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Effect of Irrigation System, Pesticide Use, and Human Resource Management on Productivity Growth of Oil Palm in Indonesia

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ABSTRACT

This study investigates the impact of irrigation systems, pesticide use, and human resource management (HRM) on the productivity growth of oil palm plantations in Indonesia. Utilizing a quantitative approach, data were collected from 120 respondents, representing various plantations, using a Likert scale (1–5). Statistical analysis was conducted using SPSS version 26 to assess the relationships between the independent variables (irrigation systems, pesticide use, and HRM) and the dependent variable (productivity growth). The findings reveal that efficient irrigation practices, responsible pesticide use, and effective HRM significantly contribute to productivity growth. Among these, HRM was found to be the most influential factor. These results highlight the need for plantation managers to prioritize resource management and workforce development to achieve sustainable productivity gains. The study provides valuable insights for enhancing oil palm productivity and promotes the adoption of sustainable practices in Indonesia's palm oil industry.

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1. INTRODUCTION

Indonesia's oil palm plantations are essential to its economy, contributing significantly to employment, exports, and agricultural productivity. However, sustaining productivity is increasingly difficult due to environmental concerns, resource management issues, and the demand for sustainable practices. As a global leader in palm oil production, Indonesia's market is dominated by refined products like Refined Palm Oil and Oleochemical Mix, though crude oil export value remains low due to downstream industrial policies [1]. The sector supports rural development by creating jobs and enhancing socio-economic conditions but is challenged by fluctuating demand and the push for sustainable practices [2]. The expansion of plantations has resulted in deforestation and socio-ecological disruptions, driven by high crude palm oil (CPO) demand and investment-focused policies [3]. Environmental issues, such as deforestation and habitat loss, highlight the need for sustainable practices and

certification programs [4], [5]. The Indonesian Sustainable Palm Oil (ISPO) certification and revenue-sharing from palm oil aim to improve governance and environmental quality through sustainable land management [6]. Strong government and stakeholder commitment is essential to enforce sustainable practices and forest conservation [7].

One crucial factor in enhancing productivity is the implementation of efficient irrigation systems. Traditional irrigation methods often result in inconsistent water supply, impacting photosynthesis and nutrient uptake, while advanced systems like drip irrigation and sensor-based technologies offer significant improvements in water efficiency and productivity [8]. Drip irrigation delivers water directly to plant roots, reducing waste and enhancing water-use efficiency; studies show that combining this method with biochar, such as vetiver grass biochar, boosts fertilizer efficiency and oil palm growth [9], [10]. Smart irrigation systems, leveraging Industry 4.0 technologies, optimize water use and economic performance, proving cost-effective in Malaysian palm oil plantations larger than 1.5 hectares by reducing water footprint and maintaining moisture [11]. Adoption of these technologies is influenced by socioeconomic and demographic factors, with younger producers, larger plantations, and access to extension services associated with higher adoption rates, although less than 15% of oil palm growers currently utilize advanced systems [12]. Additionally, farmer typology impacts adoption; groups led by females and with diverse populations are more likely to implement advanced irrigation technologies [12].

Effective pesticide application in oil palm cultivation is essential for controlling pests and diseases while minimizing environmental impact and operational costs, requiring the selection of appropriate pesticides, judicious application, and integration with sustainable management strategies. The choice of pesticide is critical; for example, Sipermetrin has shown higher efficacy than Dimehipo in controlling bagworm pests, achieving an 80-90% mortality rate compared to 40-50% with Dimehipo [13]. Mixed herbicides, like isopropylamine glyphosate combined with metsulfuron methyl, effectively control a broad range of weeds, reduce herbicide residues, and slow resistance development [14]. Excessive pesticide use, however, poses risks to ecosystems, with metals such as copper and zinc presenting notable environmental hazards [15]. Reducing management intensity, such as using mechanical weeding over herbicides, can maintain yields and improve ecological outcomes [16]. Furthermore, technical, allocative, and economic efficiencies in pesticide use are not fully optimized, suggesting improvements in input allocation [17]. Balancing economic and ecological functions is feasible by closing yield gaps through careful intensification and reducing management intensity without compromising productivity [16].

Human Resource Management (HRM) practices are essential for boosting productivity in the labor-intensive oil palm sector by ensuring workers are skilled, motivated, and efficiently allocated—vital for precision in tasks like planting, fertilizing, and harvesting. Training and development programs are critical, enhancing skills and productivity in agricultural settings [18], with online platforms and electronic tools enabling continuous employee development to keep up with industry changes [19]. Creating a motivated workforce through incentives and a supportive environment is also key, incorporating mechanisms for job satisfaction and involving employees in decision-making to boost motivation and performance [18], [20]. Efficient labor allocation and management support the adoption of labor-saving technologies and resource optimization in agriculture [21], with digital tools automating HR tasks, thus freeing up time for strategic planning [19]. Strategic HRM aligns human resources with long-term goals, deploying personnel effectively, while digitalization in HRM, like online recruitment

platforms and analytics, enhances agricultural enterprises' efficiency and competitiveness [19], [22].

Despite this, HRM practices in many oil palm plantations in Indonesia remain underdeveloped. Exploring the role of HRM in productivity growth can help policymakers and plantation managers design strategies that foster a skilled and engaged workforce. This study aims to analyze the effect of irrigation systems, pesticide use, and HRM on the productivity growth of oil palm plantations in Indonesia. By examining these factors, this research provides empirical insights into the key drivers of productivity in the sector.

2. LITERATURE REVIEW

2.1 Irrigation Systems and Agricultural Productivity

Efficient irrigation is crucial for optimizing oil palm productivity, particularly in tropical climates where water availability significantly impacts growth cycles. Advanced irrigation techniques, such as drip irrigation, have been shown to enhance water use efficiency, improve nutrient uptake, and facilitate photosynthesis, thereby increasing crop yields. Drip irrigation reduces water loss through deep percolation and soil evaporation, optimizing water resource utilization and enhancing crop growth [23]. It improves soil moisture conditions, which can increase the leaf area index and biomass accumulation, leading to higher yields [24]. In oil palm, drip irrigation has been associated with improved fertilizer use efficiency and soil quality, particularly when combined with biochar amendments [9]. Sensor-based irrigation systems allow real-time monitoring and adjustment of water levels, improving resource efficiency and reducing waste [11]. Smart irrigation systems, incorporating Industry 4.0 technologies, have shown positive economic performance and reduced water footprints in oil palm plantations, especially for larger land sizes [11]. Despite these benefits, the high costs and limited technical knowledge hinder the widespread adoption of advanced irrigation systems in Indonesia, highlighting the need for research into cost-effective solutions tailored to local conditions to facilitate broader implementation [11], [25].

2.2 Pesticide Use and Its Impact on Productivity

The role of pesticides in agricultural productivity, particularly in high-value crops like oil palm, is significant yet complex. While appropriate pesticide use can enhance crop health and yield by effectively controlling pests, improper use poses substantial environmental and economic challenges. The misuse or overuse of pesticides can lead to soil degradation, biodiversity loss, and human health risks, making sustainable practices essential. Indiscriminate pesticide use is a primary driver of global biodiversity loss, affecting birds, earthworms, and pollinators, and disrupting natural ecosystems through bioaccumulation [26]. Pesticides can degrade soil quality and harm non-target organisms, leading to ecosystem imbalances and potential food chain contamination [27], [28]. Excessive pesticide use can also lead to pest resistance,

necessitating higher chemical quantities and increasing production costs [27]. Proper pesticide application is crucial for effective pest control and crop yield, requiring the right pesticide, timing, technique, and equipment [29]. Integrated Pest Management (IPM) offers a sustainable alternative by integrating biological control and cultural practices with minimal pesticide use, reducing reliance on chemicals and maintaining effective pest control [27]. Despite its benefits, IPM adoption is limited due to knowledge gaps and perceived challenges among farmers [27].

2.3 Human Resource Management (HRM) and Agricultural Productivity

Human Resource Management (HRM) plays a pivotal role in enhancing productivity in the oil palm industry by focusing on training, motivation, and organizational culture. Effective HRM practices, such as skill development and incentive structures, are crucial for maintaining high productivity levels in labor-intensive sectors like oil palm plantations. Training and career development significantly impact employee productivity, as shown in a study at PTPN IV (Persero) Pabatu plantations, where these factors collectively explained 53.2% of the variance in work productivity, underscoring their importance in enhancing employee performance [30]. Education and training are essential for improving labor productivity, as they develop knowledge and skills critical for operational success [31]. Employee motivation and job satisfaction are also crucial, with research at PT Johan Sentosa demonstrating that both satisfaction and motivation significantly influence harvesting employees' performance, directly linked to company productivity [32]. Additionally, motivation has been found to have a positive and significant effect on productivity, as evidenced by a study at PT. Kerta Rajasa Raya, where motivation had a unidirectional and significant impact on productivity [33]. Organizational culture and compensation are further critical in enhancing employee performance, as demonstrated in Riau Province, where these factors positively affect performance, thereby supporting productivity in palm oil plantations [34].

2.4 Theoretical Framework and Hypothesis Development

The theoretical foundation for this study is based on the Resource-Based View (RBV) theory, which suggests that an organization’s resources, including physical, human, and technological assets, are central to achieving competitive advantage [35]. In the context of oil palm plantations, irrigation systems and pesticides represent critical physical and technological resources, while human resources are fundamental for efficient operation and maintenance of these assets. The RBV theory posits that organizations can achieve superior performance by optimizing their unique resources (Wernerfelt, 1984), which aligns with the aim of this study to assess how resource

management affects productivity.

Based on the above literature, the following hypotheses are formulated:

H1: Efficient irrigation systems positively influence productivity growth in oil palm plantations.

H2: Responsible pesticide use positively influences productivity growth in oil palm plantations.

H3: Effective human resource management positively influences productivity growth in oil palm plantations.

2.5 Research Gap

While previous research has explored the effects of irrigation systems, pesticide use, and HRM on agricultural productivity, studies specifically focused on oil palm plantations in Indonesia remain limited. Furthermore, existing studies tend to examine each factor in isolation rather than considering their combined impact on productivity growth. This research addresses this gap by investigating the collective influence of irrigation, pesticide application, and HRM on oil palm productivity in Indonesia. The study's findings will contribute to the body of knowledge on sustainable agricultural practices and provide practical insights for plantation managers seeking to optimize productivity through resource management.

3. METHODS

3.1 Research Design

This study employs a cross-sectional, quantitative research design to test hypotheses concerning irrigation systems, pesticide use, and human resource management (HRM) as predictors of productivity growth in oil palm plantations across Indonesia. Data were collected through a survey method targeting managers and workers in these plantations, utilizing a structured questionnaire to obtain standardized responses for statistical analysis. The target population includes oil palm plantations across Indonesia, specifically managers and supervisors involved in irrigation, pesticide application, and HRM. Given the large number of plantations, a representative sample of 120 respondents was determined, ensuring sufficient statistical power within logistical constraints. Purposive sampling was used to select plantations with active irrigation and HRM practices and regular pesticide application, thereby including respondents with relevant knowledge of the research variables and enhancing the reliability of the data collected.

3.2 Data Collection

The data in this study was collected using a structured questionnaire developed specifically for this study, with each question answered using a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree) to measure the level of agreement or frequency of implementation of the practice in question. This scale facilitates interpretation of answers and produces consistent data for analysis. The questionnaire was pilot tested on a small number of respondents to ensure clarity, relevance and reliability. Some minor adjustments were made based on feedback from the pilot test to improve the quality of the questionnaire so that it was ready for use in the full-scale survey.

3.3 Data Analysis

Data analysis was conducted using SPSS version 26, employing various analytical techniques to test the hypotheses. Descriptive statistics were used to summarize demographic data and provide an overview of respondents' profiles, plantation characteristics, and the distribution of

responses for each variable. Reliability analysis was performed to assess the internal consistency of questionnaire items for each construct (irrigation systems, pesticide use, HRM, and productivity growth), using Cronbach's alpha with a threshold of 0.70 as the standard for reliability. Pearson correlation analysis measured the strength and direction of relationships among variables, offering initial insights into the associations between irrigation, pesticide use, HRM, and productivity growth. Multiple regression analysis served as the primary technique to test the hypotheses, evaluating the combined effect of irrigation systems, pesticide use, and HRM on productivity growth, and determining the relative impact of each independent variable while controlling for others. Significance testing was conducted with a p-value threshold of 0.05, while regression coefficients and adjusted R-square values were examined to assess the explanatory power of the model.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

The sample of 120 respondents provided data on irrigation systems, pesticide use, human resource management (HRM), and productivity growth in oil palm plantations, with descriptive statistics revealing the distribution of responses for each variable. For irrigation systems, the mean score was 3.76, indicating a moderate to high level of efficiency across plantations, with a standard deviation of 0.64, showing some variability in adoption. Pesticide use had a mean score of 3.52 and a standard deviation of 0.72, reflecting moderate to frequent application and differences in perceived effectiveness. HRM received a mean score of 3.89 with a standard deviation of 0.58, indicating a generally favorable view of HRM practices but highlighting potential improvements in training and development. Productivity growth had a mean of 4.02 and a standard deviation of 0.66, suggesting positive perceptions of recent productivity increases with some variations across plantations. These descriptive results offer a preliminary insight into the management practices in oil palm plantations, indicating moderate adoption levels and a generally positive outlook on productivity growth.

The study gathered responses from a sample of 120 individuals working in or managing oil palm plantations across Indonesia, providing an overview of demographic characteristics such as roles, years of experience, education levels, plantation size, and location, essential for understanding sample diversity and accurately interpreting results. The roles included managers (30%), supervisors (35%), field workers (25%), and others (10%), offering balanced insights from both strategic and operational perspectives. Experience levels varied, with 65% of respondents having over 5 years in the industry, enhancing the reliability of their insights. Educational backgrounds ranged from high school diplomas (45%) to graduate degrees (5%), reflecting a mix of practical and formal education suited to plantation management needs. Plantation sizes varied, with 15% under 50 ha, 25% between 50-100 ha, 35% between 101-200 ha, and 25% over 200 ha, providing insights across operational scales. Locations spanned Sumatra (50%), Kalimantan (30%), Sulawesi (10%), and other areas (10%), aligning with the prominence of Sumatra and Kalimantan in Indonesia's oil palm industry and accounting for regional differences in environmental conditions and resource access.

4.2 Reliability Analysis

Cronbach's alpha values for each construct were calculated to assess internal consistency, with all constructs achieving values above the 0.70 threshold, indicating good reliability: Irrigation Systems ($\alpha = 0.826$), Pesticide Use ($\alpha = 0.783$), HRM ($\alpha = 0.854$), and Productivity Growth ($\alpha = 0.818$). These values confirm that the constructs are reliable, with items within each variable consistently measuring the intended factors.

4.3 Pearson Correlation Analysis

The correlation analysis revealed significant relationships between the independent variables (irrigation systems, pesticide use, and HRM) and the dependent variable (productivity growth). Key findings include a positive correlation between irrigation systems and productivity growth ($r = 0.575$, $p < 0.01$), suggesting that efficient irrigation practices are linked to higher productivity; a significant positive correlation between pesticide use and productivity growth ($r = 0.495$, $p < 0.01$), indicating that responsible pesticide application supports productivity gains; and a strong positive correlation between HRM and productivity growth ($r = 0.645$, $p < 0.01$), underscoring the role of effective HRM in enhancing productivity. These correlations confirm that each independent variable is significantly related to productivity growth, supporting the hypotheses.

4.4 Multiple Regression Analysis

A multiple regression analysis was conducted to examine the combined effect of irrigation systems, pesticide use, and HRM on productivity growth. The results are presented in Table 1.

Table 1. Multiple Regression Analysis Results

Variable	B	SE	β	t	p-value
Irrigation Systems	0.323	0.081	0.349	4.001	0.000
Pesticide Use	0.285	0.093	0.263	3.113	0.000
Human Resource Management (HRM)	0.456	0.076	0.485	6.435	0.000
R^2	0.632				
Adjusted R^2	0.625				

The regression model yielded an R^2 value of 0.632, indicating that 63.2% of the variation in productivity growth is explained by the combined effects of irrigation systems, pesticide use, and HRM, with each independent variable showing a significant positive impact, thereby supporting all three hypotheses. Efficient irrigation systems ($\beta = 0.349$, p 0.000) had a substantial effect on productivity growth. Responsible pesticide use ($\beta = 0.263$, $p < 0.01$) also positively influenced productivity, though to a slightly lesser extent than irrigation and HRM, who emphasized balanced pesticide application for sustainable productivity. HRM ($\beta = 0.485$, p 0.000) emerged as the most significant predictor of productivity growth, highlighting the critical role of effective workforce management in labor-intensive sectors like oil palm.

Discussion

The results of this study highlight the importance of efficient irrigation systems, responsible pesticide use, and strong HRM practices in driving productivity growth in oil palm plantations in Indonesia. The findings demonstrate that efficient irrigation systems are essential for productivity growth in oil palm plantations. This aligns with existing research emphasizing that consistent and optimized water supply is necessary for crop health and yield improvement [36]–[38]. As irrigation practices continue to evolve, plantations may consider adopting sensor-based systems or precision irrigation to enhance water management and further boost productivity. The positive impact of pesticide use on productivity growth is consistent with the findings of [29], [39], [40], who reported that balanced pesticide application helps control pests and protect crop health. However, given the environmental and health concerns associated with excessive pesticide use, these results underscore the need for sustainable pest management practices. Integrated pest management (IPM) could offer a viable approach for plantations to balance productivity with environmental responsibility.

HRM was identified as the most significant factor influencing productivity growth, underscoring the importance of skilled, engaged, and well-managed labor in

oil palm plantations. This supports the Resource-Based View (RBV) theory, which posits that effective utilization of human resources can drive competitive advantage (Barney, 1991). Investments in workforce training, incentives, and engagement practices can play a crucial role in sustaining productivity in this labor-intensive industry. Furthermore, the importance of HRM highlights the need for plantation managers to prioritize worker welfare and development to reduce turnover and attract skilled labor.

Implications for Practice

The findings of this study offer several practical implications for plantation managers and policymakers:

1. Implementing modern irrigation systems, such as precision irrigation, can help optimize water use and improve productivity, especially in regions prone to water scarcity.
2. Plantation managers should consider integrated pest management to reduce pesticide reliance while maintaining crop health, minimizing environmental impact, and lowering costs.
3. Given the significant role of HRM in productivity growth, managers should prioritize workforce development, including training programs, incentive structures, and worker engagement practices to improve productivity and worker satisfaction.

Limitations and Future Research

While this study provides valuable insights into factors affecting oil palm productivity, several limitations must be acknowledged. First, the cross-sectional design limits the ability to capture changes in productivity over time. Longitudinal studies could provide more comprehensive insights into the effects of management practices on productivity growth. Second, the study relied on self-reported data, which may introduce response bias. Future research could combine survey data with observational or experimental approaches to validate these findings further.

5. CONCLUSION

This study concludes that irrigation systems, pesticide use, and human resource management are significant determinants of productivity growth in oil palm plantations in Indonesia. The research findings indicate that effective irrigation management enhances productivity by optimizing water usage, essential in the tropical climate. Responsible pesticide application contributes to crop health, reducing pest-related losses and supporting sustainable practices. Most notably, human resource management emerged as the most critical factor, highlighting the importance of skilled labor and effective workforce management in a labor-intensive industry like oil palm plantations.

For plantation managers, these results underscore the value of investing in advanced irrigation technology, adopting sustainable pesticide practices, and enhancing HRM policies. Implementing these strategies can not only improve productivity but also support the long-term sustainability of the oil palm industry. Future studies may explore longitudinal impacts or integrate observational data to enrich understanding. Overall, this research provides actionable insights for stakeholders seeking to enhance productivity and sustainability in Indonesia's palm oil sector.

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