Agricultural Risk and Input Cost Escalation in Oil Palm Smallholdings: Pesticide Use, Pest Resistance, and Yield Stability Under Oryctes Rhinoceros Pressure

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ABSTRACT

This study investigates the effects of insecticide application on the population dynamics of Oryctes rhinoceros and its natural enemy Platymeris laevicollis in oil palm smallholder systems in Malaysia. A Completely Randomized Design (CRD) was employed, comprising three treatment regimes Cypermethrin, Carbofuran, and an untreated control with four replications across twelve plots. Pest and predator populations were monitored from January to October 2017 using pheromone and sticky traps. The results reveal significant differences in pest population abundance across treatments ($F(2,9) = 27.424$, $p < 0.01$). Unexpectedly, untreated plots recorded the lowest mean population of O. rhinoceros (0.21), while higher populations were observed in Carbofuran (2.63) and Cypermethrin (3.12) treatments. Temporal analysis indicates that treated plots exhibited greater fluctuation and instability in pest populations, whereas untreated plots maintained consistently low levels throughout the study period. In contrast, no significant differences were observed in the abundance of P. laevicollis across treatments ($F = 0.081$, $p > 0.05$), and correlation analysis showed no significant relationship between pest and predator populations. These findings suggest that insecticide application did not consistently enhance pest suppression under field conditions and may be associated with increased variability in pest population dynamics. The absence of a significant response from natural enemy populations indicates limited evidence of biological control interaction within the observed system. This study is limited to entomological observations and does not include yield or economic data; therefore, conclusions regarding economic efficiency or cost-effectiveness cannot be drawn. However, the results highlight the need for further investigation into ecological mechanisms underlying pest dynamics and support the importance of integrated pest management approaches that consider both chemical and biological factors in oil palm systems.

Keywords : Oil palm smallholders; Oryctes rhinoceros; pesticide economics; cost-effectiveness; insecticide application; pest resistance risk; integrated pest management (IPM); agricultural productivity; biological control; Platymeris laevicollis; input cost efficiency; sustainable agriculture; Malaysia plantation economy

Contribution/Originality: This study contributes to the agricultural economics and plantation management literature by providing empirical evidence on the cost-relevant outcomes of pesticide application in oil palm smallholder systems. Unlike prior studies that focus primarily on biological pest suppression, this research integrates an economic perspective by assessing the relative efficiency of insecticide use (Cypermethrin and

Carbofuran) against Oryctes rhinoceros infestation while considering the stability of natural enemy populations. The findings highlight that pesticide application yields short-term pest control benefits but does not significantly enhance biological control interactions, suggesting potential inefficiencies in chemical-dependent management strategies. The originality of this study lies in its dual focus on pest population dynamics and implied economic sustainability, offering insights into input optimization, potential cost reduction, and the value of integrating ecological balance into smallholder decision-making. These results provide a foundation for improving integrated pest management (IPM) adoption and enhancing long-term financial resilience in Malaysia's oil palm sector.

INTRODUCTION

Oil palm (Elaeis guineensis) is one of the most economically important plantation crops in Southeast Asia, particularly in Malaysia, where it contributes significantly to export earnings, rural livelihoods, and agro-industrial development. Despite its economic importance, oil palm productivity is highly vulnerable to biotic stress factors, particularly pest infestations, which can disrupt plant growth, reduce stand health, and compromise long-term plantation sustainability. Among the major insect pests affecting oil palm systems, Oryctes rhinoceros (rhinoceros beetle) remains one of the most destructive species. The pest primarily damages young palms by boring into the crown tissue, leading to reduced photosynthetic capacity, structural deformation, and, in severe cases, plant mortality. The persistence of O. rhinoceros infestations in plantation systems has been widely attributed to its high reproductive capacity, adaptability to plantation environments, and the availability of breeding sites in decomposing biomass. Consequently, effective management of this pest remains a priority for both estate managers and smallholders.

Chemical insecticides continue to be widely used as the primary control strategy against O. rhinoceros due to their immediate and operationally convenient effects. Commonly applied compounds include pyrethroids such as Cypermethrin and carbamate-based insecticides such as Carbofuran. While these chemicals are generally expected to suppress pest populations, increasing evidence suggests that their field performance may vary considerably depending on ecological conditions, application practices, and interactions with non-target organisms. In particular, the effectiveness of chemical control in open-field plantation systems is often influenced by environmental variability, pest behavior, and potential disruptions to ecological balance. In addition to direct pest suppression, oil palm ecosystems host a range of natural enemies that may contribute to regulating pest populations. Predatory insects such as Platymeris laevicollis and other arthropod species form part of the biological control network within plantation environments. However, the extent to which chemical insecticide applications affect these natural enemies and consequently influence pest dynamics remains insufficiently understood in smallholder systems. Although previous studies have examined the efficacy of insecticides in reducing pest populations, findings are often inconsistent, particularly under field conditions where ecological interactions are complex. Furthermore, limited empirical research has simultaneously examined pest populations and natural enemy responses across treated and untreated smallholder plots using controlled experimental designs. This gap is important because pest population outcomes in the field may not always follow expected patterns based solely on chemical intervention. Therefore, this study aims to empirically evaluate the effects of selected insecticide treatments (Cypermethrin and Carbofuran) on the population dynamics of Oryctes rhinoceros and its associated natural enemy Platymeris laevicollis in oil palm smallholder plots. Specifically, the study seeks to:

1. Compare pest population abundance across treated and untreated plots
2. Assess the temporal dynamics of pest populations under different treatments
3. Examine the response of natural enemy populations to insecticide application
4. Analyse the relationship between pest and predator populations

Importantly, this study focuses on biological population dynamics rather than direct economic outcomes. While pest abundance is often associated with potential crop damage, no yield or cost data were collected in this study. Therefore, any economic implications are interpreted cautiously and are proposed as directions for future research rather than direct findings.

By providing field based empirical evidence on pest and natural enemy dynamics under different treatment regimes, this study contributes to a more accurate understanding of pesticide effectiveness in real plantation conditions. The findings also offer a basis for future research integrating biological, agronomic, and economic data to support more comprehensive pest management strategies in oil palm smallholder systems.

CONCLUSION OF LITERATURE GAP

Overall, existing literature demonstrates that while chemical pesticides provide short-term suppression of Oryctes rhinoceros, they introduce long-term economic inefficiencies through resistance development and increased input dependency. Conversely, natural enemies and IPM strategies offer potential cost-saving mechanisms, but their effectiveness is constrained by ecological limitations and adoption barriers. However, limited studies have explicitly integrated pest dynamics with financial efficiency analysis at the smallholder level, particularly in the Malaysian oil palm context. This study addresses this gap by linking pest population dynamics, pesticide application, and natural enemy interactions with implicit economic implications, thereby contributing to a more holistic understanding of plantation sustainability and cost efficiency.

MATERIALS AND METHODS

Experimental Design

A Complete Randomized Design (CRD) was employed to evaluate the effects of insecticide application on pest population dynamics and natural enemy presence. Three treatment conditions were established:Cypermethrin (pyrethroid insecticide), Carbofuran (carbamate insecticide) and Untreated control (no chemical application)

Twelve oil palm smallholder plots were selected, with each treatment assigned across replicated field units to ensure comparability. Each treatment was replicated four times to improve statistical reliability. From a production economics perspective, the design enables comparison of input cost scenarios versus biological outcomes, allowing assessment of marginal productivity of pesticide investment under real farm conditions.

Sampling Procedure

Pest and natural enemy populations were monitored using a combination of pheromone traps and yellow sticky traps placed in each selected plot. Traps were inspected at regular intervals throughout the study period. Collected specimens of Oryctes rhinoceros were preserved in labelled vials, while natural enemies (Platymeris laevicollis) were carefully collected and transported to the Laboratory of Entomology, Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA (UiTM) Jasin for identification and counting. This sampling approach allows evaluation of biological output relative to chemical input intensity, which is essential for assessing cost efficiency in pest management systems.

Data Collection and Variables

The study focused on two primary biological indicators: Population abundance of Oryctes rhinoceros (pest pressure indicator) and Population abundance of Platymeris laevicollis (natural enemy indicator). In addition, treatment type (chemical vs non-chemical control) was treated as the main explanatory variable influencing pest and predator dynamics. These biological indicators are interpreted as proxies for economic performance outcomes, where lower pest abundance represents reduced potential yield loss and improved production efficiency.

Statistical Analysis

Data were analysed using IBM SPSS Statistics version 23. One-way Analysis of Variance (ANOVA) was used to determine significant differences in mean pest and natural enemy populations across treatments.Post-hoc comparisons were applied where necessary to identify differences between treatment means. Pearson correlation analysis was conducted to evaluate the relationship between pest populations and natural enemy abundance. From a finance-oriented analytical perspective, ANOVA results are used to assess the effectiveness of input expenditure (pesticide use), while correlation analysis evaluates the presence of potential biological cost-saving mechanisms.

Table 1: Mean Population of Oryctes rhinoceros Under Different Treatments

Treatment	Mean Population	ANOVA Result	Interpretation
Untreated	0.21		Lowest pest incidence
Carbofuran	2.63	F = 27.424; p < 0.01	Moderate suppression
Cypermethrin	3.12	Significant difference	Highest pest presence

The results show a statistically significant difference among treatments, indicating that pesticide application did not necessarily improve pest suppression efficiency. Interestingly, untreated plots recorded the lowest pest population, suggesting a possible natural ecological balance or reduced pest attraction. From a financial perspective, this indicates that higher chemical input does not guarantee better output, reflecting low input efficiency and weak return on pesticide investment (ROI) in treated plots.

Table 2: Monthly Dynamics of Oryctes rhinoceros Population

Period	Cypermethrin Trend	Carbofuran Trend	Untreated Trend
Jan–Feb	Declining then stable	Moderate decline	Stable very low
Mar–Jun	High fluctuation (peak 6.75)	Moderate fluctuation (peak 4.75)	Stable
Jul–Oct	Irregular decline	Gradual decline	Near zero

The treated plots show unstable pest dynamics, indicating inconsistent control performance over time. In contrast, untreated plots maintained consistently low pest levels. This suggests that pesticide application introduces high variability risk in pest control outcomes, which is economically important as it increases uncertainty in production planning and input budgeting for smallholders.

Table 3: Mean Population of Platymeris laevicollis Across Treatments

Treatment	Mean Population	ANOVA Result
Carbofuran	0.15	
Untreated	0.14	F = 0.081; p > 0.05
Cypermethrin	0.13	Not significant

There was no significant difference in natural enemy abundance across treatments. This indicates that insecticide application did not enhance or significantly suppress biological control agents. From an economic standpoint, this reflects no additional ecosystem service return from pesticide expenditure, limiting the financial justification for chemical dependence in pest control strategies.

Table 4: Correlation Between Pest and Natural Enemy Populations

Treatment	Correlation (r)	Significance
Cypermethrin	-0.013	p > 0.05
Carbofuran	Weak/none	p > 0.05
Untreated	Weak/none	p > 0.05

The correlation analysis shows no significant relationship between pest and predator populations across all treatments. This suggests that natural enemies were not functionally regulating pest populations in this system. Economically, this represents a missed opportunity for low-cost biological control, increasing reliance on chemical inputs and raising long-term production costs.

Table 5: Potential (Hypothetical) Implications for Pest Management

Indicator	Observation	Hypothetical Implication (Requires Further Validation)
Pest suppression	Lowest in untreated plots	May indicate potential for reduced chemical input under certain conditions
Treatment variability	High in treated plots	May introduce uncertainty in pest management outcomes
Natural enemies	No significant effect	Suggests limited evidence of enhanced biological control under current conditions

The economic interpretation shows that untreated plots surprisingly performed better in pest suppression efficiency while incurring zero chemical costs. This suggests that current pesticide practices may not be economically optimal. The findings support the need for cost-reduction strategies and integrated pest management (IPM) to improve long-term financial sustainability in oil palm smallholdings.

DISCUSSION

This study provides empirical evidence on the population dynamics of Oryctes rhinoceros and its associated natural enemy Platymeris laevicollis under different insecticide treatment regimes in oil palm smallholder systems. The most notable and unexpected finding is that untreated plots consistently recorded the lowest pest population, while plots treated with Cypermethrin and Carbofuran exhibited higher and more variable pest abundance. This outcome contrasts with the conventional expectation that chemical insecticides reduce pest populations under field conditions.

First, spatial heterogeneity in pest distribution may have contributed to baseline differences among plots. Although a randomized design was employed, the relatively small number of replications (n = 4 per treatment) increases the possibility that untreated plots were located in areas with inherently lower pest pressure. Because pre-treatment pest populations were not measured, it is not possible to fully rule out pre-existing differences as a contributing factor. This represents an important limitation of the study.

Second, insecticide application may have caused behavioral displacement or repellency effects, whereby adult beetles avoided treated areas and concentrated in untreated plots or vice versa. In open-field plantation systems, pest movement across plots is not restricted, and chemical cues from insecticides may influence host-seeking behavior. Such redistribution effects have been reported in other agricultural systems and can lead to misleading interpretations of treatment effectiveness when only localized counts are considered.

Third, the findings may reflect disruption of natural ecological regulation mechanisms. Although this study measured only Platymeris laevicollis, oil palm ecosystems support a broader community of natural enemies, including predatory beetles (Carabidae), parasitic wasps (e.g., Scolia spp.), and entomopathogenic fungi such as Metarhizium anisopliae. Insecticide application may have negatively affected these unmeasured beneficial organisms, reducing overall biological control capacity in treated plots. The absence of a significant treatment effect on P. laevicollis does not necessarily indicate that ecological interactions were unaffected, as other key predators or pathogens may have been more sensitive to chemical exposure.

Fourth, a potential explanation is insecticide-induced pest resurgence or hormesis, where sublethal exposure to insecticides stimulates pest reproduction or survival. Such responses have been documented in several insect taxa and may result in higher population levels following chemical application. In the case of O. rhinoceros, inconsistent suppression and fluctuating population trends observed in treated plots may reflect reduced efficacy over time or compensatory population growth mechanisms.

Fifth, insecticides may have indirectly influenced plant–insect interactions, including changes in plant physiology or microbial associations that affect pest attraction or susceptibility. Some studies suggest that chemical inputs can alter plant defense pathways or volatile emissions, potentially making treated plants more attractive or suitable for pest colonization. While this mechanism was not directly tested in this study, it provides a plausible ecological explanation that warrants further investigation.

Temporal Instability in Treated Plots

The observed greater fluctuation in pest populations over time in treated plots suggests that insecticide application did not provide stable control under field conditions. Instead, pest populations showed peaks and irregular declines, indicating inconsistent treatment effectiveness. In contrast, untreated plots maintained relatively stable and low pest populations throughout the study period. This temporal pattern highlights the importance of evaluating pest management strategies not only based on mean population levels but also on stability and predictability over time.

Natural Enemy Dynamics and Limited Biological Control Evidence

The study found no significant differences in Platymeris laevicollis populations across treatments, and no significant correlation between predator and pest abundance. This suggests that P. laevicollis may not be a dominant biological control agent for O. rhinoceros in the observed system, or that its regulatory effect is limited under the prevailing ecological conditions. However, this conclusion should be interpreted cautiously, as the study did not capture the full diversity of natural enemies present in oil palm ecosystems. Future research should adopt a broader ecological approach by including multiple predator and parasitoid taxa to better understand biological control dynamics.

Clarification on Resistance and Economic Interpretation

It is important to clarify that this study does not provide direct evidence of insecticide resistance, as no bioassays or genetic analyses were conducted. The higher pest populations observed in treated plots may be influenced by multiple ecological factors, including those discussed above, rather than resistance alone. Similarly, while pest abundance is often associated with potential crop damage, this study did not measure yield or economic outcomes. Therefore, any interpretation of economic efficiency or cost-effectiveness remains speculative and should be addressed in future research incorporating agronomic and financial data.

Implications and Future Research

The findings of this study highlight the complexity of pest management in real-world plantation systems, where ecological interactions can influence the effectiveness of chemical control strategies. The unexpected performance of untreated plots suggests that non-chemical or low-input approaches may play a more important role than previously assumed, particularly when supported by ecological processes.

CONCLUSIONS

This study examined the population dynamics of Oryctes rhinoceros and the associated natural enemy Platymeris laevicollis under Cypermethrin, Carbofuran, and untreated conditions in oil palm smallholder plots. The findings provide empirical evidence that insecticide application did not consistently result in lower pest populations under field conditions. Unexpectedly, untreated plots recorded the lowest mean abundance of O. rhinoceros, while treated plots exhibited higher and more variable pest populations over time. The results further indicate that insecticide treatments did not produce significant differences in the abundance of P. laevicollis, and no significant relationship was observed between pest and predator populations. These findings suggest that, within the context of this study, chemical control alone may not be sufficient to ensure stable suppression of O. rhinoceros populations under field conditions, and that pest dynamics are likely influenced by a combination of ecological and environmental factors not directly measured in this study. Importantly, this study is limited to entomological observations and does not include yield, cost, or economic data. Therefore, no conclusions can be drawn regarding economic efficiency, cost-effectiveness, or return on investment of the treatments. Any interpretation related to economic outcomes should be considered speculative and addressed in future research that integrates agronomic and financial measurements. The unexpected pattern of lower pest populations in untreated plots highlights the need for further investigation into underlying ecological mechanisms, including spatial variability, pest movement behavior, and the potential role of unmeasured natural enemies or environmental factors. Future studies should incorporate baseline pest assessments, broader biodiversity sampling, and integrated biological–economic analyses to better understand the complex interactions influencing pest management outcomes in oil palm systems. Overall, this study contributes to a more nuanced understanding of pesticide performance under real field conditions and underscores the importance of integrating ecological context when evaluating pest management strategies in agricultural systems.

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