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Advancing Food Security in Indonesia: Harnessing Innovative Intercropping Methods within Oil Palm Plantations for Enhanced Rice Farming

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ABSTRACT: Indonesia faces the issue of meeting the escalating food demand caused by population growth. Intercropping rice in oil palm has emerged as a promising strategy to address food production and security challenges in Indonesia. This study thoroughly explores and evaluates the potential of innovative intercropping technology, which involves integrating rice farming into oil palm and industrial forest plantations in Indonesia. The study employed a systematic literature review (SLR) methodology, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow guidelines, focusing on the keywords "intercropping technology," "rice," and "oil palm Indonesia". Using search engines in ScienceDirect and Google Scholar. From the earlier search, 1826 articles were generated, and after selection, 10 articles meeting the criteria were obtained. Out of 48 million hectares of oil palm plantations, approximately 2.4 million hectares (immature) can be utilized for intercropping with rice and capable of producing 4-5 tons per hectare. In brief, this additional rice crop production constitutes roughly a 20-25% augmentation to the national rice output. These findings highlight the significant role of rice intercropping with oil palm in increasing rice production and enhancing food security in Indonesia. Intensive research is crucial to develop innovative technologies capable of boosting both crop productivity and soil fertility, thereby supporting the increase in food production and oil palm productivity.

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KEYWORDS: Intercropping System, Crop Yields, Smallholder Livelihoods, Soil Health, Food Security

INTRODUCTION

In the lush landscapes of Indonesia, where the verdant fields of oil palm and towering industrial forest plantations dominate the horizon, a quiet revolution is taking place in agriculture. Traditional farming methods are being reimagined, and innovative intercropping technology is emerging as a beacon of hope for enhancing food production and security in this tropical archipelago. Intercropping, the practice of growing two or more crops together in the same field, has long been recognized as a sustainable agricultural technique. However, its potential in the context of oil palm and industrial forest plantations has remained largely untapped until recent years.

Indonesia, one of the world's largest producers of palm oil and a significant player in the global timber industry, faces pressing challenges in ensuring food security for its burgeoning population while sustaining its position as a key player in the global market. The conventional approach of monoculture farming in these plantations has often led to environmental degradation, soil depletion, and limited agricultural diversity. Enter innovative intercropping technology. By strategically integrating rice cultivation into oil palm and industrial forest plantations, farmers are not only diversifying their income sources but also reaping a host of environmental and socio-economic benefits.

One of the primary advantages of intercropping rice in oil palm and industrial forest plantations is the efficient use of land. With careful planning and crop selection, farmers can maximize the productivity of every hectare, significantly increasing overall yield without expanding agricultural footprint into pristine forests or critical ecosystems. Moreover, intercropping helps to mitigate the negative impacts of monoculture farming. By harnessing the complementary relationships between different crops, such as the

nitrogen-fixing abilities of legumes or the shade tolerance of certain vegetables, farmers can naturally enrich the soil, reduce pest and disease pressure, and enhance overall resilience to environmental fluctuations.

From a socio-economic perspective, innovative intercropping technology offers a lifeline to smallholder farmers, who often struggle to make ends meet in the face of volatile market prices and unpredictable weather patterns. By diversifying their crops and income streams, farmers can reduce their vulnerability to external shocks and build more resilient livelihoods. Furthermore, the integration of rice cultivation into oil palm and industrial forest plantations can contribute to rural development and poverty alleviation by creating employment opportunities, fostering community empowerment, and strengthening local food systems.

However, the successful implementation of innovative intercropping technology requires a holistic approach that encompasses technical expertise, institutional support, and stakeholder collaboration. Governments, agricultural extension services, research institutions, and private sector actors must work hand in hand to provide farmers with access to high-quality seeds, training, financial resources, and market linkages. In addition, policymakers need to create an enabling environment that incentivizes sustainable agricultural practices, protects farmers' rights, and promotes inclusive growth. This may involve developing appropriate land-use policies, establishing certification schemes for environmentally friendly products, and investing in rural infrastructure and extension services.

As Indonesia stands at the crossroads of agricultural development, the adoption of innovative intercropping technology holds immense promise for enhancing food production and security, conserving natural resources, and fostering inclusive and sustainable growth. By harnessing the power of diversity, collaboration, and innovation, we can pave the way for a brighter and more resilient future for generations to come.

MATERIALS AND METHODS

A systematic literature review (SLR) technique was used in this study, which was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow guidelines. A variety of databases and indexes, such as Science Direct and Google Scholar, were used to get the data for this research. The search was used specific keyword such as “Intercropping technology” AND “rice” AND “oil palm Indonesia” in Science Direct. In addition, Google Scholar has conducted a search with the same keywords but added “integrated” to gather relevant literature on the topic of rice-oil palm intercropping and their potential for enhancing food security.

The screening criteria are based on the title and abstract of scientific articles that were published in research journals between the years 2014 until 2024. Data on rice-oil palm intercropping is presented in the contents of all examined publications together with results of yields production

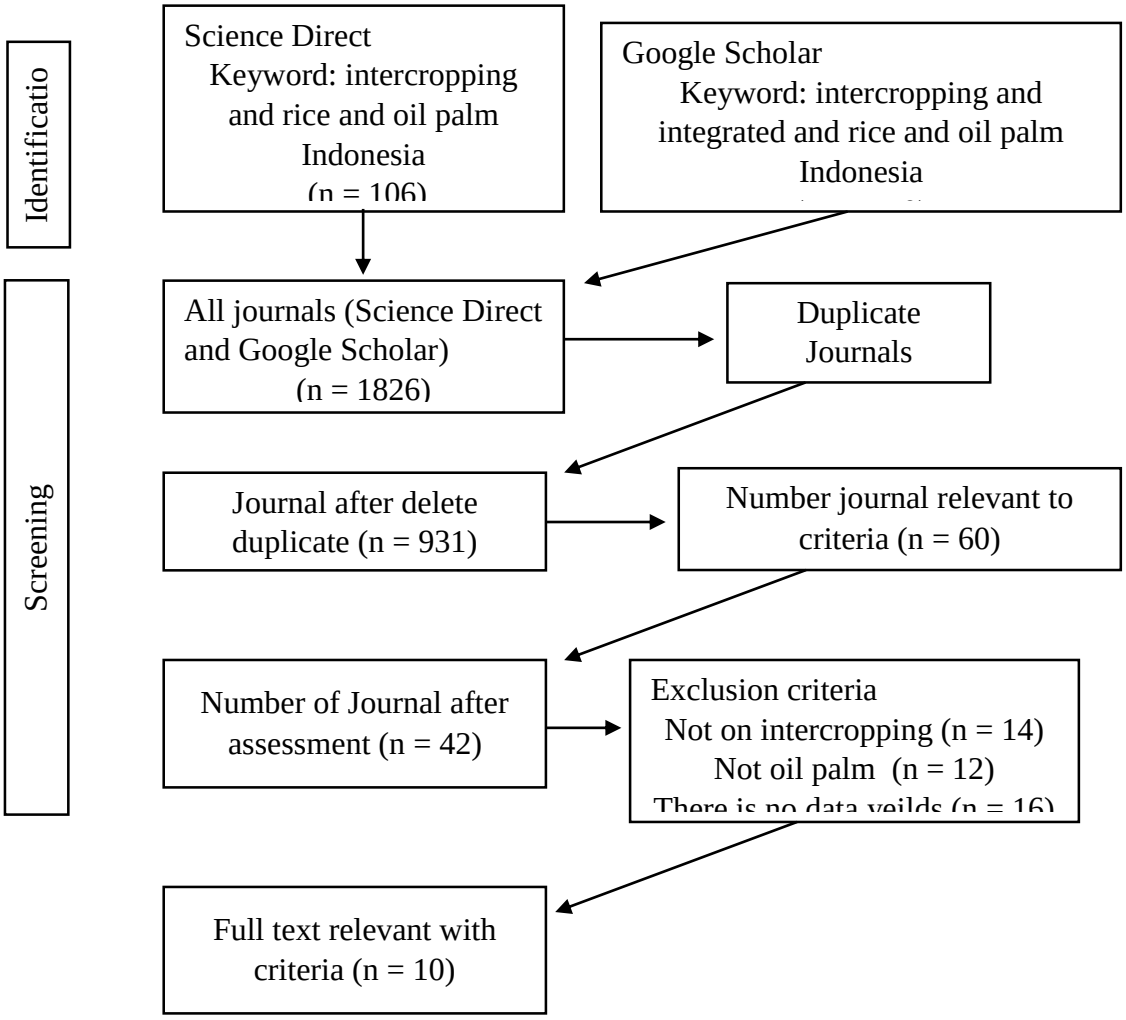

Figure 1. Flow Chart Methods Systematic Literature Review: Innovative Intercropping Technology for Rice in Oil Palm to Enhance Food production and Security in Indonesia.

Following a screening for the journal's publication date, the type of article and the type of access used, a total of 106 research papers were found from 181 results from ScienceDirect search. Screening from the title method using intercropping rice and oil palm resulted in 60 journal titles, followed by specific titles using Indonesia, which resulted in 42 appropriate journal titles. The journals with information meeting the requirements were acquired in 10 titles after being fully screened. The results underscored the favorable impact of food production and security in Indonesia, determined the effectiveness of several cropping systems on the growth and production of rice with high yielding (Alridiwansah et al., 2019)

RESEARCH RESULT AND DISCUSSION

Innovative Intercropping Technology for Rice in Oil Palm

Indonesia, as a major producer of both rice and palm oil, has a unique opportunity to develop innovative intercropping technologies for these crops. Intercropping, planting two or more crops together, offers a chance to increase productivity and land use efficiency. Interesting area of research and some potential technologies because it has many benefits including 1) Increased Land Use Efficiency by strategically planting rice between oil palm trees, especially in the early years before the palms mature and take up full space, you can maximize yield on the same land area, 2) Improved Soil Health from the shade provided by oil palms, reducing water evaporation and potentially suppressing weeds. Additionally, legumes like peanuts or soybeans can be included in the intercropping system to fix nitrogen in the soil, improving fertility for both crops. Then, diversified income for farmers to harvest two crops from the same land, providing them with a financial buffer and reducing dependence on the sometimes volatile prices of a single commodity.

Table 1. Area of oil palm plantations in Indonesia

Area (Ha)					
TBM / Immature	TM / Mature	TTM/TR/ Damaged	Total	Production (Ton)	Productivity (Kg/Ha)
2.494.012	12.353.266	528.704	48.215.405	48.215.405	3.903

Calculation of the Comparison with National Food Needs:

1. Total Rice Production from Oil Palm Intercropping:
   - Productivity of Rice in Oil Palm Intercropping: 4.47 Tonne/Ha
   - Area of Oil Palm Plantation Suitable for Intercropping: 2,494,012 Ha
   - Total rice production = Productivity x Area of Oil Palm Plantation = 4.47 Tonne/Ha x 2,494,012 Ha = 11,140,396.64 Tonne
2. Comparison with National Rice Production:
   - National Rice Production (2023): 53.63 million tonne = 53,630,000 tonne
   - Comparison of rice production from oil palm intercropping with national rice production: 11,140,396.64 Tonne / 53,630,000 Tonne x 100% = 20.77%
3. Calculation of the Percentage Contribution of Rice Yield from Intercropping Technology:

Percentage Contribution of Rice Yield from Oil Palm Intercropping Technology:

- Productivity of Rice in Oil Palm Intercropping: 4.47 Tonne/Ha
- Area of Oil Palm Plantation Suitable for Intercropping: 2,494,012 Ha
- Total rice production from intercropping: 11,140,396.64 Tonne
- Percentage contribution of rice yield from intercropping technology: (Intercropping rice production / National rice production) x 100% = (11,140,396.64 Tonne / 53,630,000 Tonne) x 100% = 20.77%

Thus, oil palm intercropping technology can contribute approximately 20.77% to national rice production in Indonesia. This indicates the significant potential of this system in increasing rice production and its contribution to food security in the country.

Innovative technologies for intercropping include upland rice varieties that can be grown in flooded paddies. Developing upland rice varieties that can thrive in drier conditions under the oil palms would be a major breakthrough. Also, nutrient management strategies for research are needed to determine the optimal fertilizer application for both rice and oil palms in an intercropping system to avoid competition for nutrients. Besides that, allelopathic plants can suppress the growth of others through the release of chemicals. Identifying allelopathic plants that can be used strategically within the system could help control weeds in the rice crop.

Overall, innovative intercropping technology has the potential to be a win-win for Indonesian farmers, increasing productivity, improving soil health, and providing economic benefits. Further research and development are needed to address the challenges and optimize this practice for Indonesian conditions.

Intercropping System of Rice with Oil Palm: Local and New Varieties

This study aims to enhance plant productivity, particularly in Sumatera Utara, by utilizing high-yielding variety seeds. Efforts are being made to optimize rice production in collaboration with oil palm plants aged under 4 years, utilizing high-yielding varieties. The research reveals that the yield production per hectare of the Kuku Balam high-yielding local variety significantly differs from other varieties, showing potential for cultivation within oil palm plantations.

Integrated rice cultivation with oil palm plantations presents a promising strategy for diversifying businesses and increasing local and regional food production. Additionally, it aligns with government initiatives aimed at achieving food self-sufficiency.

Polyculture Upland Rice Varieties between Plantation Oil Palm in Dry Land

This study tested the growth of Cilosari of various rice varieties grown in oil palm plantations, in Palembang. Cilosari rice varieties have a growth rate exceeding 80%, compared to other varieties, while Sulutan Unsrati varieties display a greater number of tillers (10 stems) and a higher chlorophyll in their leaves than other varieties. Both Cilosari and Sulutan Unsrati upland rice varieties, along with the local rice variety 4-month, demonstrated relatively robust vegetative growth under low light conditions within palm oil plantations. The results indicate that the growth performance of Sulutan Unsrati rice within the inter-rows of oil palm is superior compared to other varieties, and the local 4-month rice has the potential to be further enhanced as a shade-tolerant local upland rice.

With the condition of the inter-rows in oil palm plantations having relatively large vacant land, it can be utilized to develop intercropping with crops such as upland rice. Therefore, research is needed to understand the response of rice plants to limited light conditions within the oil palm inter-rows. It is hoped that in the future, the community can apply the results of this research after knowing how to utilize the inter-rows during the rainy season by planting upland rice varieties that are tolerant to shade under oil palms aged over 10 years, so that dryland oil palm plantations can contribute to food production.

Intercropping Upland Rice with Palm Oil in Drylands: Feasibility and Productivity

Intercropping, or simultaneous cultivation of two or more crops on the same land, offers an intriguing solution in Indonesia, where land availability is limited, and food sustainability is a critical issue. In this context, we explore the innovative approach of intercropping rice and oil palm, both strategically important crops for food security and the national economy.

Recent research has focused on planting upland rice varieties such as Inpago 5, Inpago 8, and Inpago 9 amidst young oil palm trees. Additionally, the use of dolomite as an ameliorant improves soil physical properties and pH balance. This technology not only enhances rice yield but also optimizes land utilization.

Inpago 9 stands out due to its robust growth and drought tolerance. Given Indonesia's prolonged dry seasons, using drought-resistant varieties like Inpago 9 becomes a viable solution for increasing rice production. Furthermore, financial analysis reveals that investing in this intercropping technology is economically advantageous. The high yield of Inpago 9, at 3.53 tons per hectare, underscores its potential impact on food security and economic prosperity.

Intercropping rice and oil palm represents a significant step toward achieving food sustainability in Indonesia. With the right approach, farmers can maximize land use efficiency while contributing to food security. Further research and widespread adoption of this technology hold promise for the well-being of our society.

Optimizing Rice Growth in Oil Palm Shade: A Modeling and Experimental Approach

In an effort to enhance agricultural production efficiency, particularly within agroforestry systems, a deep understanding of the interaction between light and plants is crucial. The model of light interception on virtual canopies represents an innovative approach that allows us to analyze and predict how sunlight is absorbed, diffracted, and reflected by plant canopies. Utilizing advanced 3D computational models, we can simulate real-field conditions and identify optimal planting patterns to maximize light capture by plants.

This model is highly relevant in the context of agroforestry, where there is a combination of food crops and timber or plantation crops. In such systems, the higher canopy of plantation crops can cause a reduction in light intensity reaching the food crops below. Therefore, the light interception model plays a key role in determining planting design and canopy management that will produce sufficient sunlight for both types of plants, thereby enhancing the overall productivity of the agroforestry system.

This approach not only provides insights into efficient light distribution but also assists in the selection of crop varieties that are tolerant to shade conditions. Thus, the model of light interception on virtual canopies becomes a vital tool in the development of sustainable agricultural practices that are adaptive to climate change.

This study delves into the use of light interception models in virtual canopies to optimize rice cultivation beneath oil palm canopies. This approach allows researchers to understand how light influences plant growth. By selecting planting designs that optimize transmitted light for rice, we can efficiently enhance production yields.Studies have revealed that light quantity is a key factor affecting plant morphology and architecture. Light fluctuations appear to explain variations in yield components and phenology. Therefore, understanding how light fluctuations impact seed filling processes and resource allocation is crucial. By considering these factors, we can optimize rice production within agroforestry systems.

Furthermore, this research highlights that variety responses to low light are likely hereditary. Screening varieties under full light can provide insights into their behavior under low light conditions. By choosing varieties suited for agroforestry systems, we can enhance productivity and agricultural sustainability in Indonesia.

Innovative technology within the rice-oil palm intercropping system holds great potential for improving food production and security in Indonesia. By comprehending the role of light and selecting appropriate varieties, we can achieve these goals sustainably.

Oil Palm and Crops: A Pathway to Inclusive Smallholder Farming

In the pursuit of meeting the ever-growing food demand, agricultural technology continues to evolve. One intriguing innovation is intercropping technology. In this study, we will delve into this innovative approach and explore its application in oil palm plantations to boost food production and security in Indonesia.

Intercropping technology involves planting two or more different crops simultaneously on the same plot of land. Within the context of oil palm plantations, the double row avenue system has garnered attention. Developed by the *Malaysian Palm Oil Board*, this system allows for the cultivation of other crops, such as rice, red beans, cassava, and black pepper, between rows of oil palm trees. By combining these crops, farmers can generate income from both types of plants. For instance, black pepper, a high-value crop, can be grown alongside oil palm trees. This not only diversifies income sources but also contributes to food security in the region.

Beyond economic gains, intercropping has positive environmental impacts. The system aids in better soil erosion control, enhances carbon sequestration, and reduces nitrogen leaching. These benefits are crucial in the face of climate change and ensure the sustainability of agricultural systems.This study also highlights the WaNulCAS model, which predicts crop yields from various plant combinations. The model provides insights into resource management and plays a pivotal role in further research on innovative intercropping technologies in Indonesia.

By implementing intercropping technology, oil palm plantations can become more productive and contribute significantly to food security in Indonesia. This innovation holds great potential in addressing global challenges related to food and the environment.

Table 2. Innovative Intercropping Technology for Rice in Oil Palm for Food Security in Indonesia.

Technology	Data Productivity	Fertilization	Planting Method	Location	References
Local varieties: Kuku Balam more adaptive in conditions among oil palm plants	Yield production is 4,47 ton/ha		Sub-plots is a cropping system with 4 levels, Legowo system and Tegel system	Padang, North Sumatera	Harun, M. U *et al*, 2018
Polyculture Upland Rice Varieties with Light Intensity: Cilosari and Sulutan Unsrati	Cilosari rice varieties: growth percentage of more than 80%, Sulutan unsrati tillers (10 stems) and a higher chlorophyll		The single-stem pruning	Palembang , South Sumatera	Alridiwirsah *et al*, 2019
Intercropping Upland Rice with Palm Oil in Drylands: Inpago 5, Inpago 8, Inpago 9	The highest yield Inpago 9 of 3.53 t/ha	Ameliorant materials such as dolomite 1000-2000 kg/ha. Rice fertilizer dosage is 150 kg/ha Urea, 100 kg/ha SP 36 and 50 kg/ha KCl.		Batanghari District, Jambi Province	Bobihoe, J, 2021
A Modeling and Experimental Approach : Modeling light transmission-based agroforestry system	The highest dry matter content of Plant grains is 38.7 g (Japonica 809 variety from Brazil).	3 g/L of NPK fertilizer (50% of Basacote 13-5-18 and 50% of Bio 5-3-8; Compo – expert)	Choose varieties that are sensitive to light	Southeast Asia, Indonesia	Rebolledo *et al*, 2022

Challenge and Considerations to Enhance Food production and Security in Indonesia

Currently, Indonesia faces several considerations and opportunities to enhance food production and security. Here are some things to consider:

- Competition for resources: Both oil palm and industrial trees can compete with rice for light, water, and nutrients. Research is needed to identify shade-tolerant rice varieties and refine planting patterns (e.g., alley cropping) to minimize competition.
- Shade management: Strategies like selective herbicide application and pruning practices for trees require further investigation to balance weed control with minimizing adverse effects on rice growth.

- Long-term sustainability: The long-term impact of intercropping on soil health, pest and disease dynamics, and overall ecosystem function needs thorough investigation.
- Economic viability: Studies are needed to assess the cost-benefit analysis of intercropping compared to traditional monoculture practices, considering factors like labor costs, market fluctuations, and potential yield reductions.
- Social considerations: The potential impact on smallholder farmers' livelihoods, land use rights, and access to resources requires careful consideration and appropriate social safeguards.Also the economic viability of intercropping for farmers needs to be carefully evaluated, including factors like crop yields, market prices, and labor requirements.
- Shading: As oil palms mature, they cast more shade, potentially impacting rice yields. Planting patterns and palm selection will need to be optimized.
- Pest and Disease Management: Intercropping can create new pest and disease challenges. Integrated pest management (IPM) techniques that consider both crops will be crucial.

Future Solutions

To address the challenges in integrating intercropping of oil palms and rice, solutions are needed, including:

- Machinery and Mechanization: The use of machinery or mechanization in farming practices can solve issues such as low production, lack of labor, and inefficient land use.
- Food Diversification: Over-reliance on rice can pose difficulties if local production cannot meet demand. Food diversification approaches can help alleviate supply and access difficulties.
- Regulation : Regulations that prioritize farmers as food producers can help create a more balanced food system. For example, not importing rice during planting seasons or other commodities that can be produced locally.
- Education: Education for food producers and consumers can help improve food production and usage. Household food production education can enhance household welfare, while education on food usage and waste disposal can improve efficient food usage.
- Supply and Access: Providing available and accessible food to all regions and individuals is a key component of food security. All parties need to work together to achieve high food security.
- Investment: Investment in agricultural infrastructure, such as irrigation, roads, and fertilizer usage, can help increase food production and strengthen supply systems.
- Technology: Development of technology, such as data systems, food processing technology, and distribution systems, can help increase production and farmer welfare.
- Public-Private Partnership and Collaboration : Also solutions to Indonesia's food issues require efforts from all parties. More modern or environmentally-based solutions need to be obtained to address long-standing problems. Collaboration between private sectors, government, and universities can help develop effective and efficient technology.
- System Development:
    a. Distribution System Development: Developing an effective distribution system can help improve food access and reduce inefficient food usage.
    b. Local Food System Development: Developing local food systems can help increase production and farmer welfare, as well as strengthen supply systems.
    c. Digital-Based Food System Development: Developing digital-based food systems can help improve food production and strengthen farmer welfare.
    d. Food Trade System Development: Developing open, predictive, and transparent food trade systems can help improve welfare and reduce difficulties in food supply.
    e. Local-Based Food System Development: Developing local-based food systems can help increase production and reduce difficulties in food supply.
    f. Land-Based Food System Development: Developing land-based food systems can help increase production and reduce difficulties in food supply.
    g. Small-Scale Food System Development: Developing small-scale food systems can help increase production and reduce difficulties in food supply.
    h. Technology-Based Food System Development: Developing technology-based food systems can help increase production and reduce difficulties in food supply.

Further Research Needs

- Field trials: Conducting long-term field trials in various regions and diverse conditions is crucial to evaluate the effectiveness and identify optimal practices for different contexts.

- Farmer participation: Engaging farmers in the research and development process is essential to ensure the adoption of these practices is practical, efficient, and aligns with their needs and preferences.
- Sustainability assessments: Comprehensive assessments of the long-term environmental and economic sustainability of intercropping in these specific contexts are necessary for responsible implementation.

CONCLUSION

The study concludes that innovative intercropping technology, specifically the integration of rice cultivation into oil palm and industrial forest plantations, can enhance food production and security in Indonesia. Out of 48 million hectares of oil palm plantations, approximately 2.4 million hectares (immature) can be utilized for intercropping with rice and capable of producing 4-5 tons per hectare. The additional rice crop production constitutes roughly a 20-25% augmentation to the national rice output. While innovative intercropping technology offers promising potential for enhancing food production and security in Indonesia, further research is crucial to address existing challenges and ensure its successful and sustainable implementation.

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