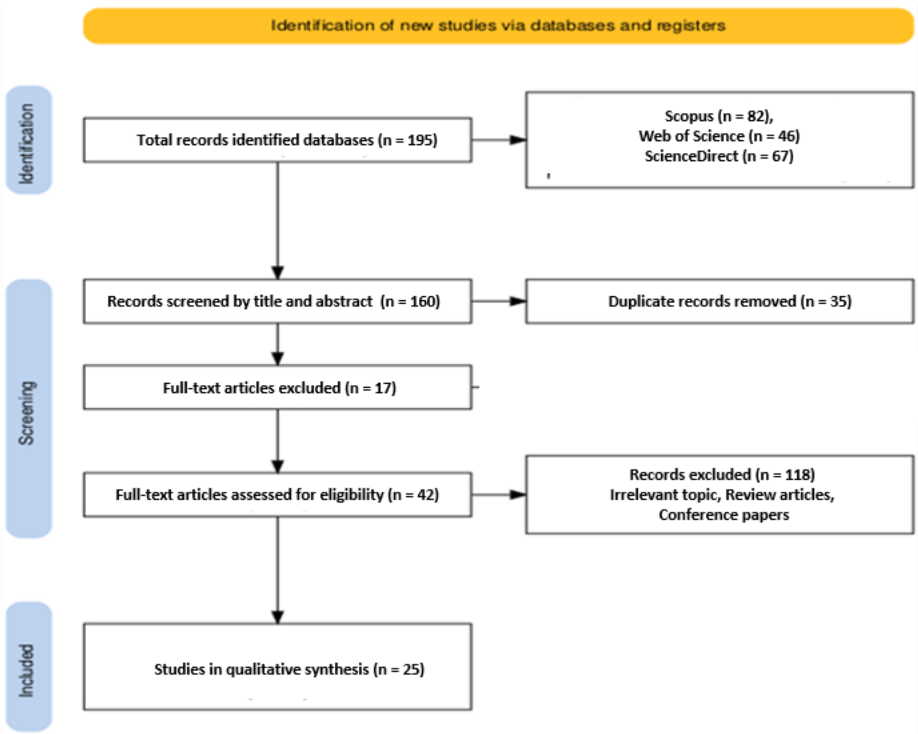

Figure 1. PRISMA 2020 flow diagram of the study selection process

RESULTS AND DISCUSSION

Characteristics of the Included Studies

Qualified studies were added for qualitative synthesis after the PRISMA 2020 screening process. The chosen papers reflected research done in major oil palm-producing nations, especially Indonesia and Malaysia, and came out between 2021 and 2026. Most research used field tests in commercial plantations; fewer were done under greenhouse or nursery settings.

The reviewed research looked at different facets of applying EFB compost, such including its impact on fresh fruit bunch (FFB) output, vegetative development, nutrient uptake, fertilizer use efficiency, and soil health indices. Studies varied greatly in terms of application rates, compost maturity, experimental duration, plantation age, and soil type, suggesting significant technique heterogeneity. Such diversity emphasizes the need of a methodical synthesis to find repeatable patterns and explain variations in reported results.

Effects of EFB Compost on Agronomic Performance

The reviewed research regularly shows that, applied within an integrated approach to nutritional management, EFB compost has the capacity to boost oil palm yield. Positive responses were usually related with more root development, more soil moisture retention, and better nutritional availability.

A number of studies found changes in vegetative development metrics, including stem girth, plant height, leaf output, and canopy structure. The slow release of nutrients from compost and better soil physical properties that encouraged root growth and nutrient absorption helped to explain these reactions.

The main agronomical sign used to assess compost efficiency was noted as fresh fruit bunch (FFB) output. Most research showed good yield responses, however the degree of change depended on plantation age, use rate, soil fertility level, and weather elements. Research on nutrient-poor soils usually showed more advantages than those on reasonably rich soils, therefore indicating that first soil conditions greatly affect compost efficacy.

Many times it was said that combining EFB compost with inorganic fertilizers is a more efficient approach to control nutrients than using either input by itself. Improved nutrient retention and decreased nutrient losses from the organic material provided by compost helped to increase fertilizer use efficiency while also sustaining crop output.

Effects of EFB Compost on Soil Health

The positive effect of EFB compost on soil health was one of the most often observed results in the examined studies. Compost acts not only as a nutrient source but also as a soil conditioner, so physical, chemical, and biological soil characteristics showed improvements.

Physical Characteristics of Soil

Usually, utilizing EFB compost helped to improve soil structure by lowering bulk density, increasing aggregate stability, and improving soil porosity. Improved aeration, root penetration, and water permeability were made possible by better soil structure. Particularly helpful in dry times, improved water-holding capacity helped to increase crop resilience under changing environmental circumstances.

Chemical Properties of Soil

The reviewed studies constantly showed rises in soil organic carbon following recurrent compost treatment. More organic matter helped to buffer soil acidity, increase nutrient retention, and boost cation exchange capacity (CEC). Commonly mentioned advantages were better soil pH and increased availability of vital nutrients like nitrogen, phosphorus, and potassium. These developments helped to lower reliance on artificial fertilizers and boost nutrient utilisation efficiency.

Biological Attributes of Soil

The vast source of organic materials that EFB compost offered for soil bacteria sparked activity and microbial biomass. More microorganisms helped to speed up organic matter breakdown and improve nutrition mineralization. Several studies also noted increases in soil enzyme activity and microbial diversity, therefore implying that ongoing compost use helps to create better and more biologically active soils.

Factors Influencing Compost Effectiveness

Though usually good, the results on EFB compost's efficacy showed significant study-to-study variation. Many interacting elements were found as main influences on agronomic response.

Compost maturity first affected breakdown rates and nutritional availability. Because minerals were more easily available and phytotoxic substances had already broken down, mature compost usually resulted in better crop responses than immature materials.

Second, application rate influenced crop yield and soil enrichment. While excessive rates raised operational expenses without corresponding yield improvement, moderate application rates usually gave balanced nutrition.

Third, compost performance was greatly influenced by plantation features including palm age, soil texture, drainage, and weather conditions. Highly degraded tropical soils with low organic matter content usually exhibited more advances than somewhat fertile soils.

Integration of EFB compost with mineral fertilizers ultimately seemed to offer continuously superior agronomic performance than either method by itself, therefore confirming integrated nutrient management to be the best approach for sustainable oil palm production.

Discussion

The results combined in this review show that EFB compost is a good organic amendment that can improve both soil quality and oil palm yield at once. Unlike mineral fertilizers, which mostly provide nutrients, compost improves the physical, chemical, and biological performance of soil, therefore fostering more ideal circumstances for long-term crop development.

The rise in soil organic carbon noted in several studies is especially significant as soil organic matter acts as the basis for nutrient cycling, water retention, microbiological activity, and soil structure stability. These developments help to boost crop output and build more resiliency against environmental stress and temperature fluctuation.

Still, studies show that compost shouldn't be regarded as a universal replacement for inorganic fertilizers. Rather, the best results usually come from integrated nutrition management, which uses organic and mineral nutrient sources in line with the needs of the crop and the site-specific soil conditions.

From a sustainability standpoint, using EFB compost helps to apply circular bioeconomy ideas by turning waste from palm oil mills into useful agricultural inputs. This method helps with environmentally sound plantation management, lowers dependency on chemical fertilizers, lessens trash buildup, and helps to sequester carbon. Thus, greater acceptance of EFB compost application could help to boost long-term plantation output and assist to meet sustainability certification criteria.

The reviewed studies taken together point to great promise for EFB compost to become a regular part of sustainable oil palm nutritional management. To support evidence-based recommendations for commercial plantations, future research should stress long-term field studies, consistent application techniques, economic viability analyses, greenhouse gas evaluations, and integrated analyses of productivity, soil health, and environmental performance.

CONCLUSION

Using the PRISMA 2020 structure, this organized review synthesized present data on the effects of empty fruit bunch (EFB) compost application on soil health and oil palm agronomic performance. The reviewed research shows that EFB compost could help to keep oil palm production sustainable by raising soil quality and crop yields. EFB compost, an organic soil amendment, not only provides vital nutrients but also improves the physical, chemical, and biological qualities of the soil, therefore fostering long-term soil health and nutrient cycling.

The results show that better nutrition availability, more effective fertilizer utilization, more soil moisture retention, and better root development are the main agronomic advantages of EFB compost. Especially when EFB compost is combined with suitable inorganic fertilizer treatment, these improvements help to increase fresh fruit bunch (FFB) output and healthier plant development. Moreover, recurrent compost addition helps indicators of sustainable soil health—such as increased soil organic carbon, better cation exchange capacity, strengthened microbial activity, and improved structural stability—all of which are critical indicators.

However, multiple site-specific elements including compost maturity, application rate, plantation age, soil qualities, weather conditions, and general plantation management affect the efficacy of EFB compost. Therefore, one piece of advice cannot be used everywhere across all oil palm growing methods. Rather, local environmental factors should guide compost management and it should be included site-specifically in nutrient management plans.

In addition to that review pointed out some knowledge gaps. Most research now focuses on short-term agricultural reactions, but long-term analyses of soil health, carbon sequestration, greenhouse gas reduction, and economic viability are still limited. Furthermore, great methodologic variation across investigations—including variations in compost properties, experimental length, and response indicators—makes straight comparison challenging and underlines the need of consistent research techniques.

All things considered, EFB compost helps to create a circular bioeconomy by transforming waste from palm oil mills into useful agricultural resources that supports sustainable nutrient management in oil palm plantations. Future studies should give long-term, multi-location field trials with consistent procedures and integrated evaluations of production, soil health, environmental performance, and financial viability top attention. Such proof will support scientific recommendations for more widespread use of EFB compost in sustainable oil palm farming and help to realize environmental sustainability and resource-efficient agricultural output.

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