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RESEARCH ARTICLE

The Need to Develop a Cost-Effective Novel Biochemical Fertilizer to Control Leaching Problems for Sustainable Oil Palm Production: A Short Note on Special Reference to the Socio-Economic Aspect

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ABSTRACT

The objectives of this review paper were to examine the significance of reducing fertilisation costs from both social and economic viewpoints and to discuss the benefits of the overall benefits of biofertilizers in the oil palm plantation, with special reference to nutrient leaching. Based on this brief analysis, creating an affordable biochemical fertiliser for sustainable growth and increased oil palm yield can tackle socioeconomic issues in the business. It can enhance farmers' profitability, foster rural development, lower production expenses, augment income for small-scale farmers, encourage social acceptance, generate new employment prospects, stimulate economic expansion, boost crop yields, improve soil fertility, and contribute to long-term environmental sustainability. This research paper highlights the necessity of creating an affordable biochemical fertiliser to promote sustainable growth and yield production in the oil palm sector, with a particular emphasis on addressing the socio-economic component of the business. Using biochemical fertilizers in oil palm production effectively addresses leaching problems, supports sustainable nutrient management, and promotes environmentally friendly practices. By embracing biochemical fertilizers, the oil palm industry can pursue a pathway towards long-term sustainability and environmental stewardship.

INTRODUCTION

Presently, within Malaysia's context, fertilizer through a standard practice application is regarded as a financially efficient method of fertilization. This is primarily due to its favorable impact on the cost of fertilization and the total cost incurred per palm oil tree within a hectare of land. Nevertheless, an additional concept exists to decrease further the expenses associated with fertilizers and workforce per acre, enhancing cost-effectiveness. The present short note aims to discuss the importance of reducing fertilization costs from social and economic perspectives (Sudradjat et al., 2018; Ng, 1977,1979). Many problems and studies have been reported on the suggestions for managing nutrient deficiency in oil palm plantations (Amiruddin et al., 2017; Broschat, 2009). Oil palm has become one of many countries' most important cash crops, contributing significantly to rural and regional development. However, the rapid expansion of oil palm plantations has raised concerns about its environmental and social impacts (Mengel & Kirkby, 1987).

On the one hand, the development of oil palm plantations has contributed to economic growth and livelihood improvement for rural communities. On the other hand, it has also led to deforestation, loss of biodiversity, and agrarian conflicts. To continue benefiting from the oil palm industry while minimizing its negative impacts, there is a need for the development of a cost-effective biochemical fertilizer. This fertilizer should promote sustainable oil palm growth and yield production and address the industry's socio-economic aspects. By developing a cost-effective biochemical fertilizer specifically designed for oil palm, we can address the environmental concerns associated with conventional fertilizers and promote sustainable growth. Additionally, this would help ensure that the economic benefits of oil palm production are distributed equitably among farmers and communities while reducing conflicts over land and resources (Goh, 2004, 2005).

The objectives of this review paper were to examine the significance of reducing fertilisation costs from both social and economic viewpoints and to discuss the benefits of the overall benefits of biofertilizers in the oil palm plantation, with special reference to nutrient leaching

2. The need to further reduce the fertilization costs

Oil palm (OP) (*Elaeis guineensis* Jacq.) is an agricultural product of significant economic importance in Malaysia and Indonesia. Optimum growth and fresh fruit production need a substantial quantity of nutrients, hence incurring costs for the operation. Nevertheless, the land that is now accessible for the growth of organic produce often has a diminished degree of fertility (Sudradjat et al., 2018). Hence, incorporating essential nutrients in the form of fertilizers becomes imperative. The knowledge regarding the soil nutrient status and the nutrient levels in OP leaves is of utmost importance to determine the appropriate use of fertilizers (Ng, 1977,1979). The physiological needs of OP need the presence of enough macronutrients and appropriate fertilization rates within the designated planted area to facilitate optimal growth and achieve optimum yield (Broschat, 2009).

According to previous studies conducted by Goh (2004, 2005), fertiliser management is a significant component of the overall budget for managing oil palm (OP) crops. The majority of the production cost in Malaysia is allocated towards the procurement of fertilizers, accounting for at least 85% or more. In conjunction with the nitrogen leaching caused by excessive precipitation in Malaysia (Fairhurst and Mutert, 1999), it is necessary to determine the ideal quantity and application rate of fertilizers to achieve optimal outcomes and maximize productivity while minimizing expenses (Sudradjat et al., 2018). Fertilizers, which constitute 70-80% of the total production cost, are the costliest input in the growth of OP (Goh and Teo, 2008). According to previous research (Tohiruddin et al., 2010), using fertilizers has been found to enhance OP yields by 50-80% on soils with optimal fertility. However, it should be noted that the extensive utilization of fertilizers, the escalating costs of imported fertilizers, and the volatile economic conditions contribute to the increased production expenses in Malaysia Goh (2004, 2005).

Numerous trial studies have examined recommendations for economically optimal nutrient management in OP plantations (Goh and Chew, 1995; Goh et al., 1993, 1996, 1998, 1999, 2000, 2003; Corley and Tinker, 2003a, 2003b; Kee and Goh, 2006). The research above typically examined various soil types, meteorological variables, ages of organic plantations, the genetic capacity of planting materials, tree spacing, groundcover conditions, soil fertility (Breure, 2003; Hardter, 1999), as well as rates and timing of fertilizer treatments aimed at mitigating nutrient losses (Goh and Hardter, 2003). In addition, the significance of minimizing chemical fertilizers during the early growth phase (Agamuthu and Broughton, 1985; Tarmizi and Mohd, 2006) is comparable to the importance of the agricultural methodologies employed in organic production.

Recently, Peng et al. (2022) proposed a new type of biochemical fertilizer through the evaluation of the Universiti Putra Malaysia (UPM) biochemical fertilizer (Treatment; T2) on immature OP plants. The purpose of this study is to compare the nutrient levels (nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and boron (B)) and vegetative parameters (frond length (FL), frond number of leaves (FNL), frond width (FW), frond thickness (FT), chlorophyll index (CI), and canopy) of immature oil palm (OP) leaflets treated with T2, to evaluate their differences with the well-established T1 treatment in Malaysia. The primary aims of this study were: a) to ascertain the chemical parameters of soil samples before the implementation of treatments at the Telang OP plantation in Kuala Lipis (Pahang), during the period between T1 and T2; b) to determine the fluctuations in the concentrations of the six nutrients in the OP leaflets at the trial site between T1 and T2; c) to assess the variations in the six vegetative parameters at the trial sites between T1 and T2; and d) to comprehend the associations between the nutrient concentrations in the OP leaflets and the vegetative parameters at the trial sites between T1 and T2. In their study, Peng et al. (27) observed that there was no statistically significant variation ($P > 0.05$) in the nutritional levels and vegetative parameters of the six leaflets and six vegetative parameters between T1 and T2. The findings of this study indicate that the rates of T1 and T2 used were sufficient to supply the necessary nutrients for supporting the vegetative development of OP throughout its juvenile stage. The combination of T2 fertilizers per hectare is projected to cost savings of RM 1113.43 or 250 USD. Additionally, reducing the number of rounds of T2 fertilizer application by RM 133.85 or 30 USD would contribute to further cost savings—the expected cost savings per hectare amount to at least RM 1247.25 or 280 USD. Based only on the use of T2 fertilizer per hectare, the economic advantage resulting from the reduction in overall costs is projected to be a minimum of 10.6%. In conclusion, their finding proposed using T2 as an innovative, economically viable, and alternative biofertilizer intervention for enhanced management of the underdeveloped OP plantation in Malaysia.

3. Socio-Economic Benefits of Biochemical Fertilizer Usage

From an economic aspect, many studies indicated that biochemical fertilizers can increase profitability and cost savings for oil palm farmers. This is because biochemical fertilizers are tailored to the specific nutrient requirements of oil palm, resulting in improved nutrient uptake and utilization. Furthermore, using biochemical fertilizers can reduce the dependency on expensive synthetic fertilizers, which can account for a significant portion of the production cost. Farmers can improve their profitability and economic viability by reducing production costs while maintaining sustainable oil palm cultivation practices (Dharmawan et al., 2020; Bakar et al., 2010; Siang et al, 2022; Munadi et al., 2021; Lim et al., 2021).

In Indonesia, for example, the socio-economic aspect of oil palm production is essential. This is because it is a significant driver of rural development and contributes significantly to the country's economy. However, there are also challenges related to land tenure, labour rights, and income disparities within the industry. Developing a cost-effective biochemical fertilizer for oil palm production could address these challenges. It can provide smallholder farmers with a more affordable option for fertilizers, reducing their production costs and increasing their income. Moreover, promoting the use of biochemical fertilizers can also contribute to social acceptability by addressing concerns related to environmental sustainability and protecting the natural environment. Developing a cost-effective biochemical fertilizer for oil palm production can also have positive socio-economic impacts by reducing reliance on chemical fertilizers (Santosa,2023; Heriyanto et al., 2019; Darras et al., 2019; Reinhart et al., 2022; Zainuddin et al., 2022; Uwumarongie-Iloria et al., 2012).

Furthermore, investing in developing a cost-effective biochemical fertilizer for oil palm production can have long-term benefits for the environment and the economy. By reducing the reliance on chemical fertilizers, which can have negative environmental impacts such as soil degradation and water pollution, biochemical fertilizers can contribute to oil palm cultivation's sustainability and long-term viability (Islami et al., 2011). Moreover, reducing the use of chemical fertilisers can help mitigate the potential detrimental effects on human health and biodiversity. Developing a cost-effective biochemical fertilizer for sustainable oil palm growth and yield production can have significant socio-economic benefits. In summary, developing a cost-effective biochemical fertilizer for oil palm production holds great potential to address socioeconomic challenges in the industry. It can improve profitability and economic viability for farmers, contribute to rural development, reduce production costs, increase income for smallholder farmers, promote social acceptability, and contribute to long-term environmental sustainability.

Developing a cost-effective biochemical fertilizer for oil palm production can have positive socio-economic impacts by reducing the reliance on expensive chemical fertilizers and lowering production costs, thereby increasing profitability for farmers (Varina et al., 2020). Furthermore, it can create new job opportunities and stimulate economic growth in oil palm-producing regions. Furthermore, developing a cost-effective biochemical fertilizer for oil palm production can lead to increased efficiency in nutrient uptake by the plants, resulting in improved crop yields and higher overall productivity. Additionally, biochemical fertilizers can improve soil fertility and nutrient availability, making healthier oil palm trees more resistant to diseases and pests. Developing a cost-effective biochemical fertilizer for sustainable oil palm growth and yield production can have significant socio-economic impacts. Developing a cost-effective biochemical fertilizer for sustainable oil palm growth and yield production can have significant socio-economic impacts.

4. Biochemical Fertilizers Usage in Mitigating Leaching Issues for Sustainable Oil Palm Cultivation

Besides the economic ramifications, nutrient leaching in oil palm plantations also has social implications. Decreased crop productivity can lead to job insecurity for plantation workers and the broader community, potentially exacerbating poverty and inequality in the region. As such, addressing nutrient leaching is not only crucial for the sustainability and profitability of oil palm cultivation but also for the well-being of the individuals and communities reliant on this industry for their livelihoods (Pupathy & Sundian, 2020; Pardon et al., 2017). In order to mitigate the socio-economic impacts of nutrient leaching, a multi-faceted approach is needed, which may encompass the use of biochemical fertilizers, adoption of best management practices, and capacity-building initiatives. By integrating sustainable agricultural practices with an emphasis on nutrient management, we can work towards mitigating the socio-economic challenges associated with nutrient leaching in oil palm plantations, ultimately contributing to the long-term sustainability of the industry and the well-being of those dependent on it (Manan et al., 2018; Isaac, 2017; Abas et al., 2021; Kadir et al., 2020). **Table 1** shows the summary of common characteristics for the comparison of chemical, organic and biofertilizers (Sundram et al., 2019).

Table 1. Comparison between chemical, organic and biofertilisers.

Characteristics	**Fertilizer**		
	Chemical	**Organic**	**Biological**
Raw material	Non-renewable	Renewable	Renewable
Nutrient release	Soluble, easily available	Balanced, slow, easily available	Very slow
Nutrient effect	Direct, fast	Direct	Indirect
Toxicity	Overuse can cause toxicity to the soil	Decomposition of harmful substances	Decomposition of harmful substances
Soil structure	Create residual effect on soil texture	Soil structure improvement	Soil structure improvement
Improvement of plant	Promote growth and root development	Promote growth and root development	Promote growth and root development
Water retention	No	Increase soil water availability	Increases soil water availability
Biodiversity in soil	Deteriorates microbial population	Encourages growth of beneficial microorganisms	Enriches biodiversity of microorganisms

Nutrients in chemical fertilizers are typically soluble and readily available to crops, resulting in immediate and significant improvement in crop growth. However, the primary focus of these synthetic fertilizers is on crop growth, with less attention to soil health. Overuse of chemical fertilizers can negatively impact soil within cultivation areas, leading to changes in its physical, chemical, and biological properties. Common consequences include nutrient leaching, altered soil pH, reduced biodiversity of soil microorganisms, increased disease susceptibility, and loss of soil fertility (Mishra and Dash, 2014). To reduce chemical dependency and preserve soil health and fertility in oil palm plantations, one effective method is integrating chemical fertilizers with organic matter and effective microorganisms during manuring activities. This integration improves nutrient mobilization from both chemical and organic sources, leveraging organic matter to enhance soil biological activities. With proper dosage and fertilizer placement methods, bio-organic and bio-chemical fertilizers can supply a balanced amount of nutrients to support plant health and promote vegetative growth (Bender et al., 2016).

Bio-organic and bio-chemical fertilizers are commonly combined with chemical fertilizers to fulfill crop nutritional requirements. Organic matter can be sourced from plants, animals, or minerals like zeolite and azomite. Plant-based organic materials such as empty fruit bunch (EFB), palm kernel shell (PKS), palm oil mill effluent (POME), cocoa shell, and coffee dregs are widely recognized. Incorporating organic materials into fertilizer production helps to retain moisture, control nutrient release for crop needs, and integrate beneficial microorganisms that break down locked nutrients in the soil. This conditioning process involves the gradual release of organic ingredients. Moreover, according to Abu Bakar et al. (2011), applying plant-based organic matter like EFB as mulch and nutrient source in oil palm fields enhances soil fertility and sustains crop production over the long term.

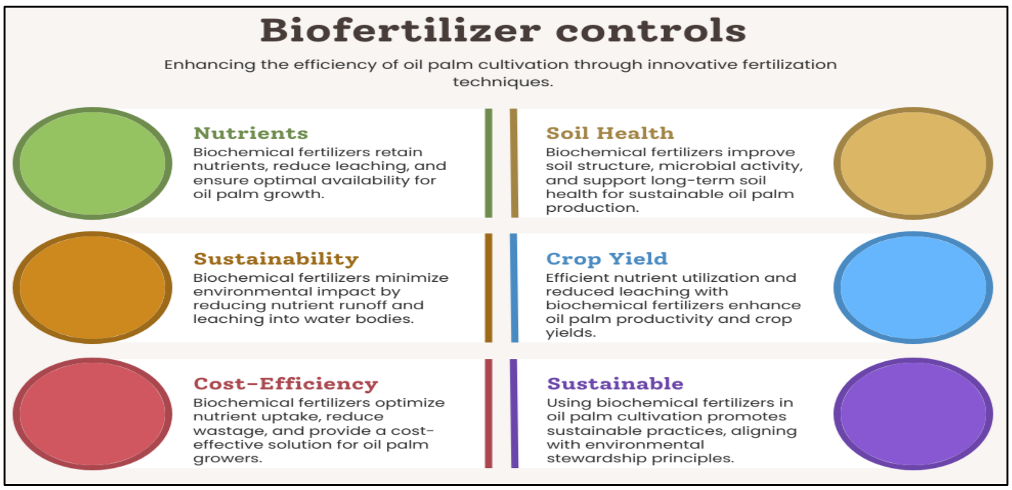

Figure *2*. The overall benefits of biofertilizers in the oil palm plantation.

The benefits of integrating organic matter and effective microorganisms have become increasingly recognized, especially in these recent years due to the enforcement of sustainable policies and ESG compliance. This integration not only improves soil health and fertility but also aligns with environmental stewardship principles. By enhancing nutrient mobilization and supporting soil biological activity, these practices contribute to sustainable agricultural systems. Additional benefits of applying biofertilizers in oil palm plantations include:

4.1) Enhanced Nutrient Management

Biochemical fertilizers retain nutrients, reduce leaching, and ensure optimal availability for oil palm growth. By minimizing nutrient loss, these fertilizers promote healthier soil and more efficient nutrient uptake. Consequently, they support sustainable agricultural practices and enhance crop yields, contributing to the long-term viability of oil palm cultivation. Leaching is a major concern in oil palm production, as it leads to the loss of essential nutrients from the soil and can result in environmental pollution. To address this issue, the use of biochemical fertilizers has emerged as a potential solution. Biochemical fertilizers are designed to release nutrients gradually, ensuring that they are available to the plants over an extended period of time (Okur, 2018; Patel et al., 2014; Calabi-Floody et al., 2018).

As a result, implementing biochemical fertilizers in oil palm production can effectively address leaching problems, support sustainable nutrient management, and promote environmentally-friendly practices for the long-term sustainability of the oil palm industry. The use of biochemical fertilizers in oil palm production has been identified as a beneficial way to control leaching problems and promote sustainable nutrient management. Biochemical fertilizers play a crucial role in addressing the leaching problems associated with oil palm production by providing a sustainable solution to nutrient management.

4.2) Enhance Sustainability by Reducing Environmental Impact

Biochemical fertilizers mitigate environmental impact by reducing nutrient runoff and leaching into water bodies. These fertilizers contain organic matter and beneficial microbes as some added values that help retain moisture, regulate nutrient release, and minimize the risk of chemical leaching, thus protecting groundwater. Incorporating biochemical fertilizers into oil palm production allows farmers to reduce leaching, promote sustainable nutrient management, and adopt environmentally-friendly practices. Furthermore, using biochemical fertilizers decreases reliance on traditional chemical fertilizers, aligning with current policies aimed at reducing chemical dependency in plantation routines. Overall, the use of biochemical fertilizers in oil palm production can help control leaching problems, promote sustainable nutrient management, and contribute to environmentally-friendly practices, ensuring the long-term viability of the oil palm industry (Bhardwaj et al., 2014; Ramasamy et al., 2020; Ka et al., 2018; Barman et al., 2019).

Therefore, using biochemical fertilizers instead of traditional chemical fertilizers significantly mitigates the negative environmental impacts associated with conventional methods. This transition to environmentally-friendly practices aligns with the increasing global focus on sustainable agriculture and responsible resource management. By adopting biochemical fertilizers, farmers help to reduce pollution and preserve natural ecosystems, particularly within their local environment. This transition also bolsters international efforts to combat climate change and promote biodiversity, demonstrating a broader commitment to ecological stewardship and the overall health of our planet.

4.3) Cost-Efficiency Through Waste Reduction

Biochemical fertilizers optimize nutrient uptake, reduce wastage, and offer a cost-effective solution for oil palm growers, particularly in large plantations. Nutrient leaching in oil palm plantations presents significant socio-economic challenges, as it not only reduces soil fertility and crop productivity but also impacts the livelihoods of farmers and workers in the industry. As nutrients leach away from the root zone, farmers incur additional costs to replenish the lost nutrients with increased fertilizer applications. Over the past 20 years, fertilization dosages in oil palm cultivation have nearly doubled due to soil exhaustion, directly affecting total operational costs. This benefits both plantations and smallholders. This additional financial burden can strain the already challenging economic conditions faced by many small-scale oil palm farmers. Moreover, reduced crop yields resulting from nutrient leaching can directly impact the income and food security of many families and communities relying on oil palm cultivation for their sustenance (Annisa et al., 2022; Hawa et al., 2021; Apori et al., 2020; Truckell et al., 2019; Maluin et al., 2020). Through the application of biochemical fertilizers, plantations can reduce the number of manuring rounds to just three, compared to the six to seven rounds typically required with chemical fertilizers, especially straight fertilizers. This reduction not only lowers input costs but also cuts labour expenses while minimizing the potential for nutrient leaching.

4.4) Improve Soil Health and Fertility

Biochemical fertilizers improve soil structure, enhance microbial activity, and support long-term soil health, ensuring sustainable oil palm production. Maintaining soil health is crucial, given that an oil palm planting cycle lasts nearly 25 years. Plantations should aim to minimize the risk of soil depletion in the cultivation areas. Using biochemical fertilizers in oil palm cultivation minimizes leaching, boosts nutrient uptake efficiency, enhances soil fertility and structure, reduces soil erosion, and promotes environmentally-friendly practices. This holistic approach not only supports the longevity of the crops but also aligns with sustainable agricultural practices essential for the industry's future.

Moreover, including organic matter in biochemical fertilizers, such as compost from empty fruit bunches and other plant-based organic materials, has a multi-faceted impact on soil health. These organic components not only supply essential nutrients but also contribute to improving soil structure, fertility and enhancing cation exchange capacity for optimal nutrients uptake by oil palms. By improving the soil's water-holding capacity and overall soil properties, biochemical fertilizers create a more favorable environment for sustained oil palm vegetative growth and, most importantly, increased yield production in oil palm cultivation. Combining biochemical fertilizers thus goes beyond addressing leaching problems to create a holistic approach towards sustainable oil palm production (Sundram et al., 2019; Mahmud & Chong, 2022).

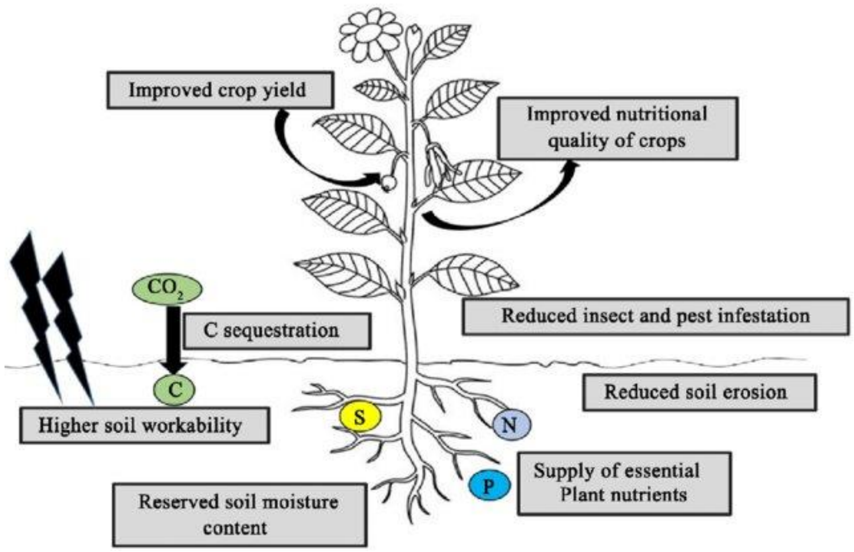

Figure *3*. Benefits of using compost in agriculture for soil health and fertility (Sultana et al., 2020).

4.5) Boosting Crop Yields with Effective Microorganisms

According to Awad et al., (2012), efficient nutrient utilization and reduced leaching with biochemical fertilizers enhance oil palm productivity and crop yields. The gradual release of nutrients by biochemical fertilizers ensures that essential elements are available to the oil palm trees over an extended period, promoting long-term nutrient uptake efficiency. This minimises leaching and improves the overall health and productivity of the oil palm plantations. As the leaching percentage is reduced, the fertilizer applied is optimally absorbed by crops, minimizing losses. This improvement positively impacts labor efficiency and total operational cost of the plantations. Furthermore, improved nutrient management supports sustainable agricultural practices, thereby enhancing the overall economic and environmental benefits for the plantations.

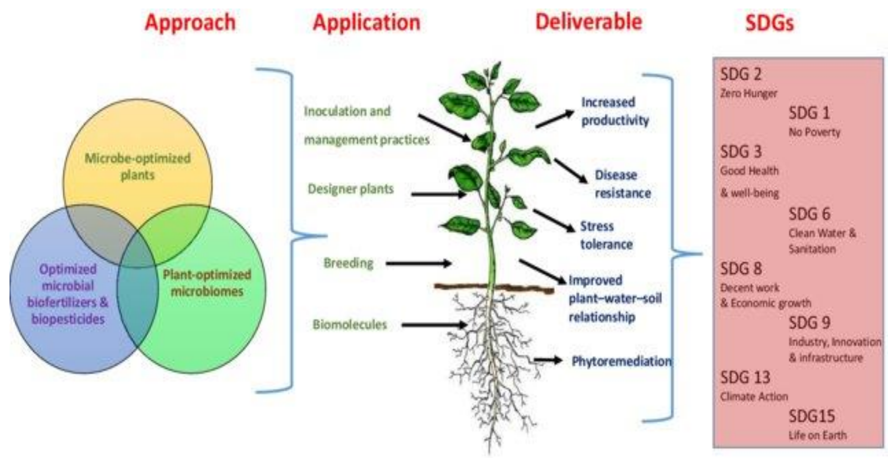

Figure 1. Sustainable increase in crop cultivation activities by harnessing microbial technology is important to deliver Sustainable Development Goals (SDGs) (Trivedi et al., 2017).

Although the increased use of synthetic and chemical inputs has boosted agricultural yields, the management practices supporting this approach have caused environmental degradation and rendered agricultural systems unsustainable (Armstrong and Taylor, 2014). Integrating effective microorganisms as an added value into fertilizers is becoming a standard practice in fertilizer manufacturing to meet ESG compliance and reduce chemical dependency in plantation routines. These microorganisms not only enhance plant growth and yield productivity but also improve soil quality and fertility. Additionally, specific effective microbes, such as N-Fixers, P-Solubilizers, and K-Mobilizers, help maintain a healthy soil ecology. This helps prevent soil-borne plant diseases caused by pathogenic microorganisms and parasites (Younas et al., 2022). Figure 4 shows the potential usage of soil microbes as a biofertilizer for sustainable oil palm cultivation.

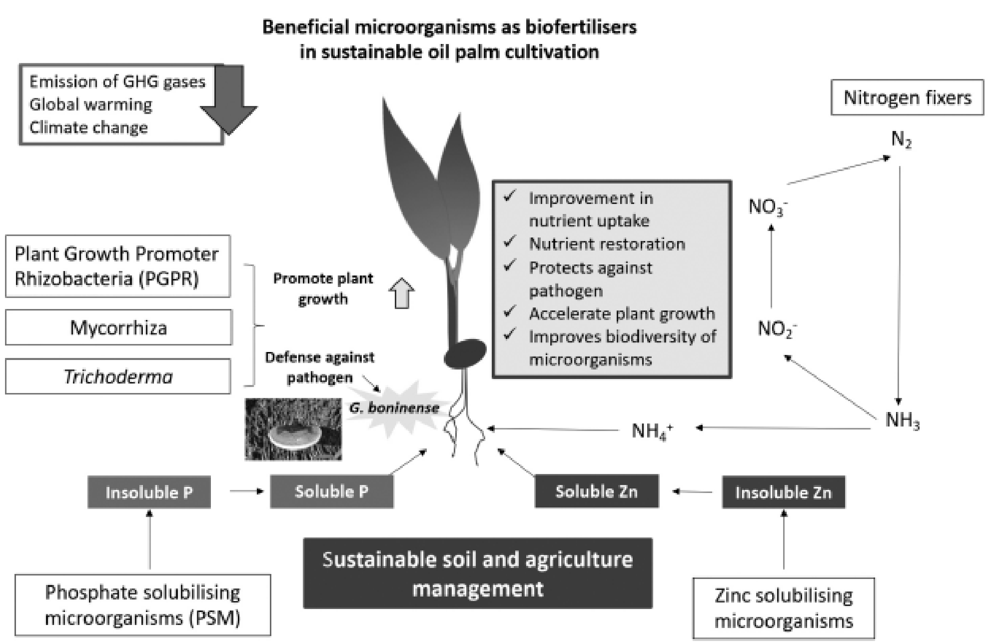

Figure 2. Potential usage of soil microbes as a biofertilizer for sustainable oil palm cultivation (Sundram et

al., 2019).

4.6) Sustainable Practices Aligned with Environmental Stewardship Principles

Utilizing biochemical fertilizers in oil palm cultivation fosters sustainable practices and aligns with environmental stewardship principles. This approach minimizes leaching, enhances nutrient uptake efficiency, and supports sustainable oil palm production. Furthermore, biochemical fertilizers often contain organic matter, such as compost or plant-based ingredients, which can enhance soil fertility and structure. These organic components provide nutrients to the oil palm trees, improve water-holding capacity, and reduce soil erosion (Khan et al., 2018; Kaur & Kaur, 2018).

The potential of biochemical fertilizers to enhance nutrient management and crop productivity extends beyond oil palm plantations, offering a promising avenue for sustainable agricultural development. As such, further research and practical implementation of biochemical fertilizers may pave the way for more resilient and environmentally friendly agricultural practices. While the use of biochemical fertilizers in oil palm production has been highlighted as beneficial, it is important to consider the opposing argument that the widespread use of these fertilizers may not be without drawbacks. Some studies have raised concerns about the potential negative impacts of biochemical fertilizers on soil ecology and microbial diversity. As such, while biochemical fertilizers offer potential benefits, further research, monitoring, and thoughtful consideration of their impacts are necessary to ensure a balanced approach to nutrient management and environmental stewardship in agricultural systems. This holistic perspective will help to navigate the complexities of adopting biochemical fertilizers and pave the way for resilient and environmentally friendly agricultural practices.

5. CONCLUDING REMARKS

In sum, the development of a cost-effective biochemical fertilizer for sustainable oil palm growth and yield production has the potential to address socioeconomic challenges in the industry. It can improve profitability for farmers, contribute to rural development, reduce production costs, increase income for smallholder farmers, promote social acceptability, create new job opportunities, stimulate economic growth, improve crop yields, enhance soil fertility, and contribute to long-term environmental sustainability. This research note emphasizes the need to develop a cost-effective biochemical fertilizer for sustainable oil palm growth and yield production, explicitly addressing the industry's socio-economic aspect. Using biochemical fertilizers in oil palm production effectively addresses leaching problems, supports sustainable nutrient management, and promotes environmentally friendly practices. By embracing biochemical fertilizers, the oil palm industry can pursue a pathway towards long-term sustainability and environmental stewardship.

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