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Implementation of Agroforestry Concept on Oil Palm Plantation: Prospects and Challenges

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ABSTRACT

In Indonesia, oil palm plantations are often associated with problems such as deforestation, biodiversity loss, and land conflicts. Agroforestry is a sustainable alternative that combines oil palm plantations with other agricultural or forestry crops to reduce environmental impacts. Most people believe that this idea can increase land productivity, improve ecosystem quality, and provide socio-economic benefits to communities living around it. However, the use of agroforestry in the oil palm industry still faces technical, social, and institutional problems that require further research. The purpose of this study is to examine the prospects and challenges of implementing the agroforestry concept in oil palm plantations in Indonesia. In addition, this study aims to provide an understanding of the potential of agroforestry as an alternative method to achieve more sustainable plantation practices. This research uses a qualitative method with a literature review approach. The data were collected from environmental organization reports, scientific publications, and relevant policy documents. Across various scales of oil palm plantations, the analysis was conducted in a descriptive-critical manner with a focus on success patterns, implementation barriers, and opportunities for agroforestry integration. According to research, agroforestry can increase biodiversity, reduce the risk of soil erosion, and generate additional income for farmers. However, lack of incentives, inconsistent regulations, and lack of knowledge of farmers about proper agroforestry techniques make it still underused. As a sustainability strategy, the application of the agroforestry concept in oil palm plantations has promising prospects. However, to overcome various obstacles to its implementation, policy support, technical training, and collaboration between the government, companies, and communities are needed.

Keywords: Agroforestry. Oil Palm. Sustainability. Environment. Farmer Income. Implementation Challenges. Land Conservation.

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INTRODUCTION

One of the strategic commodities of the Indonesian economy is palm oil. This commodity greatly helps the growth of rural areas, state revenues, and job creation (Monzon et al., 2021). Along with the increasing demand for palm oil derivative products such as cooking oil, biodiesel, and industrial raw materials worldwide, the area of oil palm plantations in Indonesia continues to increase every year. However, the development of this industry has also been falsely associated with many complex ecological and social impacts, especially when carried out in monoculture and without sustainable planning (Hamzah et al., 2019).

The expansion of oil palm plantations has been accused as the sole cause of significant deforestation, which is one of the main problems that arise. It has been accused that in order to open land for oil palm, primary forests and peatlands are destroyed completely. This may reduce biodiversity, disrupt the hydrological cycle, and release large amounts of carbon emissions. Monoculture planting patterns, on the other hand, make the ecological system more vulnerable to pests, diseases, and climate change. This makes it necessary to look for other ways to manage plantation land that are more environmentally friendly and sustainable (Umana et al., 2020).

The implementation of agroforestry systems is currently one of the most debated solutions. Agroforestry is a land management system that combines trees, agricultural crops, and/or livestock in one production system (Rifin et al., 2020). In the case of oil palm, agroforestry means combining oil palm trees with other plants that have ecological and economic benefits, such as fruit trees, forestry plants, or annual crops. This concept is considered to be able to balance production with environmental conservation and improve the socio-economic status of farmers (Dungani et al., 2018).

According to several studies, agroforestry has the ability to increase soil fertility, improve ecosystem structure, and increase community income sources (Uning et al., 2020). In agroforestry systems, crop diversification can also help smallholders reduce their dependence on a single commodity. This makes them more resilient to changes in market prices. Agroforestry produces more complex and ecologically diverse landscapes, which helps maintain biodiversity and reduces the risk of environmental degradation (Ordway et al., 2019).

Agroforestry application in oil palm plantations in Indonesia is still low, despite its enormous potential. These factors include the plantation business model that still focuses on a monoculture approach for short-term production efficiency, the lack of technical knowledge and skills of farmers, and the lack of supportive regulations. In addition, it is likely that large companies have not seen agroforestry as an economically profitable industrial strategy (Taheripour et al., 2019).

In addition, implementation problems come from institutions and policies. Agroforestry methods are not officially permitted in the current plantation licensing system. Agroforestry practices are also not supported by government incentive and subsidy programs. This creates a gap between the reality on the ground, filled with bureaucratic and structural obstacles, and the idealism of the sustainability concept (Foong et al., 2018).

In the context of small farmers, other challenges lie in limited capital, lack of access to technical training, and minimal assistance from agricultural extension institutions. Many farmers focus on short-term results and do not understand the long-term benefits of agroforestry. However, with the right approach and adequate support, agroforestry can be a promising solution to many of the problems that oil palm plantations have been facing (Descals et al., 2019).

Keeping these conditions in mind, it is imperative to conduct a thorough study on the opportunities and issues associated with implementing agroforestry in oil palm plantations. This study serves as an academic basis and policy recommendation for various stakeholders, including the government, private sector, and civil society. One can make smarter and sustainability-oriented choices based on the information gathered from various scientific literature (Pacheco, P.; Gnych, S.; Dermawan, A.; Komarudin, H.; Okarda, 2017).

This study uses a qualitative approach by reviewing scientific literature, government policies, international agency reports, and case studies in various regions. This approach allows researchers to explore the ecological, social, and institutional aspects of agroforestry implementation in oil palm plantations (Mahlia et al., 2019). Therefore, this study aims to answer two main questions, namely, to what extent the concept of agroforestry can be used to manage oil palm plantations, and what are the challenges faced in doing so. This study is expected to help transform the plantation sector towards a more inclusive, sustainable, and environmentally friendly system (Hutabarat et al., 2019).

LITERATURE REVIEW

Agroforestry is a land management system that integrates trees or woody plants with agricultural crops or livestock in one unit of land, either simultaneously or in rotation. This system not only reflects multicultural agricultural practices, but rather a comprehensive approach that synergizes ecological and economic dimensions (Meijide et al., 2020). In agroforestry, the interaction between various vegetative components and agricultural activities is designed to create a mutually beneficial relationship that can increase the efficiency of natural resource utilization. Furthermore, this concept is based on the principle of diversification and improvement of ecosystem functions that have been degraded due to monoculture practices. Therefore,

agroforestry is seen not only as a conservation strategy but also as an effort to adapt and mitigate climate change based on local wisdom and environmental sustainability (Mubin et al., 2019).

The oil palm cultivation system in Indonesia is generally still dominated by the monoculture approach, namely the practice of planting one type of plant extensively and homogeneously. Although this approach is considered economically efficient in the short term, its ecological implications are quite significant (Purnama et al., 2020). Monoculture practices in oil palm plantations have been shown to cause degradation of natural habitats, decreased levels of biodiversity, and decreased soil and water quality. In addition, homogeneous agricultural landscapes become more vulnerable to the impacts of extreme climate change, pest and disease attacks, and accelerate deforestation processes. These conditions directly contribute to increased carbon emissions at the global level, thus posing serious challenges to environmental sustainability and climate change mitigation efforts (Naidu & Moorthy, 2021).

The implementation of agroforestry systems in oil palm plantations has significant potential in supporting the restoration of ecosystem functions and encouraging sustainable land management. Through the integration of perennial plants or local trees with oil palm commodities, the ecological structure and ecosystem function can be gradually rehabilitated. The presence of additional vegetation contributes to maintaining soil moisture, improving nutrient cycles, and providing living space for fauna diversity (Qaim et al., 2020). In addition, this system is effective in reducing erosion rates and improving groundwater quality, making it a relevant and adaptive alternative approach within the framework of sustainable agricultural development, especially in tropical areas such as Indonesia (Wahyono et al., 2020).

In addition to its contribution to the ecological aspect, various literature studies also indicate that agroforestry systems have a significant positive impact on the socio-economic dimension, especially for small-scale farmers. The application of agroforestry allows farmers to obtain additional sources of income through the integration of intercrops such as bananas, cocoa, or various types of spices, without having to abandon oil palm cultivation as the main commodity. This diversification pattern plays a role in increasing the stability of farmers' income, while reducing dependence on the volatility of palm oil prices in the international market (Hamzah et al., 2019). Therefore, agroforestry not only represents a natural resource conservation strategy, but also becomes an instrument for empowering local economies that is inclusive and sustainable (Schleifer, Philip; Sun, 2018).

Several case studies have shown that the application of agroforestry systems in oil palm plantations has yielded promising results. In Kalimantan, for example, a pilot program integrating rubber, durian, and jengkol plants showed increased soil fertility and improved farmer welfare. In

Sumatra, a similar approach resulted in a significant decrease in pesticide use, due to the creation of a more stable ecological balance (Maluin et al., 2020). These empirical findings strengthen the position of agroforestry as a practical and applicable strategy that is not only conceptual, but can also be implemented adaptively according to local socio-ecological characteristics (Shrivastava et al., 2021).

The implementation of agroforestry in oil palm plantation systems in Indonesia faces various challenges, both technically and institutionally. One of the main obstacles is the limited access of farmers to adequate training, education, and technical assistance in managing agroforestry practices effectively. On the other hand, the regulatory and policy structures governing the plantation sector still show a strong tendency towards monoculture systems, with an emphasis on short-term efficiency and productivity (Mohammad et al., 2021). This kind of policy orientation creates a mismatch between the multifunctional and sustainable agroforestry approach and the existing legal and institutional framework. Therefore, structural reforms are needed in the licensing system and plantation policies to be more inclusive of integrated cultivation approaches such as agroforestry (Krist, 2020).

Agroforestry has not been substantially integrated into the national agricultural and forestry sector development policy framework. In fact, this approach has a strategic role in supporting the achievement of the Sustainable Development Goals (SDGs), especially in terms of food security, adaptation to climate change, and biodiversity conservation (Vijay et al., 2016). Unfortunately, the absence of fiscal incentive instruments, limited access to sustainable financing such as green finance schemes, and the absence of regulations that explicitly support agroforestry are major obstacles to its implementation. This condition is further exacerbated by the dominance of the palm oil plantation sector by large companies that tend to prioritize a profit-based monoculture approach, thus marginalizing sustainable agricultural practices such as agroforestry (Putri et al., 2022).

One of the main obstacles in the development of agroforestry in oil palm plantations is the lack of comprehensive and sustainable empirical research in the long term. Most of the available literature is still conceptual or based on project studies with limited duration, thus limiting the ability to generalize the effectiveness of agroforestry models in various ecological and socio-cultural conditions in Indonesia (Low et al., 2021). Therefore, there is an urgent need to strengthen interdisciplinary research that integrates agronomic, socio-cultural, economic, and policy aspects, in order to produce valid and reliable empirical data. Such data is very important as a basis for formulating holistic and adaptive policies in supporting the implementation of agroforestry more widely and sustainably (Hidayat et al., 2018).

Existing literature indicates that strengthening agroforestry practices in the plantation sector requires synergy and collaboration involving various stakeholders, such as research institutions, non-governmental organizations, governments, and private business actors. Several initiatives from oil palm plantation companies that are members of sustainability programs, such as the Roundtable on Sustainable Palm Oil (RSPO), reflect a commitment to reducing ecological impacts through the integration of agroforestry principles in their operations. However, these steps are still limited and have not become standard practices that are widely adopted by the industry (Santika et al., 2019). Therefore, more intensive and coordinated efforts are needed to encourage agroforestry to become an integral part of a sustainable and mainstream palm oil plantation agribusiness system (Santika et al., 2020).

Agroforestry offers significant prospects in improving the sustainability of oil palm plantation systems. Despite facing various complex challenges, both in terms of technical, institutional, and policy aspects, empirical evidence shows that implementing agroforestry with the right approach can overcome various ecological and social problems that arise from monoculture practices (Rashid et al., 2021). This study confirms that agroforestry is not merely an alternative, but rather an essential component in efforts to transform the plantation sector towards a more sustainable, inclusive, and environmentally friendly model in the future (Onoja et al., 2019).

METHOD

This study uses a qualitative approach with a literature review method to explore in depth the application of the agroforestry concept in oil palm plantations (Schoneveld et al., 2019). The qualitative approach was chosen because this study did not aim to measure numerical variables, but instead studied meanings, concepts, tendencies, and conceptual narratives from various academic sources and field practices. This method allows researchers to capture multiple perspectives on how agroforestry can be practically applied in the context of oil palm plantations in Indonesia (Devarajan et al., 2017).

Literature review is used because this topic involves cross-disciplinary understanding, including environmental science, forestry, socio-economics, and public policy. Researchers can collect various theories and findings from previous researchers by conducting library research. This method allows researchers to map academic trends and field practices related to agroforestry implementation and find research gaps that have not been widely discussed (Loganathan et al., 2017). This method provides a strong foundation for developing the conceptual framework of this research.

The data sources for this study came from various sources, including, but not limited to, academic books, scientific journals, research institute reports, policy documents, conference articles, and publications from international organizations such as FAO, CIFOR, and RSPO. The criteria used to select literature for this study were topic relevance (e.g., agroforestry, oil palm, sustainability), recency (e.g., the last 10 years), source validity (e.g., the last 10 years), and availability of data (e.g., the last 10 years). To ensure that the data reviewed is unbiased and accurate, this selection process was carried out systematically (Dislich et al., 2017).

Researchers used scientific databases such as Google Scholar, Scopus, ScienceDirect, and JSTOR to collect data through structured searches using keywords such as “agroforestry,” “sustainability,” “forest restoration,” and “environmental impacts.” In addition, reports from non-governmental organizations (NGOs) and policy documents from the ministries of agriculture and forestry were also analyzed (Ashton-Butt et al., 2018). Next, the literature that meets the requirements is categorized based on the main topics, namely ecology, social, economic, and policy (Kubitza et al., 2018).

Data analysis was conducted thematically, namely by determining the main theme and subject of the literature being studied. Each document was analyzed to find similarities, differences, and patterns in the application of agroforestry in oil palm plantations. Researchers created a literature matrix to facilitate mapping of arguments from each source, geographical context, and methodological approach (Ruppert et al., 2018). To create a consistent story, the findings are then discussed in a discussion.

Researchers cross-check the literature with each other to maintain the validity and legitimacy of the research. This is especially true for contradictory results. Data from academic journals, research institution reports, and field reports from trusted NGOs or media are compared to carry out the triangulation process. To ensure that the conclusions drawn are not influenced by changes in policy and social dynamics that affect agroforestry practices, researchers also consider the location and time of publication (Masazhar & Kamal, 2017).

After the data was analyzed, the researchers combined the information based on the prospects and challenges of agroforestry. Literature explaining how agroforestry implementation was successfully carried out was categorized as prospects, while technical, social, and regulatory barriers were categorized as challenges. The synthesis process is very important to create a neat discussion structure and make it easier for readers to understand the problem as a whole (Rizeei et al., 2018).

This study has limitations in terms of primary data collection and field observation because it is a library-based study. As a result, researchers cannot empirically ascertain the use of

agroforestry in certain oil palm plantation locations. In addition, the focus on secondary sources allows for bias from the original authors of the literature. However, researchers try to reduce these errors by carefully selecting literature and triangulating sources. Researchers conduct research ethically, including no plagiarism, citing sources correctly, and respecting the author's copyright. Every literature used is included in the bibliography in accordance with academic standards. In addition, researchers remain unbiased and impartial in presenting their results (Pramudya et al., 2017).

The purpose of this study, namely to identify various prospects and challenges of implementing agroforestry in the context of oil palm plantations, is very relevant to the selection of qualitative literature review methods. This study is expected to increase understanding of the position of agroforestry as a potential solution to the sustainability crisis of the palm oil industry. In addition, it will provide suggestions for policy makers, academics, and field actors to encourage wider and more efficient implementation (Carvalho et al., 2018).

RESULTS

Agroforestry is a multidimensional systemic approach, integrating forestry and agricultural elements in a mutually supportive integrated land use system. In the context of oil palm plantation management, agroforestry refers to the practice of inserting forestry or food crop species between rows of oil palms to form a more heterogeneous, resilient, and sustainable agricultural system (Cooper et al., 2020). This approach not only results in diversification of production results but also builds more stable and balanced micro-ecosystem conditions. The implementation of agroforestry systems in oil palm plantations has the potential to create a symbiotic relationship between the main crop and intercrops that can strengthen each other ecologically and economically. Thus, agroforestry can be seen as a viable alternative model to the intensive monoculture system that has so far dominated the oil palm industry landscape (Woittiez et al., 2017).

Agroforestry systems have significant potential to reduce the negative environmental impacts caused by monoculture-based oil palm plantation expansion, such as soil degradation, decreased biodiversity, and disruption of the hydrological cycle. By creating a more complex layered vegetation structure, agroforestry allows for increased carbon storage capacity and strengthens the soil's ability to retain moisture. Integration of native tree species into oil palm plantation landscapes has been shown to substantially increase the biodiversity index, even up to three times compared to monoculture oil palm systems (Harahap et al., 2019). In addition, this approach also functions as a natural barrier against wind and soil erosion, especially in highland

areas and sloping areas that are very vulnerable to land damage due to conventional cultivation methods (Furumo & Aide, 2017).

Findings in various literatures show that agroforestry systems not only contribute to environmental sustainability but also open up wider economic opportunities for oil palm farmers, especially those who are classified as small-scale farmers. Through the integration of intercrops such as cocoa, coffee, bananas, or other types of horticulture between rows of oil palm trees, farmers obtain additional sources of income that are faster and more diverse than relying only on the relatively longer oil palm harvest period (Benzertiha et al., 2019). This crop diversification not only increases the economic stability of farmer households but also strengthens food security and reduces the risk of dependence on a single commodity that is highly influenced by price volatility in the global market (Cheng, Yu, Xu, Liu, et al., 2018).

The study findings also indicate that the implementation of agroforestry systems in oil palm plantations faces a number of technical constraints that cannot be ignored. One of the main challenges is the competition for resources between the main crop (oil palm) and intercrops in terms of access to sunlight, water, and soil nutrients. If intercrops are planted too closely or have a higher canopy, this can inhibit the photosynthesis process in oil palm, which has an impact on decreasing productivity (Rifin et al., 2020). Several studies even noted the potential for a decrease in palm oil yields of up to 15–20% if spatial arrangements and selection of plant types are not designed optimally. In addition, agroforestry systems require more complex managerial and agronomic skills because farmers must be able to manage two or more types of commodities with different planting cycles and cultivation techniques, which in turn also increases the need for labor in the maintenance and harvesting process (Doan et al., 2016).

The implementation of agroforestry systems in oil palm plantations still faces structural obstacles due to the lack of policy support from the government. The national regulatory framework, such as the Plantation Law and the Government Regulation on Spatial Planning, shows a tendency to support large-scale monoculture cultivation patterns. This condition creates legal obstacles, especially for farmers who seek to integrate forestry components into their plantation systems, because land status often does not accommodate agroforestry practices (Yarak et al., 2021). In addition, limitations in the form of financial incentives and the unavailability of financing schemes specifically for the development of agroforestry in the palm oil sector, also weaken the potential for adoption and replication of this model on a wider scale (Gad et al., 2018).

The majority of oil palm farmers, especially independent farmers, still face limited understanding of the benefits and implementation techniques of agroforestry systems. The dominant mindset that has been formed so far places monoculture as the only oil palm cultivation

method that is considered valid and effective. Limited access to technical training, learning materials, and field assistance are the main factors in the low level of agroforestry adoption at the local level (Danylo et al., 2021). In addition, minimal access to agricultural innovation, including the availability of quality intercrop seeds and sustainable agricultural inputs such as organic fertilizers, also hampers the optimal implementation of agroforestry without systematic external intervention and support (Cheng, Yu, Xu, Lu, et al., 2018).

Several literature identify the successful implementation of agroforestry systems in oil palm plantations through the support of partner institutions such as CIFOR, ICRAF, and local non-governmental organizations. These initiatives are able to bridge collaboration between farmers, academics, and policymakers in building a community-based innovation ecosystem (Syahza & Asmit, 2019). One concrete example is the Smart Agroforestry project in West Kalimantan, which successfully integrated more than 1,000 hectares of smallholder oil palm land with local forestry tree species and food crops. The results showed increased productivity and significant contributions to land conservation. This case study underscores the importance of cross-sector synergy as a key factor in the successful implementation of adaptive and sustainable agroforestry (Strona et al., 2018).

Literature review shows that the success of agroforestry implementation is highly dependent on the design of a system that is contextual and responsive to local characteristics. There is no single standard model that can be applied universally. Various approaches, such as strip cropping, alley cropping, and buffer zone systems, have their own advantages that are relevant depending on specific factors such as topography, climate conditions, and the socio-economic dynamics of the local community (Abdul Majid et al., 2021). Flexibility in designing agroforestry systems is a determining factor in ensuring their sustainability, where models designed in a participatory manner with local communities have proven to be more effective than top-down and uniform approaches (Strona et al., 2018).

The integration of agroforestry systems in oil palm plantations opens up significant opportunities to improve the reputation of Indonesian palm oil commodities at the global level. Based on reports from the RSPO (Roundtable on Sustainable Palm Oil) and the Rainforest Alliance, agroforestry practices are seen as indicators that support the fulfillment of sustainability principles (Momoh & Osofero, 2020). Companies that adopt this approach have the potential to gain access to premium market segments, especially in Europe, where strict environmental standards apply. Thus, agroforestry not only provides benefits to small-scale farmers but also becomes a valuable strategy for large companies in maintaining competitiveness and responding

to international market pressures related to sustainability and deforestation issues (Arslan et al., 2017).

Overall, literature research shows that the application of agroforestry in oil palm plantations is a strategic opportunity to produce a more equitable, weather-resistant, and environmentally friendly agricultural system. However, to achieve this widely, systemic changes are needed, supported by supportive policies, sustainable technical training, and creative incentive-based financing. For agroforestry to become a technical solution and part of the sustainable development plan for the plantation sector in Indonesia, integration between local and national approaches is needed (Ameen et al., 2022).

DISCUSSION

Agroforestry is a land use method that combines agriculture, forestry, and sometimes livestock farming in one land management system with the aim of simultaneously increasing ecological and economic efficiency. The integration of agroforestry in oil palm plantations can be defined as the combination of local trees or forestry plants and food or horticultural crops among rows of oil palm plants. This results in a more complex and diverse production system and a symbiotic relationship between the various parts that support each other. For example, cover crops used in agroforestry reduce erosion and maintain soil moisture, while hardwood trees can provide useful shade during the early growth period of the oil palm. Therefore, the system develops into a multi-functional approach that allows for dual or even multiple productivity in one area (Vijay et al., 2016).

In oil palm monocultures, erosion, nutrient leaching, and intensive use of chemical fertilizers degrade soil quality. By enhancing natural nutrient cycling through the organic litter layer of trees and shrubs integrated into the system, agroforestry can address these issues. The addition of organic matter from the leaves and roots of agroforestry plants improves soil structure, cation exchange capacity, and soil microbiology. In addition, the deeper root systems of agroforestry trees have the ability to absorb water from the subsoil and channel it back to the topsoil through hydraulic processes. Ultimately, this increases the availability of water for oil palm plants. This mechanism is especially important in places where seasonal rainfall is high and the risk of drought is high (Onoja et al., 2019).

Biodiversity is critical to assessing the health of a land’s ecosystem. Because they provide only one type of vegetation and canopy structure, homogenous oil palm monoculture systems tend to reduce the number of local flora and fauna species. By providing multiple layers of vegetation, agroforestry offers solutions for a variety of organisms, from soil microbes to birds and

small mammals. Studies have shown that agroforestry farming systems can sustain more species than conventional farming systems. It reduces reliance on pesticides by restoring the natural balance in pest and predator populations. Biodiversity also benefits a range of ecosystem functions, including pollination, natural pest control, and the decomposition of organic matter (Cooper et al., 2020).

One of the main concerns of farmers is the potential decline in oil palm yields due to inter-plant competition in agroforestry systems. However, various studies have shown that with the right system design, oil palm productivity can be maintained or even increased due to improved soil health and better microclimate. Moreover, agroforestry allows for income diversification through the harvest of other commodities such as fruits, medicinal plants, or non-timber forestry products. This additional income is very important in increasing the economic resilience of farmers to fluctuations in oil palm prices in the global market. Another benefit is the reduction in input costs such as fertilizers and pesticides because the system becomes more ecologically self-sufficient (Dauvergne, 2018).

Adoption of agroforestry by farmers still faces many social and cultural challenges. Agroforestry is considered complicated and high-risk by many farmers who have long been accustomed to monoculture systems. This reluctance is often due to a lack of technical information, a lack of real-world examples, and concerns about potential poor outcomes. Consequently, a participatory approach is needed, in which farmers are involved from the planning stage. This will allow the system to be tailored to local needs (Schleifer, Philip; Sun, 2018). To ensure that farmers' knowledge and skills can develop along with the implementation of agroforestry, this approach also needs to be supported by training programs, extension, and strengthening of farmer institutions.

Without proper technical planning, agroforestry cannot be applied carelessly. Companion plants for oil palm must be selected by considering many things, such as rooting patterns, light requirements, life cycles, and ecological suitability. Plants that are too competitive can interfere with oil palm growth, while plants that are not adaptive will not provide economic or ecological benefits (Qaim et al., 2020). More complex planting and maintenance patterns are required by agroforestry systems, which make farmers work harder. Therefore, to create an ideal system that is easy for farmers to use, agronomists, foresters, and agricultural ecologists need technical assistance.

The government has an important role to play in building a policy ecosystem that supports the growth of agroforestry. Smallholders will not dare to take the risk of switching to this new and more complex system if they do not receive sufficient incentives. According to the literature,

incentives can include seed subsidies, technical training, access to environmentally friendly financing, and sustainable product labels. In addition, land use regulations must simplify the administration of farmer groups and provide legal space for agroforestry in forest and plantation areas (Mubin et al., 2019).

The success of agroforestry depends on improving the capacity of farmers. Agroecology-based agricultural education must be included in formal and informal education systems, from field schools, farmer-farmer training, to field demonstrations. Inclusive and sustainable programs must focus on technology transfer and increasing awareness of the environment and entrepreneurship. Local farmers' knowledge must be considered as part of the solution, not just as recipients of technical interventions.(Chew et al., 2021).

According to long-term cost-benefit analysis, agroforestry is better than monoculture systems. Farmers benefit from income diversification, input reduction, and long-term yield stability, although initial investment in agroforestry is required due to the need for seedlings and land preparation (Dharmawan et al., 2020). The literature emphasizes that business models that support agroforestry schemes, such as farmer cooperatives and local agro-industry models, as well as collaboration with the private sector that prioritizes sustainability, are essential.

By increasing vegetative biomass and soil carbon content, agroforestry plays a significant role in sequestering carbon emissions. This system sequesters more carbon than open oil palm land because of the presence of hardwood trees. In addition, the literature notes the potential of this system in supporting carbon trading programs, which will open up new income opportunities for farmers who have the ability to manage agroforestry sustainably. Part of the agricultural sector's solution to climate change is agroforestry (Sen et al., 2021).

Agroforestry follows the sustainability principles of RSPO and ISPO that emphasize social welfare, environmental conservation, and transparency. Agroforestry practices help farmers meet various certification criteria, including organic waste management, biodiversity conservation, and soil conservation. In addition, the implementation of agroforestry improves the reputation and added value of palm oil products in the international market, which increasingly demands transparency and ethical production (Monzon et al., 2021).

Many agroforestry models have been developed to meet the various socio-economic and agro-climatic conditions of farmers. Intercropping of fruit trees (such as durian or mango) between oil palm rows, integration of annual crops (such as ginger or turmeric), and silvopasture models with smallholder livestock are some of the models (Wahyono et al., 2020). The system should be relevant, productive, and efficient if the model is adapted to local conditions. According to the literature, further research is needed to evaluate the impact of each model in Indonesia.

More efficient and adaptive agroforestry management can be achieved with the help of technology. Smart farming applications, digital mapping tools, and sensor-based soil moisture and nutrient monitoring systems help farmers make better choices. Agroforestry information systems are strengthened by the integration of these technologies, allowing for real-time impact assessments and making systems more responsive to environmental changes (Krist, 2020).

Agroforestry is considered a transformational approach that can bridge the needs of production and conservation, and the palm oil industry is increasingly being forced to become more environmentally friendly around the world (Benzertiha et al., 2019). This system is not just a technical alternative, it is a sustainable development model that balances social, ecological and economic aspects. Agroforestry has the potential to be a key component in renewing palm oil plantation systems in Indonesia and other producing countries, with multi-stakeholder support, continued research and strong political will.

CONCLUSION

The concept of agroforestry shows great potential for building more sustainable and environmentally friendly production systems. Research shows that agroforestry has the ability to overcome the negative effects of oil palm monoculture systems, including land degradation, loss of biodiversity, and overall ecosystem degradation. Agroforestry practices can improve soil fertility, reduce erosion, and support more equitable water availability throughout the year by incorporating perennials, shade trees, and other commodities into oil palm cultivation systems. This system also helps farmers expand their income sources, reduce their dependence on a single product, and improve local food security. Overall, the literature research shows that agroforestry is a multidimensional approach that addresses the sustainability crisis of the palm oil industry by combining ecological, social, and economic aspects. It is not just a technical agricultural strategy.

However, agroforestry in oil palm plantations still faces many technical, social, and institutional challenges. From a technical perspective, to ensure that this system does not interfere with oil palm growth and productivity, a deep understanding of the characteristics of appropriate companion plants, shade management, and crop rotation is needed. Socially, the absence of policies that explicitly support and encourage the implementation of agroforestry in oil palm plantations is a major obstacle to the widespread implementation of agroforestry. On the other hand, farmer resistance is caused by fear of decreasing yields and a lack of knowledge and training support. In order for agroforestry to be accepted and implemented massively in the field, strong policy interventions based on scientific evidence, as well as ongoing education and mentoring programs, are needed.

To find out how the implementation of agroforestry impacts oil palm plantations in various agroecological regions, further research should concentrate more on empirical field studies. Literature review has shown many theoretical and conceptual benefits of agroforestry. However, to evaluate how effective this system is in various climate conditions, soil types, and social characteristics of farmers, contextual data from real locations is needed. Future studies can use case study methods in areas that have implemented agroforestry on oil palm land. This will allow for recording best practices, technical constraints, and economic reactions of farmers.

The next suggestion is that future research should include more institutional and policy elements related to the implementation of agroforestry in oil palm plantations. It is important to examine how agricultural regulations, land use, and government incentive programs affect farmers' willingness to adopt agroforestry systems. Analysis of policy documents, interviews with stakeholders, and comparative research with countries or regions that have implemented similar methods are appropriate ways to strengthen theoretical literature analysis.

REFERENCES

Abdul Majid, N., Ramli, Z., Md Sum, S., & Awang, A. H. (2021). Sustainable palm oil certification scheme frameworks and impacts: A systematic literature review. Sustainability, 13(6), 3263. https://doi.org/10.3390/su13063263

Ameen, M., Zamri, N. M., May, S. T., Azizan, M. T., Aqsha, A., Sabzoi, N., & Sher, F. (2022). Effect of acid catalysts on hydrothermal carbonization of Malaysian oil palm residues (leaves, fronds, and shells) for hydrochar production. Biomass Conversion and Biorefinery, 12(1), 103–114. https://doi.org/10.1007/s13399-020-01201-2

Arslan, F. N., Şapçı, A. N., Duru, F., & Kara, H. (2017). A study on monitoring of frying performance and oxidative stability of cottonseed and palm oil blends in comparison with original oils. International Journal of Food Properties, 20(3), 704–717. https://doi.org/10.1080/10942912.2016.1177544

Ashton-Butt, A., Aryawan, A. A. K., Hood, A. S. C., Naim, M., Purnomo, D., Suhardi, Wahyuningsih, R., Willcock, S., Poppy, G. M., Caliman, J.-P., Turner, E. C., Foster, W. A., Peh, K. S.-H., & Snaddon, J. L. (2018). Understory vegetation in oil palm plantations benefits soil biodiversity and decomposition rates. Frontiers in Forests and Global Change, 1, Article 10. https://doi.org/10.3389/ffgc.2018.00010

Benzertiha, A., Kierończyk, B., Rawski, M., Kołodziejski, P., Bryszak, M., & Józefiak, D. (2019). Insect oil as an alternative to palm oil and poultry fat in broiler chicken nutrition. Animals, 9(3), 116. https://doi.org/10.3390/ani9030116

Carvalho, F. G., de Oliveira Roque, F., Barbosa, L., de Assis Montag, L. F., & Juen, L. (2018). Oil palm plantation is not a suitable environment for most forest specialist species of Odonata in Amazonia. Animal Conservation, 21(6), 526–533. https://doi.org/10.1111/acv.12427

Cheng, Y., Yu, L., Xu, Y., Liu, X., Lu, H., Cracknell, A. P., Kanniah, K., & Gong, P. (2018). Towards global oil palm plantation mapping using remote-sensing data. International Journal of Remote Sensing, 39(18), 5891–5906. https://doi.org/10.1080/01431161.2018.1492182

Cheng, Y., Yu, L., Xu, Y., Lu, H., Cracknell, A. P., Kanniah, K., & Gong, P. (2018). Mapping oil palm extent in Malaysia using ALOS-2 PALSAR-2 data. International Journal of Remote Sensing, 39(2), 432–452. https://doi.org/10.1080/01431161.2017.1387309

Chew, C. L., Ng, C. Y., Hong, W. O., Wu, T. Y., Lee, Y.-Y., Low, L. E., Kong, P. S., & Chan, E. S. (2021). Improving sustainability of palm oil production by increasing oil extraction rate: A review. Food and Bioprocess Technology, 14(4), 573–586. https://doi.org/10.1007/s11947-020-02555-1

Cooper, H. V., Evers, S., Aplin, P., Crout, N., Dahalan, M. P. B., & Sjogersten, S. (2020). Greenhouse gas emissions resulting from conversion of peat swamp forest to oil palm plantation. Nature Communications, 11(1), Article 407. https://doi.org/10.1038/s41467-020-14298-w

Danylo, O., Pirker, J., Lemoine, G., Ceccherini, G., See, L., McCallum, I., Hadi, Kraxner, F., Achard, F., & Fritz, S. (2021). A map of the extent and year of detection of oil palm plantations in Indonesia, Malaysia and Thailand. Scientific Data, 8(1), Article 96. https://doi.org/10.1038/s41597-021-00867-1

Dauvergne, P. (2018). The global politics of the business of “sustainable” palm oil. Global Environmental Politics, 18(2), 34–52. https://doi.org/10.1162/glep_a_00455

Descals, A., Szantoi, Z., Meijaard, E., Sutikno, H., Rindanata, G., & Wich, S. (2019). Oil palm (Elaeis guineensis) mapping with details: Smallholder versus industrial plantations and their extent in Riau, Sumatra. Remote Sensing, 11(21), Article 2590. https://doi.org/10.3390/rs11212590

Devarajan, Y., Munuswamy, D. B., Mahalingam, A., & Nagappan, B. (2017). Performance, combustion, and emission analysis of neat palm oil biodiesel and higher alcohol blends in a diesel engine. Energy & Fuels, 31(12), 13796–13801. https://doi.org/10.1021/acs.energyfuels.7b02939

Dharmawan, A. H., Mardiyaningsih, D. I., Komarudin, H., Ghazoul, J., Pacheco, P., & Rahmadian, F. (2020). Dynamics of rural economy: A socio-economic understanding of oil palm expansion and landscape changes in East Kalimantan, Indonesia. Land, 9(7), Article 213. https://doi.org/10.3390/land9070213

Dislich, C., Keyel, A. C., Salecker, J., Kisel, Y., Meyer, K. M., Auliya, M., Barnes, A. D., Corre, M. D., Darras, K., Faust, H., Hess, B., Klasen, S., Knohl, A., Kreft, H., Meijide, A., Nurdiansyah, F., Otten, F., Pe’er, G., Steinebach, S., … Wiegand, K. (2017). A review of the ecosystem functions in oil palm plantations, using forests as a reference system. Biological Reviews, 92(3), 1539–1569. https://doi.org/10.1111/brv.12295

Doan, C. D., Patel, A. R., Tavernier, I., De Clercq, N., Van Raemdonck, K., Van de Walle, D., Delbaere, C., & Dewettinck, K. (2016). The feasibility of wax-based oleogel as a potential co-structurant with palm oil in low-saturated fat confectionery fillings. European Journal of Lipid Science and Technology, 118(12), 1903–1914. https://doi.org/10.1002/ejlt.201500172

Dungani, R., Aditiawati, P., Aprilia, S., Yuniarti, K., Karliati, T., Suwandhi, I., & Sumardi, I. (2018). Biomaterial from oil palm waste: Properties, characterization and applications. In Palm oil (pp. 1–20). InTech. https://doi.org/10.5772/intechopen.76412

Foong, S. Z. Y., Lam, Y. L., Andiappan, V., Foo, D. C. Y., & Ng, D. K. S. (2018). A systematic approach for the synthesis and optimization of palm oil milling processes. Industrial & Engineering Chemistry Research, 57(8), 2945–2955. https://doi.org/10.1021/acs.iecr.7b04788

Furumo, P. R., & Aide, T. M. (2017). Characterizing commercial oil palm expansion in Latin America: Land use change and trade. Environmental Research Letters, 12(2), Article 024008. https://doi.org/10.1088/1748-9326/aa5892

Gad, M. S., El-Araby, R., Abed, K. A., El-Ibiari, N. N., El Morsi, A. K., & El-Diwani, G. I. (2018). Performance and emissions characteristics of C.I. engine fueled with palm oil/palm oil methyl ester blended with diesel fuel. Egyptian Journal of Petroleum, 27(2), 215–219. https://doi.org/10.1016/j.ejpe.2017.05.009

Hamzah, N., Tokimatsu, K., & Yoshikawa, K. (2019). Solid fuel from oil palm biomass residues and municipal solid waste by hydrothermal treatment for electrical power generation in Malaysia: A review. Sustainability, 11(4), Article 1060. https://doi.org/10.3390/su11041060

Harahap, F., Leduc, S., Mesfun, S., Khatiwada, D., Kraxner, F., & Silveira, S. (2019). Opportunities to optimize the palm oil supply chain in Sumatra, Indonesia. Energies, 12(3), Article 420. https://doi.org/10.3390/en12030420

Hidayat, N. K., Offermans, A., & Glasbergen, P. (2018). Sustainable palm oil as a public responsibility? On the governance capacity of Indonesian Standard for Sustainable Palm Oil (ISPO). Agriculture and Human Values, 35(1), 223–242. https://doi.org/10.1007/s10460-017-9816-6

Hutabarat, S., Slingerland, M., & Dries, L. (2019). Explaining the “certification gap” for different types of oil palm smallholders in Riau Province, Indonesia. The Journal of Environment & Development, 28(3), 253–281. https://doi.org/10.1177/1070496519854505

Krist, S. (2020). Palm kernel oil/palm oil. In Vegetable fats and oils (pp. 513–521). Springer International Publishing. https://doi.org/10.1007/978-3-030-30314-3_82

Kubitza, C., Krishna, V. V., Alamsyah, Z., & Qaim, M. (2018). The economics behind an ecological crisis: Livelihood effects of oil palm expansion in Sumatra, Indonesia. Human Ecology, 46(1), 107–116. https://doi.org/10.1007/s10745-017-9965-7

Loganathan, R., Subramaniam, K. M., Radhakrishnan, A. K., Choo, Y.-M., & Teng, K.-T. (2017). Health-promoting effects of red palm oil: Evidence from animal and human studies. Nutrition Reviews, 75(2), 98–113. https://doi.org/10.1093/nutrit/nuw054

Low, S. S., Bong, K. X., Mubashir, M., Cheng, C. K., Lam, M. K., Lim, J. W., Ho, Y. C., Lee, K. T., Munawaroh, H. S. H., & Show, P. L. (2021). Microalgae cultivation in palm oil mill effluent (POME) treatment and biofuel production. Sustainability, 13(6), Article 3247. https://doi.org/10.3390/su13063247

Mahlia, T. M. I., Ismail, N., Hossain, N., Silitonga, A. S., & Shamsuddin, A. H. (2019). Palm oil and its wastes as bioenergy sources: A comprehensive review. Environmental Science and Pollution Research, 26(15), 14849–14866. https://doi.org/10.1007/s11356-019-04563-x

Maluin, F. N., Hussein, M. Z., & Idris, A. S. (2020). An overview of the oil palm industry: Challenges and some emerging opportunities for nanotechnology development. Agronomy, 10(3), Article 356. https://doi.org/10.3390/agronomy10030356

Masazhar, A. N. I., & Kamal, M. M. (2017). Digital image processing technique for palm oil leaf disease detection using multiclass SVM classifier. In 2017 IEEE 4th International Conference on Smart Instrumentation, Measurement and Application (ICSIMA) (pp. 1–6). IEEE. https://doi.org/10.1109/ICSIMA.2017.8311978

Meijide, A., de la Rua, C., Guillaume, T., Röll, A., Hassler, E., Stiegler, C., Tjoa, A., June, T., Corre, M. D., Veldkamp, E., & Knohl, A. (2020). Measured greenhouse gas budgets challenge emission savings from palm-oil biodiesel. Nature Communications, 11(1), Article 1089. https://doi.org/10.1038/s41467-020-14852-6

Mohammad, S., Baidurah, S., Kobayashi, T., Ismail, N., & Leh, C. P. (2021). Palm oil mill effluent treatment processes—A review. Processes, 9(5), Article 739. https://doi.org/10.3390/pr9050739

Momoh, E. O., & Osofero, A. I. (2020). Recent developments in the application of oil palm fibers in cement composites. Frontiers of Structural and Civil Engineering, 14(1), 94–108. https://doi.org/10.1007/s11709-019-0576-9

Monzon, J. P., Slingerland, M. A., Rahutomo, S., Agus, F., Oberthür, T., Andrade, J. F., Couëdel, A., Rattalino Edreira, J. I., Hekman, W., van den Beuken, R., Hidayat, F., Pradiko, I., Purwantomo, D. K. G., Donough, C. R., Sugianto, H., Lim, Y. L., Farrell, T., & Grassini, P. (2021). Fostering a climate-smart intensification for oil palm. Nature Sustainability, 4(7), 595–601. https://doi.org/10.1038/s41893-021-00700-y

Mubin, N. A., Nadarajoo, E., Shafri, H. Z. M., & Hamedianfar, A. (2019). Young and mature oil palm tree detection and counting using convolutional neural network deep learning method. International Journal of Remote Sensing, 40(19), 7500–7515. https://doi.org/10.1080/01431161.2019.1569282

Naidu, L., & Moorthy, R. (2021). A review of key sustainability issues in Malaysian palm oil industry. Sustainability, 13(19), Article 10839. https://doi.org/10.3390/su131910839

Onoja, E., Chandren, S., Abdul Razak, F. I., Mahat, N. A., & Wahab, R. A. (2019). Oil palm (Elaeis guineensis) biomass in Malaysia: The present and future prospects. Waste and Biomass Valorization, 10(8), 2099–2117. https://doi.org/10.1007/s12649-018-0258-1

Ordway, E. M., Naylor, R. L., Nkongho, R. N., & Lambin, E. F. (2019). Oil palm expansion and deforestation in Southwest Cameroon associated with proliferation of informal mills. Nature Communications, 10(1), Article 114. https://doi.org/10.1038/s41467-018-07915-2

Pacheco, P., Gnych, S., Dermawan, A., Komarudin, H., & Okarda, B. (2017). The palm oil global value chain: Implications for economic growth and social and environmental sustainability. CIFOR. https://doi.org/10.17528/cifor/006405

Pramudya, E. P., Hospes, O., & Termeer, C. J. A. M. (2017). Governing the palm-oil sector through finance: The changing roles of the Indonesian state. Bulletin of Indonesian Economic Studies, 53(1), 57–82. https://doi.org/10.1080/00074918.2016.1228829

Purnama, K. O., Setyaningsih, D., Hambali, E., & Taniwiryono, D. (2020). Processing, characteristics, and potential application of red palm oil - A review. International Journal of Oil Palm, 3(2), 40–55. https://doi.org/10.35876/ijop.v3i2.47

Putri, E. I. K., Dharmawan, A. H., Hospes, O., Yulian, B. E., Amalia, R., Mardiyaningsih, D. I., Kinseng, R. A., Tonny, F., Pramudya, E. P., Rahmadian, F., & Suradiredja, D. Y. (2022). The oil palm governance: Challenges of sustainability policy in Indonesia. Sustainability, 14(3), Article 1820. https://doi.org/10.3390/su14031820

Qaim, M., Sibhatu, K. T., Siregar, H., & Grass, I. (2020). Environmental, economic, and social consequences of the oil palm boom. Annual Review of Resource Economics, 12(1), 321–344. https://doi.org/10.1146/annurev-resource-110119-024922

Rashid, M., Bari, B. S., Yusup, Y., Kamaruddin, M. A., & Khan, N. (2021). A comprehensive review of crop yield prediction using machine learning approaches with special emphasis on palm oil yield prediction. IEEE Access, 9, 63406–63439. https://doi.org/10.1109/ACCESS.2021.3075159

Rifin, A., Feryanto, Herawati, & Harianto. (2020). Assessing the impact of limiting Indonesian palm oil exports to the European Union. Journal of Economic Structures, 9(1), Article 26. https://doi.org/10.1186/s40008-020-00202-8

Rizeei, H. M., Shafri, H. Z. M., Mohamoud, M. A., Pradhan, B., & Kalantar, B. (2018). Oil palm counting and age estimation from WorldView-3 imagery and LiDAR data using an integrated OBIA height model and regression analysis. Journal of Sensors, 2018, Article 2536327. https://doi.org/10.1155/2018/2536327

Ruppert, N., Holzner, A., See, K. W., Gisbrecht, A., & Beck, A. (2018). Activity budgets and habitat use of wild southern pig-tailed macaques (Macaca nemestrina) in oil palm plantation and forest. International Journal of Primatology, 39(2), 237–251. https://doi.org/10.1007/s10764-018-0032-z

Santika, T., Wilson, K. A., Budiharta, S., Law, E. A., Poh, T. M., Ancrenaz, M., Struebig, M. J., & Meijaard, E. (2019). Does oil palm agriculture help alleviate poverty? A multidimensional counterfactual assessment of oil palm development in Indonesia. World Development, 120, 105–117. https://doi.org/10.1016/j.worlddev.2019.04.012

Santika, T., Wilson, K. A., Law, E. A., St John, F. A. V., Carlson, K. M., Gibbs, H., Morgans, C. L., Ancrenaz, M., Meijaard, E., & Struebig, M. J. (2021). Impact of palm oil sustainability certification on village well-being and poverty in Indonesia. Nature Sustainability, 4(2), 109–119. https://doi.org/10.1038/s41893-020-00630-1

Schleifer, P., & Sun, Y. (2018). Emerging markets and private governance: The political economy of sustainable palm oil in China and India. Review of International Political Economy, 25(2), 190–214. https://doi.org/10.1080/09692290.2017.1418759

Schoneveld, G. C., Ekowati, D., Andrianto, A., & van der Haar, S. (2019). Modeling peat- and forestland conversion by oil palm smallholders in Indonesian Borneo. Environmental Research Letters, 14(1), Article 014006. https://doi.org/10.1088/1748-9326/aaf044

Sen, B., Gupta, M., Mia, M., Pimenov, D., & Mikołajczyk, T. (2021). Performance assessment of minimum quantity castor-palm oil mixtures in hard-milling operation. Materials, 14(1), Article 198. https://doi.org/10.3390/ma14010198

Shrivastava, P., Khongphakdi, P., Palamanit, A., Kumar, A., & Tekasakul, P. (2021). Investigation of physicochemical properties of oil palm biomass for evaluating potential of biofuels production via pyrolysis processes. Biomass Conversion and Biorefinery, 11(5), 1987–2001. https://doi.org/10.1007/s13399-019-00596-x

Strona, G., Stringer, S. D., Vieilledent, G., Szantoi, Z., Garcia-Ulloa, J., & Wich, S. A. (2018). Small room for compromise between oil palm cultivation and primate conservation in Africa. Proceedings of the National Academy of Sciences, 115(35), 8811–8816. https://doi.org/10.1073/pnas.1804775115

Syahza, A., & Asmit, B. (2020). Development of palm oil sector and future challenge in Riau Province, Indonesia. Journal of Science and Technology Policy Management, 11(2), 149–170. https://doi.org/10.1108/JSTPM-07-2018-0073

Taheripour, F., Hertel, T. W., & Ramankutty, N. (2019). Market-mediated responses confound policies to limit deforestation from oil palm expansion in Malaysia and Indonesia. Proceedings of the National Academy of Sciences, 116(38), 19193–19199. https://doi.org/10.1073/pnas.1903476116

Umana, U. S., Ebong, M. S., & Godwin, E. O. (2020). Biomass production from oil palm and its value chain. Journal of Human, Earth, and Future, 1(1), 30–38. https://doi.org/10.28991/HEF-2020-01-01-04

Uning, R., Latif, M. T., Othman, M., Juneng, L., Mohd Hanif, N., Nadzir, M. S. M., Abdul Maulud, K. N., Jaafar, W. S. W. M., Said, N. F. S., Ahamad, F., & Takriff, M. S. (2020). A review of Southeast Asian oil palm and its CO2 fluxes. Sustainability, 12(12), Article 5077. https://doi.org/10.3390/su12125077

Vijay, V., Pimm, S. L., Jenkins, C. N., & Smith, S. J. (2016). The impacts of oil palm on recent deforestation and biodiversity loss. PLOS ONE, 11(7), Article e0159668. https://doi.org/10.1371/journal.pone.0159668

Wahyono, Y., Hadiyanto, H., Budihardjo, M. A., & Adiansyah, J. S. (2020). Assessing the environmental performance of palm oil biodiesel production in Indonesia: A life cycle assessment approach. Energies, 13(12), Article 3248. https://doi.org/10.3390/en13123248

Woittiez, L. S., van Wijk, M. T., Slingerland, M., van Noordwijk, M., & Giller, K. E. (2017). Yield gaps in oil palm: A quantitative review of contributing factors. European Journal of Agronomy, 83, 57–77. https://doi.org/10.1016/j.eja.2016.11.002

Yarak, K., Witayangkurn, A., Kritiyutanont, K., Arunplod, C., & Shibasaki, R. (2021). Oil palm tree detection and health classification on high-resolution imagery using deep learning. Agriculture, 11(2), Article 183. https://doi.org/10.3390/agriculture11020183