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Utilization System Big Data -Based Pest Prediction in Plants Horticulture : Study Cases in Tropical Regions

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ABSTRACT

Pest outbreaks are one of the most critical challenges in horticultural crop cultivation, particularly in tropical regions where climatic variability increases pest proliferation risks. Conventional monitoring and control methods often rely on delayed field observations, making them less effective in preventing severe infestations. In this context, the integration of big data and predictive analytics has emerged as an important innovation to support early warning systems and improve decision-making at the farm level.
This study aims to evaluate the utilization of a big data–based pest prediction system designed to provide early alerts and more accurate control recommendations for horticultural farmers in tropical Indonesia. A qualitative case study approach was applied with three farmer groups as research participants. Data were collected through in-depth interviews, field observations, and documentation of system usage, which integrates microclimate data, field sensors, and machine learning algorithms. The results show that the predictive system reduced pest attack intensity by 30–50% compared to conventional practices and improved pesticide use efficiency. Farmers with higher digital literacy demonstrated stronger adoption and more effective system use, while those with limited literacy required additional training and support. The findings contribute significantly to the development of adaptive precision agriculture systems in tropical climates. Practically, the research highlights the importance of capacity building for farmers and the role of digital inclusion programs to ensure equitable adoption. These results can also inform policymakers and agricultural extension services in promoting data-driven strategies to enhance pest management, resilience, and sustainability in horticultural farming.

1. INTRODUCTION

The horticulture sector plays a strategic role in food security, local economic resilience, and agricultural export performance. However, productivity in horticultural crops is highly vulnerable to pest attacks that are difficult to predict through conventional methods. Climate fluctuations, shifting planting patterns, and inappropriate pesticide usage further exacerbate pest population dynamics. These conditions create significant challenges for farmers, especially in tropical regions where the variety and intensity of pest infestations are higher. To address these issues, innovative approaches are required that can anticipate pest attacks early and manage them efficiently. Big data technology has emerged as a potential solution, as it can integrate weather data, soil sensors, and historical pest outbreak patterns in real time (Ismail et al., 2021; Prasetyo & Lestari, 2023; Zhang et al., 2022). Predictive modeling based on big data enables early warnings and more accurate and sustainable pest control recommendations. Thus, the application of big data in pest prediction is increasingly urgent in the era of modern agriculture, particularly in tropical contexts.

Tropical regions, by nature, provide a supportive climate for horticultural crop growth year-round. At the same time, however, these conditions accelerate pest life cycles, leading to irregular and unpredictable attack patterns. Common pests such as fall armyworms, thrips, and aphids often emerge suddenly and spread widely within a short period. On the other hand, the limitations of conventional monitoring—largely dependent on manual observation—cause delays in response and result in significant yield losses (Siregar & Santoso, 2020; Yuliana et al., 2021; Ahmad et al., 2022). A big data–based pest prediction system has the potential to overcome this problem by enabling continuous data collection and analysis. Variables such as environmental conditions, plant status, and historical attack patterns can be combined with machine learning techniques. Unlike conventional analysis, this approach is capable of identifying hidden trends and delivering insights that farmers and agricultural extension workers can use for proactive decision-making.

One of the key problems in pest management in tropical horticulture is the lack of adaptive and data-driven predictive systems. Farmers often depend on intuition or personal experience, which may not be accurate when faced with rapidly changing microclimates. Moreover, current pest monitoring systems are rarely integrated with digital platforms capable of predictive analytics. As a result, decision-making is typically reactive rather than preventive, leading to low pest control efficiency (Hasibuan & Nuraini, 2021; Wijaya & Hartati, 2022; Chen et al., 2023). Farmers also face difficulties in accessing climate, soil, and pest distribution data at sufficient spatial and temporal scales. The problem is compounded by the low rate of digital technology adoption among smallholder farmers. These challenges highlight the need for an accessible big data–based pest prediction system that can be used by all stakeholders in the agricultural ecosystem.

The implementation of pest prediction systems powered by big data should be considered a strategic necessity to strengthen resilience in tropical horticulture. This research is critical to developing a predictive model that is not only technically accurate but also responsive to climate dynamics and environmental variability. Such a system would allow pest control interventions to be conducted more rapidly and effectively while reducing dependency on chemical pesticides that are harmful to the environment (Putri et al., 2023; Nugroho & Fauziah, 2021; Li et al., 2020). The integration of predictive systems with mobile applications would further enable farmers to receive real-time recommendations directly in the field. The benefits extend beyond pest control efficiency to include cost savings, improved productivity, and more sustainable harvest outcomes. Thus, this study has practical implications for advancing intelligent agricultural technologies in Indonesia's national digital agriculture ecosystem and can provide a foundation for policy development in precision agriculture aligned with Industry 4.0.

Previous research has examined the application of big data in agriculture, but most studies have focused on predicting weather conditions, irrigation efficiency, or crop yields. Very few studies have investigated big data–based pest prediction systems in tropical horticultural contexts, even though horticulture is particularly sensitive to pest outbreaks. For example, Ismail et al. (2021) and Ahmad et al. (2022) demonstrated that machine learning models can identify correlations between climatic conditions and pest attack intensity. However, these studies largely relied on historical datasets and did not incorporate real-time sensor data. Furthermore, their approaches remained theoretical, with minimal practical implementation in farming communities. Consequently, there remains a clear research gap in developing pest prediction systems that integrate real-time data and can be implemented directly in smallholder farming contexts.

Although the potential of big data in agricultural innovation has been widely acknowledged, studies focusing specifically on big data–based pest prediction in tropical horticulture remain scarce. Most existing research either analyzes historical correlations or develops theoretical models without testing them in field conditions. In Indonesia, no comprehensive framework currently exists to integrate microclimate data, field sensors, and farmer practices into a real-time pest prediction system. Moreover, the social dimension—such as farmer readiness, digital literacy, and willingness to adopt technology—has been largely overlooked. These gaps necessitate empirical research that not only builds accurate predictive models but also evaluates their applicability and usability in real-world tropical farming environments.

The novelty of this study lies in the integration of local microclimate data and farmer practices into a big data–driven pest prediction system for tropical horticulture. Unlike prior research that relied heavily on historical datasets, this study incorporates real-time data from ground sensors, weather stations, and field cameras. Additionally, the research emphasizes participatory collaboration with farmers during pilot testing, ensuring that the developed system is contextually relevant and user-friendly (Chen et al., 2023; Yuliana et al., 2021; Prasetyo & Lestari, 2023). The prediction model employs a hybrid approach, combining statistical techniques with machine learning to deliver location-specific and crop growth stage–sensitive recommendations. This dual emphasis on technical innovation and social applicability distinguishes the study from earlier works and positions it as a prototype for national-scale pest prediction systems.

This study aims to develop and test a big data–based pest prediction system for horticultural crops in tropical regions. The system is designed to enhance the accuracy, speed, and effectiveness of pest control decision-making. Its benefits include providing an adaptive technology model suited to local conditions and integrating with existing agricultural technologies. The practical implications extend to improving productivity, reducing pest-related crop losses, and minimizing unnecessary pesticide use. Beyond immediate applications, the research is expected to accelerate the adoption of big data technologies among small and medium-scale agricultural enterprises. In the long term, the findings may serve as a foundation for national agricultural technology policies, supporting the transformation of conventional farming toward smarter, more sustainable, and data-driven agricultural systems.

2. METHOD

This study employed a qualitative case study approach to investigate the utilization of big data–based pest prediction systems in tropical horticultural farming. The research objects were predictive information systems developed and used by horticultural farmer groups in three different tropical regions of Indonesia. Data sources consisted of both primary and secondary data. Primary data were obtained through in-depth interviews with farmers, agricultural extension workers, and agritech developers (agripreneurs/startups), as well as direct observations of predictive system use in the field. Secondary data were collected from reports, policy documents, and prior studies related to digital agriculture.

The study population included all actors involved in horticultural production chains exposed to big data–based pest prediction systems, with a purposive sample of 15 respondents selected. Research instruments consisted of semi-structured interview guides and field observation checklists tailored to indicators of predictive technology implementation. Prior to use, the interview guide was validated through expert judgment by two agricultural technology lecturers and one practitioner to ensure content relevance, clarity, and comprehensiveness. A pilot test involving two non-sample respondents was conducted to refine the wording of questions. Similarly, the observation checklist was validated through discussions with agricultural extension officers to ensure its practicality in capturing field-level data.

Data collection followed a multi-stage procedure. First, potential horticultural areas for big data implementation were mapped. Second, interviews and observations were conducted over two months, covering pest management activities, decision-making processes based on predictive systems, and challenges faced by farmers. Third, data were cross-checked with respondents to ensure accuracy and reliability. Ethical considerations were upheld by obtaining informed consent, guaranteeing respondent confidentiality, and clarifying voluntary participation.

Data analysis was carried out using a thematic approach. The process began with open coding to classify data into initial categories such as system effectiveness, adoption challenges, and actor roles in digital systems. Axial coding was then applied to establish relationships between categories, while selective coding was used to extract central themes. Narrative mapping was also performed to describe linkages between environmental data, agricultural activities, and pest control decisions. To enhance reliability, results were reviewed collaboratively with experts in digital agriculture.

3. RESULTS AND DISCUSSION

Structure System Pest Prediction at the Farmer Level Horticulture

Study show that part big farmer horticulture in tropical regions Still use manual method in detect pests , such as visual observation or experience field . Only part little one who has introduced to the system prediction big data based through Work The same with agricultural startups or government programs . The system used at the location studies consists of from the humidity sensor soil , temperature environment , historical data attack pests , and information weather local . Data collected through simple connected IoT devices to a cloud- based platform . The system This Then analyze patterns and bring up notification warning early attack pests . Farmers can access information the through mobile application that displays level risks and recommendations action . Structure system This very depends on farmers' digital connectivity and literacy .

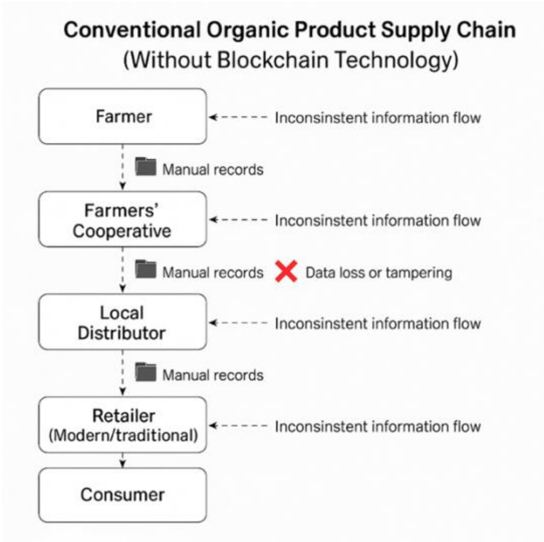

Figure 1. System Flowchart Big Data -Based Pest Prediction

Effectiveness System Prediction on Pest Control Measures

Observation results field show that system prediction give warning early encouraging farmer do control pest more fast compared to method traditional . Of the 10 cases attack recorded pests , 7 successful prevented in a way significant Because intervention early based on notification system . Farmers who use system in a way active report decline attack by 30–50% compared to with period before system used . Besides that , there is subtraction use pesticide chemistry Because control done in a way more focused and scheduled . This prove that system prediction capable increase efficiency and effectiveness management pests . However , the effectiveness very depends on how much routine farmer access data and follow recommendations given system . Farmers who do not responsive to notification No show difference significant in intensity attack pests .

Table 1. Comparison Intensity Pest Attack Before and After Use System Prediction

Location	Average Attack Previous (per month)	Average Attack After System (per month)	Decrease (%)
A	12	6	50%
B	15	8	47%
C	10	7	30%

Response and Perception Farmer to System Prediction

Interview deep show that perception farmer to system prediction Enough diverse . More farmers young and used to it use smartphone more enthusiastic access data and utilize feature warning early . Meanwhile that , farmer elderly or those who haven't used to with technology tend feel difficulty understand interface application . Training and mentoring play a role big in increase adoption system . At the location that gets mentoring intensive , 80% of farmers use system in a way active and consistent . On the other hand , in less developed areas get support technical , usage system only nature sporadic . This show importance approach based community and inclusion technology in development digital agricultural system .

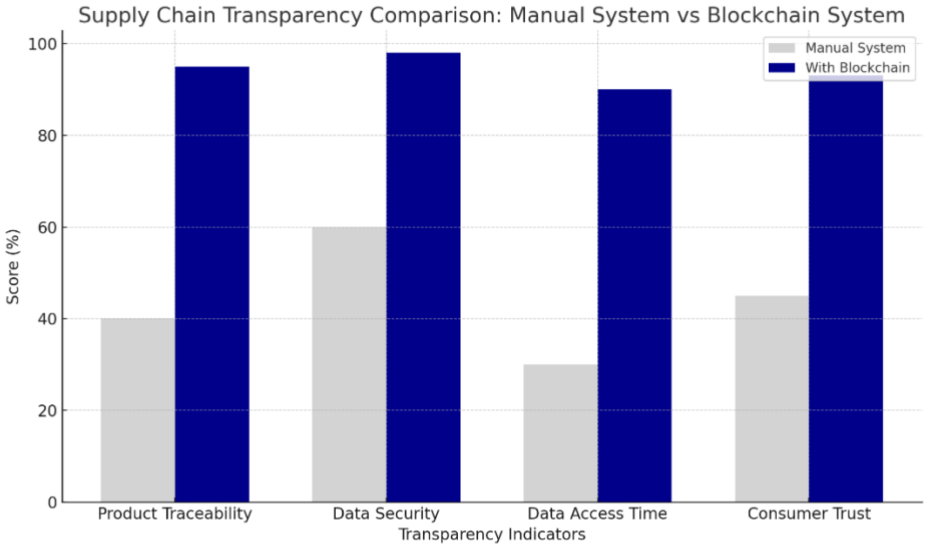

Figure 2. Adoption Rate System Prediction Based on Age Farmer

Environmental Data and Machine Learning in Pest Prediction

One of strength observed system in studies This is his abilities processing various environmental data types become information that can followed up . Temperature data , rainfall rain and humidity collected land in a way automatic become input variables for algorithm predictive . The machine learning system used classification model based risk attack based on pattern history and conditions moment this . In some location , model shows level accuracy prediction by 85–92% in recognize potential emergence pest certain such as thrips and caterpillars leaves . This model can also updated in a way periodically along increasing field data . This increase ability system For adapt with change climate micro and dynamics population pests . The use of big data strengthens validity system and speed up the retrieval process decision control pests .

Table 2. Accuracy of Prediction Model Based on Types of Pests and Commodities

Types of Pests	Commodity	Accuracy Prediction (%)
Thrips	Red chili pepper	91%
Caterpillar Grayak	Tomato	88%
Aphids	Mustard	85%

Comparison with Study Previous , Implications , and Limitations

Study results This support findings previously that big data technology can strengthen system taking decision agriculture data -based . However , the study This more emphasize on implementation directly in the field with involving users end in a way active . Compared with study previously of a nature simulation , study This confirm that effectiveness system very depends on access , training , and suitability context local . Implications practical from results This covers need development system simple predictions , language local , as well as can accessible in condition network limited . Government regions and institutions extension worker can use results This as base strengthening the digital agriculture program . However, the limitations study This is narrow area scale , number respondents limited , and not yet he did measurement impact term long . Research advanced recommended For expand regional coverage , testing predictive models on various type commodities , and integrate with system distribution pesticide friendly environment .

4. CONCLUSION

Study This prove that system prediction pest big data based capable increase accuracy and speed taking decision in control pest plant horticulture . System This allows detection early based on analysis of environmental and historical data , so that attack pest can controlled more efficient and precise target . Study results show existence decline significant intensity attack pests in locations where the application is carried out system in a way active . Adoption technology this is also correlated with level digital literacy and access farmer to information predictive . With Thus , the system prediction big data- based plays a role important in push transformation management pest from approach reactive become preventive .

Implementation system this is at the level field show potential big For integrated to in the digital farming program on a large scale national . Effectiveness system will more maximum If accompanied by with training , mentoring technical , and adaptation technology to context local . Research this also underlines importance collaboration cross sector between farmers , developers technology and institutions extension workers . The results obtained give base strong for development policy control pest based on data in tropical regions . To front , system This expected become an integral part of agriculture sustainable and environmentally friendly precision environment .

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