Factors Influencing Precision Agriculture Adoption among Farmers: A Case Study in Kelantan, Malaysia

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ABSTRACT

This research examines the key factors influencing the adoption of precision agriculture (PA) among farmers in Kelantan, Malaysia. Specifically, the study investigates how the cost of technologies, farmers' knowledge levels, awareness, technological infrastructure, and initial investment requirements shape the likelihood of adopting precision agriculture practices in the region. By employing a quantitative approach and factor analysis, that integrate socio-demographic characteristics with critical determinants of adoption, this study offers important insights into the economic implications of PA, opportunities for crop yield optimization, and potential strategies to strengthen agricultural productivity in Kelantan. The findings reveal that awareness, economic return and knowledge enhancement are central to improving precision agriculture adoption. Limited understanding of concepts and inadequate exposure to technology-based farming methods remain major obstacles among smallholders. Additionally, recommendations for providing financial support and incentives are proposed to overcome financial barriers and encourage farmers to adopt precision agriculture technologies. Overall, this research contributes to the growing body of literature on precision agriculture adoption in Malaysia by emphasizing the combined importance of technological advancements, knowledge dissemination, financial support, and collaborative efforts. Strengthening these elements is crucial for driving successful precision agriculture adoption, enhancing farm profitability and crop yield while promoting sustainable agricultural development in Kelantan, Malaysia.

Keywords: Precision agriculture, Technology adoption, Farmers, Agricultural sustainability

1. INTRODUCTION

Agriculture in Malaysia presents numerous challenges due to the rising demand for food and the intensifying effects of climate change. Precision agriculture is increasingly recognized as a vital approach to enhance crop yield and profitability in this context. Alam et al. (2017) assert that rapid climatic changes are impacting food production and households' capacity to get enough nourishment in the country. Over the past five years, household food accessibility has been increasingly fragile due to climate-related issues (Alam et al., 2019). This underscores the importance of innovative and precise agricultural techniques—such as precision agriculture (PA) to mitigate climate risks and strengthen national food security.

Crop yield and profitability are crucial for the agriculture sector in Malaysia. According to research by Shariff and Khor (2008), households experiencing food insecurity typically include a large number of children, unemployed moms, and no land ownership, all of which heighten vulnerability and reduce coping capacity. These socioeconomic constraints highlight the need for improved agricultural productivity to sustain household food availability. Janrao and Shah (2022) further argue that the strategic selection of suitable crops, supported by more accurate and technology-enabled agricultural practices, can significantly improve productivity and profitability, aligning closely with the objectives of precision agriculture.

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Technology advancement has become a key determinant of modern agricultural transformation and significantly influences modern agricultural practices. Majumdar et al. (2017) elucidate that data mining and machine learning can assist farmers in making informed decisions grounded in actual data. Chahal et al. (2020) demonstrate that the utilization of cover crops enhances the yield and profitability of primary crops, indicating that sustainable practices can bolster farmer income. In Malaysia, climate change is anticipated to diminish paddy production (Alam et al., 2011); hence, precision agriculture approaches such as optimal irrigation and precise crop selection can assist farmers in mitigating these effects.

Despite the advantages of precision agriculture, its implementation in Kelantan encounters numerous challenges. A significant problem is the lack of understanding among farmers. Many farmers lack a clear comprehension of precision agriculture (PA) and its potential benefits. A further difficulty is the inadequate technology infrastructure in certain regions. Farmers cannot readily implement precision agriculture practices without adequate tools, equipment, and technical support. Furthermore, the initial expenditure for procuring PA technology, including sensors, monitoring devices, drones, and data tools, is considerably elevated. This instills fear in numerous farmers, particularly small-scale cultivators, regarding investment.

The concerns of limited understanding, insufficient technology, and elevated initial costs hinder farmers in Kelantan from adopting precision agriculture. Addressing these issues is crucial to ensure that PA can be effectively utilized to enhance agricultural output, bolster food security, and augment the profitability of farmers in the region.

2. LITERATURE REVIEW

Precision agriculture (PA) has been widely discussed as a modern approach that can help farmers increase crop yield, reduce production cost and improve decision-making using technology. Many studies highlight how PA can support sustainable farming, especially in countries that face climate challenges, including Malaysia. This section reviews past research related to PA adoption, focusing on economic return, knowledge, awareness, technological infrastructure and initial investment.

Economic benefit is one of the strongest reasons why farmers are willing to adopt precision agriculture. Janrao and Shah (2022) explained that using more accurate methods in crop production can help farmers improve yield and profit. Precision tools such as optimized irrigation, soil sensors and automated systems allow farmers to use water and fertilizer more efficiently. Chahal et al. (2020) also found that sustainable practices, like planting cover crops, can increase profit margins and support better crop performance. These studies show that when farmers see real financial advantage, they are more likely to use PA technologies.

Knowledge plays a major role in farmers' readiness to adopt new technologies. Farmers who have experience with irrigation technology or other farming tools usually feel more confident using PA. Majumdar et al. (2017) highlight how data mining and machine learning can support decision-making in farming, but to use these tools effectively, farmers need basic technical understanding. Without proper knowledge, farmers may feel unsure or afraid to try something new. Therefore, training, workshops and exposure are important to increase farmers' skills and confidence in using PA tools.

Awareness is another key factor that affects PA adoption. Many farmers are still not familiar with PA concepts or how the technology works. This low awareness has been highlighted in many local studies, especially in rural areas. When farmers do not fully understand the benefits, they are less likely to adopt the technology even if it can improve productivity. Raising awareness through extension services, demonstration farms or agricultural programs is necessary to help farmers see the usefulness of PA.

Infrastructure refers to the availability of tools, equipment, internet access and technical support. In many parts of Malaysia, including Kelantan, infrastructure is still limited. Some farmers do not have access to reliable internet connection or digital devices, which makes PA adoption more difficult. Majumdar et al. (2017) mention that technology-based farming requires good digital support for data collection and analysis. Without proper infrastructure, farmers cannot use PA tools efficiently, even if they want to adopt the technology.

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One of the biggest challenges in adopting precision agriculture is the high initial investment which farmers could not afford (Barnes et al., 2019). Tools like sensors, drones and smart irrigation systems are expensive, especially for small farmers. This financial burden makes farmers hesitate to adopt PA even when they understand the long-term efficiency and sustainability benefits (Mizik & Gyarmati, 2023). Many studies highlight that cost is a major barrier in developing countries, where farmers usually depend on small land areas and limited income (Kendall et al., 2021). The high cost of buying, maintaining and learning to use PA tools reduces the adoption rate, despite evidence showing that PA can improve yield, resource-use efficiency and profitability over time (Getahun et al., 2024).

Climate change creates additional pressure for farmers to adopt new solutions. Alam et al. (2019) reported that climate change has strong negative effects on Malaysian crop production and household food security. This makes PA even more important, because it can help farmers reduce climate risks and increase crop resilience. By using real-time data, PA can assist farmers in managing water, fertilizer and crop health more effectively, which is important in uncertain weather conditions.).

3.METHOD

Methodology was designed to systematically investigate the factors that influence the adoption of precision agriculture among farmers in Kelantan. A quantitative research approach was employed as it allowed for empirical data collection, objective measurement and statistical analysis like factor analysis is used to ensure reliable and generalizable findings. This method helps to produce findings that are more objective and easier to compare across groups of farmers.

Descriptive analysis is the method of utilizing statistical methods, such as measures of frequency, central tendency, dispersion, and location, to characterize or summarize a set of data (Vikas, 2018). In quantitative research, describing response characteristics, such as the average of a single variable, like age, or the relationship between two variables such as age and creativity, is the first stage in statistical analysis after data collection. This analysis was used in the present research to clarify the demographics section which made it easier to identify the characteristic of the respondents.

Conceptual Framework

A conceptual framework is used to guide the survey questions and help explain or predict the relationship between the variables in this study. Figure 1 shows the factors influencing precision agriculture adoption among farmers in Kelantan. Precision agriculture adoption is the dependent variable, while the independent variables include economic return, knowledge of optimized irrigation, awareness level, technological infrastructure and initial investment.

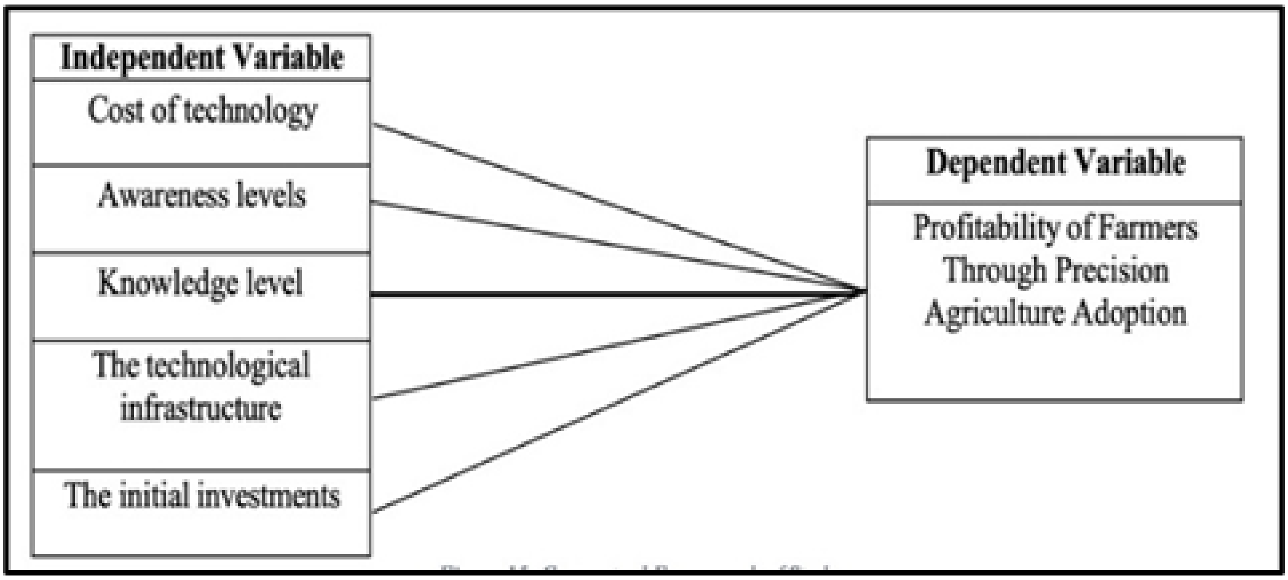

Figure 1. The conceptual framework of the study

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Questionnaire Design and Sampling Size

The questionnaire for this study was prepared after reviewing previous research related to factors influencing precision agriculture adoption. The questions include multiple-choice items, closed-ended questions and Likert scale statements. The survey is divided into two parts. Section A collects demographic information from farmers, while Section B focuses on the variables that influence the adoption of precision agriculture.

For this study, a simple random sampling was used because it gives each farmer an equal chance of being selected (Lauren, 2020). This method also helps to reduce bias and gives more accurate representation of the population. Based on the sample size formula suggested by Daniel (1999), the study collected responses from 384 farmers in Kelantan as a sample size, representing the population of farmers involved in crop production in the state.

4. RESULTS AND DISCUSSION

The key findings derived from the survey of Kelantan farmers that involve in adoption of precision agriculture are shown in this section.

(1) Demographic Profile of Respondents

Table 1 presents the data utilized for this investigation, which was acquired from the farmers in Kelantan. The result reveals that many respondents (72.9%) are aged 19-30, with Malay respondents representing the largest percentage (207 respondents, or 53.9%) while males (239 respondents, or 62.3%) predominate in the business. Diploma education constitutes the predominant level of education at 34.9% (134 individuals), succeeded by degree education at 29.9%, secondary education at 21.4%, and primary education at 13.8%. The prevalent status is single, reported by 238 respondents (62%), followed by married status, indicated by 144 respondents (37.5%). The biggest income bracket, with 151 respondents (39.3%), is RM2100-RM3000, followed by RM800-RM2000 (37%), RM3100-RM4000 (17.3%), RM4100-RM5000 (3.4%), RM5100-RM6000 (0.8%), and RM6100-RM10000 (2.4%). The predominant farm size is 0.8-5 acres, comprising 90.5%, followed by the 5.1-10 acres category at 9.7%.

The majority of respondents (24%) have cultivated chili, followed by spinach (15.6%), okra (12.2%), cucumber (7.3%), purple eggplant (6.8%), onion (6.5%), cabbage (6.5%), carrot (5.7%), long beans (4.9%), soybeans (4.4%), tomato (3.9%), and sugarcane (2.1%). Meanwhile, the majority of respondents (54.2%) have operated their businesses for 1-5 years, while 156 respondents (40.8%) have been in company for 6-10 years, and 20 respondents (5.5%) for 11-33 years. The most prevalent type of precision agriculture utilized is sensors, employed by 100 respondents (26%), followed by the Internet of Things (91 respondents, 23.7%), autonomous vehicles (21.6%), drones (19.5%), and robotics (9.1%).

(2) Socio-cultural factors, risk perception, and farmer attitudes toward innovation

Beyond financial and experience in farming background, socio-cultural factors, risk perception, and farmer attitudes toward innovation play a crucial role in shaping precision agriculture (PA) adoption decisions. Farmers in in this region contexts often rely on traditional practices passed down through generations, which may reduce openness toward technologically intensive innovations. Older farmers, in particular, tend to exhibit higher levels of risk aversion and lower digital literacy, making them less willing to experiment with unfamiliar technologies despite potential long-term benefits (Herath et al., 2012; Tey & Brindal, 2012). Perceived uncertainty regarding technology performance, maintenance requirements, and data reliability can further discourage adoption, especially where extension services and peer learning are limited (Rezaei-Moghaddam & Salehi, 2010). These socio-cultural and psychological dimensions interact with socio-economic barriers, suggesting that adoption strategies must address not only cost and training but also trust-building and behavioural readiness among farmers.

(3) Comparative effectiveness of different precision agriculture technologies

The effectiveness and adoption potential of precision agriculture technologies vary considerably depending on their complexity, cost, and compatibility with existing farming systems. Entry-level technologies such as soil sensors (26%), basic Internet of Things (IoT) applications (23.7%), and sensor (26%) tend to deliver more immediate and observable benefits, particularly in terms yield stabilization, making them more attractive to smallholders (Barnes et al., 2019; Mizik & Gyarmati, 2023). In contrast, capital-intensive technologies such as robotics (9.1%) and autonomous vehicles (21.6%) often require substantial financial investment, advanced technical skills, and reliable digital infrastructure, which can limit their practicality for small-scale farmers. As such, the comparative effectiveness of PA technologies is context-dependent, and adoption outcomes are strongly influenced by the alignment between technology characteristics and farmers' resource endowments (Getahun et al., 2024).

(4) Variation in adoption across crop types and farm sizes

Adoption of precision agriculture technologies also differs across crop types and farm sizes, reflecting variations in production cycles, risk exposure, and expected returns. High-value and short-cycle crops such as chili, leafy vegetables, and horticultural produce are more likely to benefit from precision irrigation, nutrient management, and real-time monitoring due to their sensitivity to environmental conditions and input efficiency (Janrao & Shah, 2022). Small-scale farms, which dominate agricultural production in Kelantan, often prioritize low-cost and modular technologies that can be incrementally adopted, whereas larger farms may be better positioned to invest in integrated PA systems. These findings highlight the importance of crop- and scale-specific adoption strategies, rather than a one-size-fits-all approach, when promoting precision agriculture among diverse farming systems.

Factor Analysis

A factor analysis was conducted to identify the factors influencing the adoption of precision agriculture among farmers in Kelantan, Malaysia. The Kaiser-Meyer-Olkin (KMO) measure yielded a value of 0.716, which exceeds the minimum requirement of 0.5. Additionally, Bartlett's Test showed significance at the 1% level, confirming that the factor analysis is appropriate for this study.

According to Kaiser (1974), a KMO value above 0.5 is considered minimally acceptable. Values between 0.5 and 0.7 are deemed fair, while those from 0.7 to 0.8 are rated as good. Values between 0.8 and 0.9 are classified as great, and values above 0.9 are considered superb. Therefore, with a KMO value of 0.716, our analysis falls into the moderately good category (Andy Field, 2009).

The reliability test for each factor, measured using Cronbach's Alpha, returned values above 0.5, indicating that the variables are both valid and reliable (as shown in Table 5). The factors influencing the adoption of precision agriculture among farmers in Kelantan include economic return, knowledge of optimized irrigation, awareness level adoption of precision, technological infrastructure, and initial investment faced by the farmer.

TABLE I Respondents' Demographic Profile

Variables	**Frequency (n)**	**Percentage (%)**
Age		
19- 30	280	72.9
31-40	61	15.6
41-50	29	7.7
51-60	10	2.7
61-66	4	1.1

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Gender		
Male	239	62.3
Female	145	37.8
Race		
Malay	207	53.9
Chinese	107	27.9
Indian	70	18.2
Level of Education		
Secondary	82	21.4
Primary	53	13.8
Diploma	134	34.9
Degree	115	29.9
Marital Status		
Single	238	62
Married	144	37.5
Others	2	0.5
Monthly Income		
RM800-RM2000	142	37
RM2100-RM3000	151	39.3
RM3100-RM4000	66	17.3
RM4100-RM5000	13	3.4
RM5100-RM6000	3	0.8
RM6000-RM10000	9	2.4
Farm Size		
0.8-5 acres	347	90.5
5.1-10 acres	37	9.7
Type of Crop		
Onion	25	6.5
Okra	47	12.2
Spinach	60	15.6
Chili	92	24
Cucumber	28	7.3
Long Beans	19	4.9
Cabbage	25	6.5
Carrot	22	5.7
Soybeans	17	4.4

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Purple Eggplant	26	6.8
Tomato	15	3.9
Sugarcane	8	2.1
Years of Farming 1-5 years	208	54.2
6-10 years	156	40.8
11-33 years	20	5.5
Type of Precision Agriculture Drones	75	19.5
Sensor	100	26
IoT	91	23.7
Robotics	35	9.1
Autonomous Vehicle	83	21.6

TABLE II Factor Analysis

Factor Extracted	**Factor Loading**
Factor 1: Economic Return	
F1: I expect that the adoption of optimized irrigation technologies will lead to a significant increase in crop yield.	0.785
F2: I believe that optimized irrigation technologies will reduce water usage on my farm's.	0.816
F3: I anticipate that the adoption of optimized irrigation technologies will lead to cost savings	0.787
Cronbach's Alpha	0.71
Eigenvalue	1.9
% variance explained	63.34
Cumulative % variance explained	63.34
Factor 2: Knowledge of Optimized Irrigation	
F1: I have implemented optimized irrigation techniques on my farm	0.738
F2: The adoption of optimized irrigation has led to water savings on my farm	0.772
F3: Optimized irrigation has improved my crop yield and quality	0.762
F4: I intend to expand the use of optimized irrigation practices in the future	0.779
F5: I would recommend optimized irrigation practices to other farmers for improved efficiency	0.755
Cronbach's Alpha	0.818
Eigenvalue	2.897
% variance explained	57.936
Cumulative % variance explained	57.936
Factor 3: Awareness Level Adoption of Precision Agriculture	
F1: I am aware of the potential economic returns of precision agriculture adoption	0.654
F2: I have received information about precision agriculture through agricultural seminars or workshops	0.667
F3: I am aware of the potential benefits of precision agriculture in increasing farm profitability	0.503
F4: I am interested in learning more about how precision	0.601

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F5: I am considering adopting precision agriculture practices on my farm in the future.	0.584
Cronbach's Alpha	0.159
Eigenvalue	1.171
% variance explained	23.423
Cumulative % variance explained	23.423
Factor 4: The Technological Infrastructure	
F1: I have access to technical support for precision agriculture technologies	0.572
F2: I believe that access to technological infrastructure can improve my farm's profitability	0.903
F3: I use precision agriculture tools such as GPS guidance systems or drones on my farm	0.505
F4: Data collected through precision agriculture tools have helped me make informed decisions on my farm	0.517
F5: I believe enhancing technological infrastructure is crucial for the profitability of farmers in Kelantan	0.673
Cronbach's Alpha	0.184
Eigenvalue	1.234
% variance explained	24.69
Cumulative % variance explained	24.69
Factor 5: The Initial Investment	
F1: Investing in precision agriculture technologies is essential for improving farm profitability	0.526
F2: I believe that the initial investment in precision agriculture will lead to long-term financial gains	0.593
F3: I feel adequately supported in making informed decisions about the initial investment in precision agriculture	0.512
F4: I believe the returns on investment from precision agriculture will lead to increased profitability in the long run	0.591
F5: I see investment in precision agriculture as a strategic decision for the sustainability of my farm	0.702
Cronbach's Alpha	0.442
Eigenvalue	1.617
% variance explained	32.339
Cumulative % variance explained	32.339

Table II indicates that all factor loadings exceeded 0.5. Five critical aspects were identified: economic return, expertise in optimal irrigation, awareness of precision adoption, technological infrastructure, and initial investment. The removal of additional elements did not substantially enhance the alpha values for any scale. All factors reside within the permissible range of 0.5. A high Cronbach's alpha coefficient signifies a robust association among the items. Collectively, these five factors account for 63.34% of the total variance in the data.

The initial factor, "Economic Return," comprised three elements with factor loadings over 0.6, all falling within an acceptable range. The items had strong reliability, evidenced by a Cronbach's alpha score of 0.710. The statement included "I expect that adopting optimized irrigation technologies will lead to a significant increase in crop yield," "I believe that optimized irrigation technologies will reduce water usage on my farm," and "I anticipate that adopting optimized irrigation technologies will lead to cost savings." The factor loadings varied from 0.785 to 0.816, with a maximum of 0.816 and a minimum of 0.785. Collectively, these items accounted for 63.34% of the variance in the data, with an eigenvalue of 1.9 for this factor.

The second factor, labeled "Knowledge of Optimized Irrigation," was extracted using five items. Each item had factor loadings between 0.7 and 0.8, all within the acceptable range. The Cronbach's alpha score for these

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five items was 0.818, indicating good consistency. The items included: "I have implemented optimized irrigation techniques on my farm," "The adoption of optimized irrigation has led to water savings on my farm," "Optimized irrigation has improved my crop yield and quality," "I intend to expand the use of optimized irrigation practices in the future," and "I would recommend optimized irrigation practices to other farmers for improved efficiency." These items together explained 57.936% of the cumulative variance in the data, with an eigenvalue of 2.897 for this factor. The third element, "Awareness Level Adoption of Precision Agriculture," was extracted from five items. The factor loadings were adequate, with three items exceeding 0.6 and two items between 0.5 and 0.6. All things met standards. Cronbach's alpha for these five items was 0.159. Meanwhile five items extracted "Technological Infrastructure," as the fourth factor. The factor loadings were acceptable: one item was larger than 0.9, one was 0.6–0.7, and three were 0.5–0.6. The final component, "Initial Investment," has five items. Each item had a factor loading above 0.5, which was acceptable. Cronbach's alpha for these five items was 0.442 while the factor loadings varied between 0.702 to 0.512.

The internal consistency of each scale was assessed with Cronbach's alpha. The results for the criteria were as follows: economic return (0.710), understanding of optimum irrigation (0.818), awareness level of precision adoption (0.159), technological infrastructure (0.184), and initial investment (0.442). The scores varied from moderate to good: 0.710 for economic return (3 items), 0.818 for knowledge of optimal irrigation (5 items), 0.159 for awareness level of precision adoption (5 items), 0.184 for technological infrastructure (5 items), and 0.442 for initial investment (5 items). Composite scores for each of the five factors were generated by averaging the items with their principal loading on each component.

An elevated score in the economic return factor category signifies that economic return is the primary determinant of precision agriculture adoption among farmers in Kelantan, Malaysia. Enhanced economic returns can further augment farmers' profitability (Mdoda et al., 2025). This is succeeded by understanding optimum irrigation, the degree of acceptance of accuracy, technological infrastructure, and initial investment. Omar et al. (2013) asserts that numerous governments promote educational or training opportunities for farmers to enhance their technological efficiency. Entities such as the State of Agriculture offer information, training, demonstrations, and the exchange of experiences on the implementation of precision agriculture. The government provides incentives such as fertilizer, equipment, insecticides, fungicides, and other resources to motivate farmers to improve their production.

Knowledge is a crucial factor that enhances the efficiency and profitability of smallholders in production (Mohammad Sultan and Showkat, 2014). Smallholders with less educational attainment may find it challenging to comprehend and fully leverage technology tools and precision farming. Formal education enhances farmers' knowledge, whereas non-formal education offers practical instruction and suitable agricultural techniques, enabling smallholders to stay abreast of developments and advanced technologies. Consequently, governmental interventions are essential to promote additional education and training aimed at enhancing profitability and agricultural output, notably by elevating the educational attainment of smallholders in the Kelantan region.

This investigation demonstrates that all five criteria substantially affect profitability and technical efficiency among smallholders in Kelantan, Malaysia. Prior empirical evidence supports this finding, as technology availability, farmer capability, and innovation readiness have long been associated with variations in smallholder productivity and efficiency (Awunyo-Vitor et al., 2016; Kerorsa, 2025).

Herath et al. (2012) and Alouw et al. (2020) assert that insufficient technology constitutes a significant limitation for farmers, especially in developing regions where smallholders lack access to modern inputs, machinery, and digital tools. The elevated score for the technological constraint category in this study indicates that aged smallholders encounter greater challenges in accessing new technologies. Older farmers are often more risk-averse, possess lower digital literacy, and rely heavily on traditional and inherited practices, thereby reducing their willingness to adopt modern innovations (Abdullah et al., 2014; Tey & Brindal, 2012).

Moreover, perceptions, knowledge, and education also significantly affect the adoption of precision agriculture and technological innovation among smallholders. Studies consistently show that farmers with higher levels of education and training demonstrate stronger technology acceptance, higher awareness of long-term benefits, and greater technical efficiency (Rezaei-Moghaddam & Salehi, 2010; Kiptot et al., 2022). This aligns with the findings within the research area, where inadequate exposure to training and limited access to extension services hinder the adoption of advanced precision agriculture and farm technologies.

V. CONCLUSION

The research highlights the importance of precision farming as a promising solution for improving agricultural crops and improving crop yield and productivity. The study examines relationships between economic return, knowledge, awareness, technological infrastructure, initial investments, and adoption rates. Findings reveal significant socio-demographic factors influencing precision farming adoption.

To ensure technology can be adopted and be easily used by many people, financial support and incentives are crucial to address financial barriers that hinder farmers from investing in precision agriculture technologies and create solutions specifically for small-scale farmers.

Moreover, investigating future trends like block chain integration, robotics and Artificial intelligence in agriculture is necessary due to their transformational potential impacts. Recommendations include fostering collaboration among government agencies, agricultural cooperatives, and private sector, industry partners, and farmers to facilitate adoption of precision agriculture technologies, improving crop yield, enhancing profitability, and promoting sustainable agricultural practices as well as safeguarding farmers' interests and data privacy. This analysis not only provides insights on the current landscape but also charts a clear path for the future adoption of precision agriculture farming.

Although this study provides important information about factors influencing PA adoption in Kelantan, several limitations remain. The results may challenge common assumptions about precision agriculture adoption, in some extents, may surpass or undermine adoption rates in Malaysia context and may introduce response bias. Adoption was not only influenced by socio-economics, perception or awareness and key barriers include financial constraints, limited understanding of technology applications, but it was also determined by disparities in different PA technologies, crop types, or farm scales. Hence, the research may restrict to generalize of the findings to other states in Malaysia with different agro-ecological conditions or socio-economic contexts.

Addressing this will require longitudinal designs, mixed-methods approaches, and comparative studies across regions to close the gap between sample bias and decision-making. Despite these limitations, the study offers notable insights to gear efforts towards more adoption and integration of precision agriculture for sustainable agricultural practices in Kelantan.

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