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Prospects Habitat Management to Control Pest Population on Annual Plant to Support Sustainable Agricultural Development in Indonesia

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Sustainable agricultural development has become a global imperative due to environmental degradation and the contemporary shortage of agricultural products. This necessitates further research, and the present study investigates the impact of habitat management on pest population control and its implications for sustainable agricultural development in Indonesia. Additionally, the study evaluates the moderating role of government support in the relationship between habitat management and pest population control. Data were collected through survey questionnaires administered to farmers. The study assessed data reliability and examined relationships between variables using Smart-PLS. The findings indicate that habitat management positively influences pest population control, which in turn has a positive impact on sustainable agricultural development in Indonesia. Furthermore, the results demonstrate that government support in the agricultural sector significantly moderates the relationship between habitat management and pest population control. The study offers valuable insights for policymakers in formulating strategies to enhance sustainable agricultural development through effective habitat management and pest control measures.

Keywords: Habitat Management, Sustainable Agricultural Development, Government Agricultural Sector Support, Control of Pest Population.

Introduction

Indonesia's agricultural sector remains vital, sustaining the livelihoods of millions and contributing significantly to the nation's food security. However, one of the primary obstacles to achieving high agricultural productivity is persistent pest infestations, which result in substantial crop losses annually. Traditionally, farmers have relied on chemical pesticides to manage pest populations. However, the excessive use of these chemicals has raised concerns over soil health degradation, environmental harm, and the emergence of pesticide-resistant pest species (Zhou, Li, & Achal, 2024). In response to these challenges, sustainable alternatives such as habitat management have gained attention. Habitat management involves modifying agricultural landscapes to discourage the proliferation of pest populations. This approach supports biodiversity, encourages the presence of beneficial organisms, and promotes ecosystem services, offering a viable and sustainable alternative to pesticide dependence. Understanding the relationship between habitat management, pest control, and sustainable agricultural development is crucial for developing effective strategies and policies to enhance agricultural resilience in Indonesia.
Habitat management is a vital ecological approach to controlling pest populations by promoting biodiversity and natural predator activity (Chase et al., 2020). Techniques such as intercropping, hedgerows, and maintaining natural vegetation foster stable agroecosystems where pests face natural checks. Jaworski et al. (2023) report that habitat diversification reduces pest density and crop damage, with practices like flowering strips attracting beneficial insects to manage pests and reduce pesticide use. This approach also combats pesticide resistance, making Indonesia's biodiversity-rich agricultural sector well-suited for its adoption. However, its success depends heavily on support from the agricultural sector (Baker, Green, & Loker, 2020). The successful implementation of habitat management practices by farmers largely depends on agricultural policies, institutional frameworks, and resource availability. Providing subsidies to encourage ecological farming, training on habitat management techniques, and conducting research on IPM can strengthen the link between habitat management and pest control. Hunt, Blackburn, & Rowland (2019) argue that farmers are more likely to adopt habitat-based pest control methods in countries where agricultural policies emphasise sustainability. Conversely, insufficient sector support, such as limited funding and inadequate technical assistance, poses challenges to sustaining habitat management strategies. Integrating habitat management into national agricultural programmes and reinforcing its adoption through incentives can foster more effective pest control and facilitate a resilient and environmentally sustainable agricultural transition in Indonesia.
Effective pest control is essential for sustaining key aspects of agricultural development, including yield stability, food security, and environmental health. Proper management of pest populations not only enhances farmers' productivity and prevents crop losses but also promotes income stability and reduces dependence on costly chemical inputs. Ahmad, Muhammad, & Sajjad (2020) highlight that sustainable pest control encompasses habitat management, biological control, and IPM strategies, fostering a balanced agricultural system where pest suppression does not compromise the ecosystem. Research has shown that reducing pesticide dependence can sustain both effective pest control and long-term soil fertility, ultimately supporting biodiversity and improving water quality—key elements of sustainable agriculture. In Indonesia, where agriculture remains vital for rural livelihoods, adopting eco-friendly pest management approaches contributes to

both economic and environmental sustainability. Moreover, sustainable pest control practices are essential for building farm resilience against climate and market fluctuations (Srivastav et al., 2021).

The effectiveness of pest control plays a crucial mediating role in the relationship between habitat management and sustainable agricultural development. Habitat management incorporates ecological strategies to promote biodiversity and natural pest suppression, which are pivotal for sustainable agriculture. The extent of pest population control determines the success of this approach. When habitat management significantly reduces pest populations, it creates favourable conditions for higher agricultural yields, lower input costs, and improved environmental health, all contributing to sustainability (Redlich, Martin, & Steffan-Dewenter, 2021). Integrated pest control measures within habitat management have been associated with enhanced long-term agricultural productivity. As Staton et al. (2019) note, well-managed natural habitats often experience fewer pest outbreaks, greater pest suppression, and increased pollination services, resulting in higher crop quantity and quality. Scaling up this strategy is particularly important in Indonesia, where smallholder farmers rely heavily on annual crops. Effective pest control within habitat management is essential for broader agricultural sustainability. Policymakers and agricultural practitioners should recognise pest control as a critical link between habitat management and sustainable agricultural development to optimise outcomes in the farming sector.

This study investigates habitat management with the primary objective of exploring its role in pest population control and its implications for sustainable agricultural development in Indonesia. Specifically, it examines whether habitat management directly influences pest control, how support from the agricultural sector moderates this relationship, and whether pest control mediates the link between habitat management and agricultural sustainability. Despite the growing interest in ecological pest management, research on this topic in Indonesia remains limited, particularly regarding the factors that determine the effectiveness of habitat management when institutional support is present. Additionally, existing studies have not sufficiently explored the mediating role of pest control in the relationship between habitat management and sustainability. This study addresses these research gaps, contributing to a better understanding of sustainable pest control strategies and their long-term implications for agricultural resilience. The subsequent sections will present a literature review and outline the methods for data collection and analysis to evaluate the proposed relationships.

Literature Review

This study investigates the impact of habitat management on pest population control within Indonesia's agricultural sector. Habitat management plays a vital role in pest control by altering the agricultural landscape to favour the presence of natural pest enemies. This approach promotes biodiversity and ecological balance, reducing the need for chemical pesticides and supporting long-term pest suppression. Research by Altieri & Nicholls (2019) demonstrates that diverse cropping systems, hedgerows, and vegetation strips provide favourable conditions for predators and parasitoids, enhancing biological pest control. Similarly, HE et al. (2019) indicate that increasing plant diversity within or around farmlands regulates pests by offering alternative food sources and shelter for beneficial insects. The presence of semi-natural habitats, such as flowering plants and cover crops, supports the abundance and effectiveness of natural enemies, thereby reducing pest outbreaks. Fischbein & Corley (2022) highlight that increasing the proportion of non-crop habitats enhances habitat complexity, which promotes the survival and foraging efficiency of biological control agents, leading to more stable pest control outcomes. Evidence also suggests that habitat-based pest management improves crop health and productivity. Farms adopting habitat management measures reportedly suffer less pest damage compared to those relying solely on chemical control (HE et al., 2019). Furthermore, habitat manipulation techniques, including intercropping and buffer zones, have been shown to enhance agricultural ecosystems' resilience to pest pressure and sustain natural enemy populations. These findings underscore the efficacy of habitat management in promoting sustainable pest control through natural predator enhancement. Therefore, we say that,

H1: Habitat management has a positive impact on controlling pest population.

This study also examines the moderating role of government support in the relationship between habitat management and pest control in Indonesia. Effective agricultural sector management is essential for successful habitat-based pest control, requiring resource provision, supportive policies, and farmer education. Government subsidies, research funding, farmer training, and cooperatives are crucial in fostering adoption. Zheng et al. (2019) highlight that financial incentives encourage farmers to adopt ecological farming practices, enhancing pest control effectiveness. Without proper institutional support, transitioning from conventional pesticide-based methods to sustainable habitat management can be challenging. Technical assistance and extension services further strengthen the habitat management-pest control link. Angon et al. (2023) emphasise that well-trained farmers are more likely to implement habitat management effectively, preventing pest infestations. Additionally, knowledge dissemination through training programmes increases awareness of biological pest control, enabling farmers to integrate habitat management strategies more successfully (Tonle et al., 2024). This relationship is further influenced by policy frameworks that promote biodiversity-friendly pest management. Government regulations encouraging ecological practices have been shown to increase farmer participation in habitat management initiatives, leading to reduced pesticide use. Moreover, Baker et al. (2020) suggest that robust institutional support can facilitate the long-term adoption of habitat-based pest control methods, integrating them into national agricultural development strategies. These findings highlight the significance of agricultural sector support in strengthening the impact of habitat

management on pest control. Based on this, the following hypothesis is proposed,

H2: Agricultural sector support moderates the relation between habitat management and control pest population.

This study also explores the impact of pest population control on sustainable agricultural development in Indonesia. Effective pest control is essential for sustaining agricultural productivity, ensuring crop health, stabilising yields, and reducing dependence on chemical inputs. Subedi, Poudel, & Aryal (2023) affirm that pest management strategies which mitigate infestations support higher agricultural productivity, contributing to food security and economic stability. Reduced pest irritation fosters crop resilience, enabling farmers to cultivate higher-quality produce at lower costs, thereby promoting long-term agricultural sustainability. Environmentally friendly pest control methods also help maintain ecological balance, minimising environmental harm. Bueno et al. (2021) suggest that pesticide use can be further reduced through IPM strategies involving biological control and habitat management, decreasing soil and water contamination. Ecological pest control methods also promote biodiversity by conserving beneficial insects and microorganisms, supporting sustainable farming practices (Subedi et al., 2023). Additionally, sustainable pest control measures offer economic advantages by reducing crop losses and lowering production costs, thus improving farmers' profitability and enabling investment in long-term agricultural improvements. Heeb, Jenner, & Cock (2019) highlight that sustainable pest management enhances climate resilience by reducing the carbon footprint associated with chemical pesticide production and application. These findings underscore the critical role of pest population control in achieving sustainable agricultural development while maintaining environmental and economic stability. Therefore, the following hypothesis is proposed,

H3: Control pest population has a positive impact on sustainable agricultural development.

The study further examines the mediating role of pest population control in the relationship between habitat management and sustainable agricultural development in Indonesia. Habitat management and sustainable agricultural practices are interconnected through pest control, which mediates outcomes related to crop protection, reduced chemical dependence, and ecological stability. Ratnadass et al. (2021) demonstrate that habitat management strategies such as intercropping and maintaining vegetation buffers foster the presence of natural pest predators, thereby enhancing pest suppression. Research also indicates that employing ecological habitat management to regulate pest populations creates a more resilient agricultural system and promotes long-term sustainability. Effective pest control through habitat management directly supports sustainable farming practices by reducing reliance on chemical pesticides. Habitat-enhanced biological control has been associated with lower pesticide use, decreased soil and water contamination, and the conservation of biodiversity (Shields et al., 2019). Sustainable pest suppression also minimally disrupts beneficial insect populations, contributing to ecosystem stability and promoting long-term agricultural productivity. Heeb et al. (2019) highlight that farms employing habitat-based pest management experience fewer crop losses and lower production costs, leading to higher profits and increased investments in sustainable farming practices. Furthermore, reduced pest pressure enhances yield stability, enabling farmers to maintain consistent food production with minimal dependence on external inputs. These findings underscore the role of pest population control as a critical mediator, strengthening the relationship between habitat management and sustainable agricultural development by ensuring ecological viability, economic benefits, and environmental sustainability. Consequently, the following hypothesis is proposed:

H4: Control pest population mediates the relation between habitat management and sustainable agricultural development.

Research Methods

This study investigates the impact of habitat management on pest population control and its implications for sustainable agricultural development in Indonesia. Additionally, it examines the moderating role of government agricultural sector support in the relationship between habitat management and pest population control. Data were collected from farmers using survey questionnaires. The variables were measured using validated scales from previous studies: habitat management was assessed with five items from Klefoth et al. (2023); pest population control was measured using six items adapted from Lazaridou & Michailidis (2023); agricultural sector support was evaluated with four items from Zaremohzzabieh et al. (2022); and sustainable agricultural development was assessed with five items from Taiwo, Akinwole, & Ogundepo (2024).

The study involved farmers as respondents, selected through simple random sampling. Surveys were distributed through personal visits, with 502 questionnaires initially disseminated. After a few days, 290 valid responses were collected, yielding a response rate of approximately 57.77 percent. Data reliability and variable associations were examined using Smart-PLS, a widely employed tool for primary data analysis, particularly suited for complex models (Hair Jr, Howard, & Nitzl, 2020). The assessment of the measurement model involved two key components: convergent and discriminant validity. Convergent validity was evaluated using several criteria. Cronbach's Alpha values above 0.70 indicated a strong correlation among items. Composite reliability (CR) values above 0.70 further confirmed item reliability. Factor loadings above 0.50 indicated strong item correlations, and average variance extracted (AVE) values above 0.50 demonstrated sufficient shared variance among items (Hair et al., 2017). Additionally, the structural model was assessed to evaluate the associations among variables.

The discriminant validity was assessed using multiple criteria. First, the Fornell-Larcker criterion required that a variable’s correlation with itself be higher than its correlations with other variables. Cross-loadings were also

examined, with item correlations within their respective variables expected to be higher than with other variables. Additionally, the Heterotrait-Monotrait (HTMT) ratio was used, and values below 0.90 indicated acceptable discriminant validity (Hair, Gabriel, & Patel, 2014). The structural model assessment highlighted the relationships between variables. Beta values indicated the direction of relationships, with p-values below 0.05 and t-values above 1.96 suggesting statistically significant associations (Hair Jr et al., 2020). The study included four key variables: habitat management (HM) as a predictor, agricultural sector support (ASS) as a moderator, control of pest population (CPP) as a mediator, and sustainable agricultural development (SAD) as the dependent variable. Figure 1 visually represents these relationships.

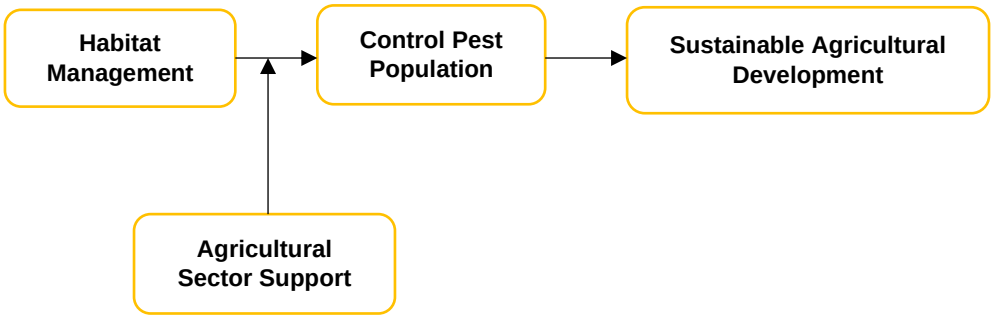

Figure 1: Theoretical Model.

Research Findings

The present study investigates the effect of habitat management on pest population control and its subsequent impact on sustainable agricultural development. Additionally, it examines the moderating role of government agricultural sector support in the relationship between habitat management and pest population control. The study assesses convergent validity by examining the correlation between items. This was evaluated using CR and Cronbach's Alpha, both yielding values above 0.70. Furthermore, the AVE and factor loadings both exceeded 0.50, indicating strong item correlations. These results are presented in Table 1 and visually represented in Figure 2.

Table 1: Convergent Validity.

Constructs	Items	Loadings	Alpha	CR	AVE
Agricultural Sector Support	ASS1	0.865	0.899	0.929	0.766
	ASS2	0.875			
	ASS3	0.881			
	ASS4	0.881			
Control of Pest Population	CPP1	0.850	0.909	0.929	0.687
	CPP2	0.808			
	CPP3	0.820			
	CPP4	0.863			
	CPP5	0.767			
	CPP6	0.861			
Habitat Management	HM1	0.588	0.832	0.858	0.552
	HM2	0.678			
	HM3	0.871			
	HM4	0.860			
	HM5	0.677			
Sustainable Agricultural Development	SAD1	0.865	0.884	0.915	0.684
	SAD2	0.831			
	SAD3	0.804			
	SAD4	0.780			
	SAD5	0.853			

The study also evaluates discriminant validity to assess the correlation between variables. This was examined using the Fornell-Larcker criterion, which revealed that the values indicating correlations within the same construct were higher than those showing correlations with other constructs. These findings suggest a low correlation between variables, confirming discriminant validity. The results are presented in Table 2. The study further evaluates discriminant validity through cross-loadings. The results reveal that the values indicating correlations within the same construct were higher than those showing correlations with other constructs. These findings confirm a low correlation between variables, ensuring discriminant validity. The results are presented in Table 3.

Table 2: Fornell Larcker.

	ASS	CPP	HM	SAD
ASS	0.875			
CPP	0.397	0.829		
HM	0.610	0.413	0.743	
SAD	0.422	0.516	0.474	0.827

Table 3: Cross-Loadings.

	ASS	CPP	HM	SAD
ASS1	**0.865**	0.339	0.513	0.320
ASS2	**0.875**	0.338	0.560	0.385
ASS3	**0.881**	0.318	0.512	0.359
ASS4	**0.881**	0.386	0.549	0.407
CPP1	0.343	**0.850**	0.348	0.441
CPP2	0.319	**0.808**	0.394	0.446
CPP3	0.337	**0.820**	0.339	0.407
CPP4	0.300	**0.863**	0.272	0.375
CPP5	0.359	**0.767**	0.403	0.476
CPP6	0.293	**0.861**	0.257	0.390
HM1	0.623	0.175	**0.588**	0.263
HM2	0.660	0.163	**0.678**	0.245
HM3	0.395	0.406	**0.871**	0.446
HM4	0.354	0.426	**0.860**	0.441
HM5	0.662	0.168	**0.677**	0.246
SAD1	0.347	0.482	0.404	**0.865**
SAD2	0.352	0.439	0.436	**0.831**
SAD3	0.348	0.395	0.403	**0.804**
SAD4	0.332	0.405	0.373	**0.780**
SAD5	0.367	0.402	0.339	**0.853**

The study further assesses discriminant validity using the HTMT ratio. The findings reveal that the values remained below the 0.90 threshold, indicating a low correlation between variables and confirming acceptable discriminant validity. These results are presented in Table 4. Moreover, the path analysis results revealed that habitat management positively influences pest population control, supporting H1. Additionally, pest population control has a positive association with sustainable agricultural development in Indonesia, supporting H3. The findings further demonstrated that government agricultural sector support significantly moderates the relationship between habitat management and pest population control, supporting H2. Lastly, pest population control significantly mediates the relationship between habitat management and sustainable agricultural development in Indonesia, supporting H4. These findings are presented in Table 5 and Figure 3.

Table 4: Heterotrait Monotrait Ratio.

	ASS	CPP	HM	SAD
ASS				
CPP	0.432			
HM	0.805	0.389		
SAD	0.472	0.566	0.494	

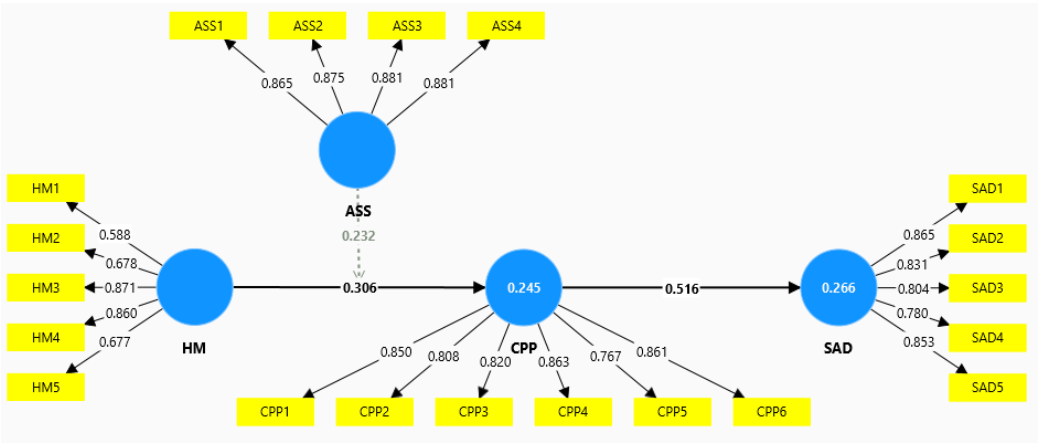

Figure 2: Measurement Assessment Model.

Table 5: Path Analysis

Relationships	Beta	Standard Deviation	T Statistics	P Values
ASS -> CPP	0.302	0.068	4.464	0.000
CPP -> SAD	0.516	0.046	11.092	0.000
HM -> CPP	0.306	0.081	3.800	0.000
ASS x HM -> CPP	0.232	0.059	3.901	0.000
ASS -> CPP -> SAD	0.156	0.033	4.769	0.000
HM -> CPP -> SAD	0.158	0.050	3.130	0.002

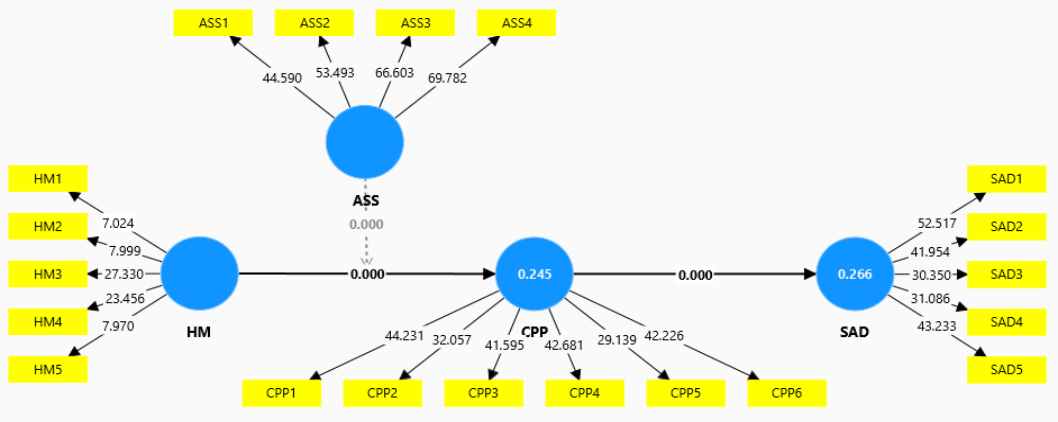

Figure 3: Structural Assessment Model.

Discussion

The research highlights that habitat management plays a critical role in controlling pest populations and promoting sustainable agricultural development in Indonesia. With increasing concerns over pesticide pollution and habitat degradation, habitat management emerges as a viable alternative. The study investigates how habitat management contributes to pest regulation while exploring the moderating role of agricultural sector support and the mediating effect of pest control in fostering sustainable agricultural outcomes. Understanding these relationships is crucial for developing ecological farming systems that safeguard Indonesian agriculture from pests threatening national food security while enhancing resilience and functionality.

The findings demonstrate that habitat management strategies create ecological conditions conducive to natural pest control. Practices such as intercropping and the use of vegetation strips provide habitats for beneficial predators, reducing the need for chemical pesticides. Bonato et al. (2023) confirm that mixed land-use areas effectively control pests through natural biological methods, lowering overall pest densities. Additionally, Sánchez-Bayo & Wyckhuys (2019) report that farms incorporating predator habitats as natural refuges experience fewer pest outbreaks, leading to improved crop yields. The study aligns with existing literature in underscoring the benefits of habitat management for pest control. Given Indonesia's prevalent monoculture farming practices, promoting habitat diversity could help reduce pest infestations, improve soil quality, and enhance biodiversity.

The research also highlights the importance of agricultural sector support in the successful adoption of habitat management practices. Institutional backing, including policy frameworks, financial assistance, and educational programmes, plays a vital role in encouraging farmers to adopt ecological pest control methods. Norton & Alwang (2020) found that government incentives and extension services promote the adoption of sustainable pest control techniques. Similarly, Deguine et al. (2021) emphasise that farmers are less likely to transition from conventional pesticide-based approaches to ecological alternatives without financial and technical support. To enhance adoption rates in Indonesia, policy measures should prioritise habitat management subsidies and integrate farmer training with research initiatives. Agricultural sector support creates environments that facilitate the adoption of habitat-based pest control strategies, reducing dependence on synthetic pesticides. Providing adequate funding and access to knowledge resources empowers farmers to implement habitat management practices, thereby strengthening agricultural systems and promoting long-term sustainability.

Effective pest control is vital for sustainable agricultural development as it prevents crop losses, enhances yields, and safeguards the environment. The study highlights that pest monitoring practices contribute to long-term sustainability by maintaining soil health and reducing chemical inputs. Baker et al. (2020) found that biological control methods within integrated pest management systems improve soil fertility and promote ecological stability, supporting sustainable agriculture. Similarly, Horgan & Kudavidanage (2020) demonstrated that agricultural areas employing non-chemical pest control achieve higher yields and lower production costs compared to regions reliant on extensive pesticide use. These findings underscore the importance of adopting sustainable pest control practices to build resilient agricultural systems. Small-scale farmers in Indonesia can benefit significantly from implementing biological pest control methods, improving productivity while minimising environmental harm. Reduced pesticide use helps preserve beneficial organisms, prevents soil degradation, and supports sustainable farming practices, thereby contributing to food security. The study also emphasises the crucial relationship between habitat management and sustainable agriculture, mediated by effective pest control methods.

Habitat management creates ecologically conducive environments for pest suppression, realising its full sustainability potential through effective pest management outcomes. By integrating habitat management practices, pest control becomes a fundamental mechanism for achieving long-term agricultural sustainability. Previous studies, such as Khan et al. (2023), demonstrate that habitat conservation-based pest management reduces reliance on chemical pesticides, resulting in improved environmental conditions and greater yield security. Incorporating pest control methods into habitat management practices fosters ecological stability, preventing biodiversity loss while establishing sustainable agricultural systems (Alyokhin, Nault, & Brown, 2020). Consequently, this study suggests that raising awareness of pest control mediation in Indonesia can optimise habitat management strategies, thereby enhancing agricultural sustainability.

Conclusion

This study underscores the critical role of habitat management in pest control and the necessity of sustainable agricultural development in Indonesia. The findings confirm that habitat management serves as an effective pest reduction strategy when ecological balance is enhanced and backed by agricultural sector support. Beyond crop protection, effective pest management promotes long-term sustainability by reducing pesticide dependence and improving soil quality. Additionally, the research highlights that pest control mediates the relationship between habitat management and agricultural sustainability, enabling the integration of ecological strategies with long-term productivity. The findings emphasise the need for policies and programmes that support habitat-based pest management to sustain productivity and conserve the environment. While the study makes valuable contributions, limitations remain, necessitating future research on other influencing factors. Strengthening the relationship between habitat management, pest control, and sustainability could foster the development of resilient and sustainable agricultural systems in Indonesia.

Implications

The findings of this study offer significant insights for promoting sustainable agriculture and developing policies

that support ecological pest control. The research highlights the effectiveness of habitat management techniques in controlling pest populations, encouraging farmers to adopt ecological farming practices to reduce pesticide usage and enhance biodiversity. These insights provide policymakers with a foundation for creating supportive regulations, training programmes, and subsidies to facilitate the adoption of habitat-based pest control methods. Incorporating habitat management strategies into agricultural extension services can further promote acceptance among farmers. The study underscores the need for increased institutional support from authorities to enhance pest control effectiveness at all levels. These strategies collectively contribute to agricultural sustainability, food security, and environmental conservation in Indonesia over the long term.

Limitations

This study has several limitations that must be acknowledged. Its focus on habitat management and pest control within Indonesia's specific agricultural context limits its generalisability to regions with different climatic, ecological, and socio-economic conditions. Additionally, the reliance on available data may not fully capture long-term variations in pest populations and agricultural sustainability. The study also did not extensively explore critical factors such as farmer attitudes, financial constraints, and land use policies, which significantly influence the adoption of habitat management. Future research should incorporate broader geographical scopes, long-term datasets, and supplementary variables to provide more comprehensive insights into sustainable pest control strategies.

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