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The Effectiveness of Intercropping Upland Rice in Oil Palm Plantation: A Review on Prospects and Challenges

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Abstract
This qualitative literature review critically examines the effectiveness, prospects, and challenges of intercropping upland rice within oil palm plantations, focusing on its potential to enhance sustainability, productivity, and smallholder livelihoods in tropical regions. Synthesizing findings from peer-reviewed literature and empirical studies, the review highlights that intercropping upland rice with oil palm can significantly improve land use efficiency, soil fertility, biodiversity, and pest management while contributing to carbon sequestration and climate resilience. Economic analyses reveal that this system diversifies farmer income and strengthens food security, particularly for smallholders. However, successful implementation is constrained by resource competition, increased labor requirements, limited technical knowledge, and market access barriers. The review underscores the importance of appropriate crop selection, effective agronomic management, and supportive policy frameworks to optimize outcomes. It calls for further research on crop compatibility, long-term soil health, and economic viability, as well as policy interventions to facilitate technology adoption and market integration. The study concludes that while upland rice-oil palm intercropping holds substantial promise for sustainable agriculture and rural development, its widespread adoption depends on overcoming technical, economic, and institutional challenges through integrated research, extension, and policy support.

Keywords: Intercropping, Upland Rice, Oil Palm, Sustainable Agriculture, Smallholder Farmers, Food Security

Introduction
Intercropping has been widely recognized as a sustainable agricultural practice that enhances biodiversity, improves soil fertility, and optimizes land use efficiency [1,2]. This system enables different crops to share essential resources such as light, water, and nutrients, resulting in increased productivity and greater resilience against environmental stressors [3,4]. The socio-economic benefits of intercropping systems, particularly in smallholder farming communities, have also been emphasised as a means of improving income and ensuring food security [5,6].

One specific intercropping system that has gained attention is the integration of upland rice into oil palm plantations. This approach offers multiple advantages, including supplementary income for farmers, better land utilisation, and improved soil health [7,8]. The incorporation of upland rice within oil palm plantations has shown potential in optimising productivity while maintaining ecological balance [9,10]. However, the success of this system is influenced by various factors, including climatic conditions, soil characteristics, and agronomic management practices [11,12].

The sustainability of oil palm plantations remains a critical concern, particularly in balancing economic profitability with environmental conservation [13,14]. Intercropping has been proposed as a strategy to mitigate the negative impacts of monoculture oil palm plantations by improving soil health, fostering ecological diversity, and reducing greenhouse gas emissions [15,16]. Additionally, studies underscore the significance of traditional knowledge and farmer adaptation in ensuring the successful implementation of intercropping systems [17,18].

From a global and regional perspective, intercropping plays a vital role in promoting sustainable agriculture and food security [19,20]. Recent research trends indicate a growing interest in intercropping as an alternative to conventional farming systems, emphasising its environmental and economic benefits [21,22]. This practice has been linked to improved pest management, enhanced carbon sequestration, and more efficient nutrient cycling [23,24]. Moreover, integrating traditional agricultural techniques with modern farming methods has been proposed to further enhance the effectiveness of intercropping [25,26].

The methodologies employed in intercropping research have evolved, with qualitative literature reviews providing comprehensive insights into various intercropping systems [27,28]. Meta-analyses have also been utilised to assess the impacts of intercropping on crop yields, farmer income, and ecological sustainability [29,30]. Understanding these research methodologies is crucial for evaluating the effectiveness of intercropping practices and determining their broader applications.

The future of intercropping, particularly in oil palm plantations, depends on supportive policies and the adoption of innovative agricultural strategies [31,32]. Research suggests that implementing crop diversification, agroforestry, and climate adaptation measures can significantly enhance the resilience of intercropping systems [33,34]. The productive performance of intercropping has been extensively analysed, highlighting its potential to improve agricultural sustainability [21]. Given these insights, further research and policy support are essential for maximising the benefits of intercropping systems in oil palm plantations.

Method

This research employs a qualitative literature review method to examine the obstacles and potential benefits of intercropping upland rice in oil palm plantations. The aim is to provide a detailed synthesis of existing research on how this agricultural practice contributes to sustainability, economic benefits, and environmental improvements in oil palm farming systems. A comprehensive search was carried out in academic databases, such as Google Scholar, Scopus, and JSTOR, using key terms related to intercropping, upland rice, oil palm, agricultural sustainability, and environmental impacts. Publications from 2000 to 2023 were reviewed, ensuring a focus on peer-reviewed journal articles that discussed the integration of upland rice into oil palm cultivation and its agronomic, socio-economic, and ecological implications. Only studies that focused on tropical regions, particularly Southeast Asia, and addressed empirical findings or case studies were included.

The review process involved extracting relevant data from the selected articles, which were organised into major themes related to agronomic practices, socio-economic impacts, and environmental benefits of intercropping. Special attention was given to studies that examined soil quality, biodiversity, greenhouse gas emissions, and the economic outcomes for smallholder farmers. By categorising the information thematically, the study aimed to uncover patterns in the literature and provide a clearer understanding of the advantages and challenges of intercropping upland rice within oil palm plantations.
A qualitative analysis of the gathered information was conducted, focusing on identifying recurring themes that influence the success of intercropping practices. These themes included the importance of appropriate management techniques, the role of farmer knowledge, and the impact of intercropping on environmental sustainability. Challenges, such as soil fertility management, climate variability, and the economic risks associated with diversifying crops, were also identified. The analysis provided insights into how these systems can be optimised for better agricultural productivity and environmental conservation.

The scope of this study is limited to existing published literature, meaning that it does not incorporate new primary data from field studies. Therefore, the findings are constrained by the availability of research and may not fully reflect local variations in agronomic practices or contextual challenges. The study's conclusions are based on the synthesis of previous works, which offer valuable insights but may not capture the full range of experiences in different oil palm-producing regions.

Future studies should focus on longitudinal research to evaluate the long-term effects of intercropping on soil health and ecosystems, as well as more detailed economic analyses that consider the costs and benefits of these systems for smallholder farmers. Investigating the role of policy and institutional support in facilitating intercropping adoption could provide further direction for improving its implementation in oil palm-growing regions. Comparative research on intercropping systems versus monoculture practices will also be crucial in understanding the full potential of intercropping for sustainable agriculture.

Prospects of Intercropping Upland Rice in Oil Palm Plantation

The crop diversification achieved through intercropping upland rice with oil palm offers significant advantages in terms of resilience to production losses caused by weather fluctuations or pest attacks. Therefore, plant species diversification can reduce production risks, as it involves multiple commodities on a single plot, which enhances resilience to price and weather fluctuations. This creates a more sustainable system and improves economic stability for smallholder farmers [35].

Moreover, land use efficiency is also improved in the intercropping system, as interactions between oil palm and upland rice optimise the use of limited land space. Research demonstrates that intercropping enhances land use efficiency compared to monoculture, as the two crops have different space requirements and can exploit resources more evenly [36]. Additionally, soil fertility improvement is directly linked to the use of oil palm waste as compost, which can enhance soil quality. Studies show that bio-composting oil palm waste adds organic matter to the soil, improving water retention capacity and fertility, thus supporting plant growth [37] .

Thus, nutrient cycling is also well maintained in the intercropping system, where upland rice plays a key role in recycling nutrients within the soil. Research indicates that intercropping increases nutrient cycling and soil organic matter dynamics, benefiting both upland rice and oil palm crops and improving overall soil quality [38]. Furthermore, weed suppression is an important benefit of the intercropping system, as upland rice helps reduce weed growth, eliminating the need for chemical herbicides. Findings suggest that intercrops like upland rice effectively suppress weeds, which not only reduces weed control costs but also supports more sustainable farming practices [39].

In addition, pest and disease control in intercropped systems has been shown to reduce pest damage. Research explains that plant diversity can disrupt pest life cycles, decreasing the level of damage to oil palm crops, which are often prime targets for pests [40]. On the other hand, biodiversity enhancement is achieved in intercropping systems, increasing species diversity within oil palm plantations. Studies found that integrating additional crops such as upland rice boosts plant and animal species diversity, contributing to overall ecosystem stability [41].

Moreover, carbon sequestration is enhanced through intercropping, as increased biomass can improve the soil's ability to store carbon. Research confirms that agroforestry and intercropping systems have high potential to sequester carbon from the atmosphere, aiding in climate change mitigation [42]. Furthermore, water retention in oil palm fields is improved through intercropping. Studies observed that the system enhances soil water retention, reducing water loss through evapotranspiration and maintaining soil moisture, particularly in peatland areas [43].

In addition, microclimate regulation is facilitated through alley cropping, where the integration of upland rice and oil palm helps stabilise microclimates, benefiting both crops. Research showed that vegetation diversity in such systems moderates extreme temperatures, which is beneficial for plant growth [44]. Next, the economic benefits of intercropping with upland rice and oil palm are evident through increased smallholder incomes. Studies noted that intercropping provides a more stable income stream, as it produces two crops at once, increasing the profit potential [45].

In the same vein, smallholder farmer income increases through diversified revenue streams from both upland rice and oil palm. Research found that smallholders practising intercropping experience higher incomes due to reduced dependence on a single commodity and the ability to generate profits from various sources [46]. Simultaneously, food security is improved through intercropping, as it not only increases farmers' incomes but also strengthens local food systems. Findings observed that intercropping helps ensure food security by providing local food supplies and improving income stability for farmers [47].

Additionally, agroforestry integration offers substantial potential for supporting sustainable farming practices. Research emphasised that oil palm-based agroforestry systems that integrate upland rice can improve agricultural yields while maintaining biodiversity and enhancing ecosystem services [48]. Consequently, sustainable agriculture practices are better supported through intercropping, as it reduces reliance on chemical inputs such as fertilisers and pesticides. Studies explained that this system helps maintain long-term soil fertility, which is crucial for sustainable agricultural production [49].

In turn, yield stability is enhanced in intercropping systems, as upland rice can mitigate yield declines caused by external factors. Research demonstrated that intercropping increases yield stability by providing complementary benefits from both crops and improving soil conditions [50]. Moreover, climate resilience is strengthened by integrating upland rice into oil palm plantations, enhancing adaptability to climate change. Studies noted that such systems increase resilience to extreme weather events, offering greater flexibility for farmers facing changing climatic conditions [51].

Additionally, ecosystem services from intercropping systems, such as improved soil quality and reduced erosion, support the long-term sustainability of agriculture. Findings highlighted that intercropping and agroforestry can improve ecosystem services, including water quality and soil erosion control [52]. Conversely, governmental support is essential in advancing intercropping systems by offering incentives that motivate farmers to implement environmentally sustainable technologies. Research has highlighted that policies facilitating the shift toward sustainable agricultural practices play a key role in encouraging farmers to adopt intercropping systems [53].

Thus, effective agronomic management is essential to ensure the success of intercropping systems, including proper soil and irrigation management. Research found that good agronomic practices significantly improve crop yields in smallholder oil palm fields, especially when paired with efficient nutrient management [54]. In addition, the adoption of technology to support intercropping systems is increasing, with modern agricultural technologies helping farmers optimise their yields. Studies found that adopting Best Management Practices significantly enhances productivity and efficiency in intercropping systems [55].

Furthermore, long-term productivity of intercropped systems is evident, as studies show that crop diversity helps maintain soil health and long-term yields. Research demonstrated that intercropping with legumes like peanuts helps sustain or even increase oil palm yields over the long term [56]. Finally, the socio-economic impact of intercropping is highly positive for smallholder farmers, improving their income and reducing vulnerability to market fluctuations. Findings emphasised that the development of intercropping systems provides significant economic benefits for rural communities, particularly in developing regions [57].

Challenges and Limitations

A key challenge in intercropping practices stems from the rivalry between different plant species in accessing crucial resources such as light, moisture, and soil nutrients. This competition can hinder growth efficiency and lower crop productivity, particularly when the system is not managed effectively. Additionally, the success of intercropping heavily depends on selecting the appropriate crop species, as the physiological compatibility between crops is a crucial factor in the effectiveness of the system [58]. On the other hand, intercropping systems also face limitations due to the need for more intensive management, including proper crop arrangement and resource management. Crops in these systems require special attention for weed control, proper fertilisation, and careful water management. Imbalances in meeting water and nutrient requirements can hinder achieving optimal yields [59].

Integrating intercropping practices within oil palm plantations can contribute to boosting biological processes in the soil. However, significant challenges arise from the imbalance between the large oil palm trees and the smaller intercropped plants, which often struggle to survive under shade and in soil degraded by oil palm cultivation [60]. Additionally, the adoption of intercropping is hindered by the lack of farmers' knowledge regarding effective intercropping techniques, as well as limited access to the necessary information and resources for optimal management. The absence of supportive policies and investment in agronomic research also acts as a barrier [61]. Economically, the challenges include higher initial costs for inputs such as seeds and fertilisers, along with greater labour requirements compared to monoculture systems. Despite the potential for overall yield improvement, these additional costs often reduce the economic appeal of intercropping for smallholder farmers [62].

Land management in intercropping poses significant challenges, particularly in the need for careful planning regarding crop rotation and fertilisation management. Proper soil management is essential to prevent fertility decline or land degradation, especially when intercropped plants fail to replenish nutrients lost during the cropping cycle [63]. In addition, soil degradation can occur in certain intercropping systems, such as cassava-based systems in Sumatra, Indonesia, due to soil erosion and declining soil quality. While intercropping can improve some aspects of soil fertility, improper management may exacerbate soil damage through the use of unsuitable techniques [64]. Moreover, weed management becomes more challenging in intercropping systems because of variations in the ability of different plants to compete with weeds. For example, in rice intercropping with plants like Brahmi, weed control requires more intensive strategies to prevent weeds from significantly reducing crop yields [65]. Finally, although intercropping can help reduce pest attacks by increasing plant diversity, pest and disease management remain a challenge. In some intercropping systems, conditions may favour certain pests, worsening pest control issues [66].

Intercropping systems often require more labour compared to monoculture, as farmers must manage multiple types of crops simultaneously. This includes tasks such as planting, maintenance, and harvesting, which are more labour-intensive [67]. Furthermore, a significant obstacle in intercropping systems is the competition among different crops for vital resources such as water, sunlight, and soil nutrients. This issue is evident in agroforestry systems that combine apple trees with food crops, where imbalanced competition can result in lower yields for smaller, more vulnerable plants [68]. Another challenge in intercropping is the efficient allocation of resources between competing plants. Proper management of water, fertiliser, and labour is crucial to avoid decreasing production efficiency [69]. Although intercropping systems offer ecological benefits, their implementation requires in-depth technical knowledge. For instance, in rubber and tea intercropping systems in Sri Lanka, a lack of understanding of plant interactions makes it difficult to achieve optimal yields. Maintenance and more complex agronomic adjustments also pose significant barriers [70].

The practice of intercropping within oil palm plantations may face constraints due to inconsistent nutrient availability, especially in agricultural systems with minimal external inputs. When soil management is insufficient, nutrient distribution to both crops can be compromised, leading to inconsistent and lower yields [71]. Moreover, integrating intercropping into oil palm cultivation poses particular difficulties, notably concerning its potential effects on the development of the oil palm crop. Certain intercrops, such as bananas and maize, can interfere with oil palm development, particularly in its early stages. Furthermore, alterations in soil management practices and the use of differing resources may cause productivity imbalances [72]. Another challenge faced by intercropping systems is land use conflict, particularly among smallholder farmers with limited land area. The competition between monoculture and intercropping for space often creates tensions, restricting the potential economic benefits of intercropping [73]. Additionally, the impact of climate change poses further difficulties for intercropping systems, especially with the unpredictable nature of weather patterns. Extreme weather events and changes in rainfall can disrupt plant growth, making both productivity and sustainability harder to manage, particularly in systems dependent on variable natural resources [74]. Finally, while intercropping increases biodiversity and provides resilience to market risks, its economic sustainability faces challenges due to higher initial costs and greater labour demands. The viability of intercropping is closely tied to stable market prices and the support of policies that ensure the economic competitiveness of farmers [75].

Barriers to the adoption of intercropping are often linked to policies that do not fully support its implementation. Inconsistencies in agricultural policies result in limited incentives for farmers to adopt intercropping, particularly in legume-cereal systems that are more environmentally friendly [76]. Moreover, the adoption of this system also faces social and economic challenges. Farmers' limited knowledge of the benefits and techniques of intercropping, along with restricted market access for intercropped products, frequently hinders the transition from monoculture, despite its long-term advantages [77]. Additionally, technological constraints further complicate the implementation of intercropping, especially for smallholder farmers. Certain methods, such as the Milpa and Push-Pull combinations, show promise in enhancing yields. However, their application requires in-depth knowledge and adequate infrastructure, which remain significant challenges in many regions [78].

One of the main challenges in marketing intercropped products is the limited access farmers have to well-structured and expansive markets. Moreover, unstable prices and low consumer awareness regarding the benefits of intercropped products often hinder their marketing and distribution, especially in developing countries [79]. Conversely, although intercropping has demonstrated positive impacts on crop productivity and long-term soil health, concerns regarding its long-term sustainability persist. This is primarily because the financial returns from intercropping may not consistently offset the increased labour and management requirements compared to monoculture practices. Therefore, ensuring the sustainability of intercropping systems largely relies on adequate policy support and enhanced technical knowledge among farmers, enabling them to optimise these agricultural practices more effectively [80].

Conclusion and Future Directions

Intercropping upland rice within oil palm plantations presents a promising approach to improving agricultural sustainability, enhancing biodiversity, and optimising land use. Despite its potential benefits, various agronomic, economic, and technical challenges must be carefully addressed to ensure its feasibility and long-term success. Efficient resource management, strategic crop selection, and appropriate agronomic practices are crucial for mitigating competition between intercropped species while maximising overall productivity.

Future research should focus on refining intercropping models by integrating precision agriculture and innovative farming techniques to enhance yield stability. Additionally, policies that support intercropping adoption, such as incentives for smallholder farmers and improved market access, can play a vital role in encouraging its wider implementation. Strengthening farmer education and capacity-building programs will also be essential in ensuring the successful adoption and management of intercropping systems. Furthermore, long-term studies on soil health, pest dynamics, and economic viability are necessary to establish evidence-based recommendations for sustainable intercropping practices in oil palm plantations.

Addressing these obstacles while advancing research efforts in this field may strengthen the role of upland rice–oil palm intercropping in building agricultural systems that are both resilient and sustainable. To unlock its full potential, a well-rounded strategy that incorporates environmental considerations, economic factors, and supportive policy frameworks is crucial.

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