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The use of Digital Technologies in Agricultural Cultivation: A Case of a Developing Nation with Rice as a Staple Food

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The rapid growth of urbanization and industrialization worldwide has exacerbated the scarcity of arable land resources, highlighting the critical need for sustainable development. To achieve this, it is essential to conduct a comprehensive assessment of the efficiency of cultivated land use. Besides, in Indonesia, rice farming plays a vital role in providing food for the population. While the green revolution program initiated in 1968 has increased rice productivity, it has also negatively impacted the environment and decreased productivity. Hence, the current study aims to examine the influence of sustainable agricultural technologies, including the system of rice intensification, organic farming, and integrated pest management, in enhancing rice productivity, further leading to the enhanced socio-economic development of a nation. This study applied a quantitative research methodology using SmartPLS 3.0 to analyze data collected from the farmers at local administrative levels of a provinces of Indonesia. The study suggests that implementing sustainable agricultural technologies, such as SRI, organic farming, and integrated pest management, can increase productivity while supporting economic activities in upstream and downstream sectors. The government and other stakeholders are recommended to prioritize ecological and environmental aspects when considering the adoption of new agricultural technologies.

Key words: Digital Technologies, Agricultural, Cultivation, Developing Nation, Rice, Staple Food.

1. INTRODUCTION

The agricultural sector plays a crucial role in the economic development of developing countries. It serves multiple purposes, such as providing food for the population, producing raw materials for the industry, and consuming industrial products (Hamidi et al., 2022). As rice remains a staple food for a large part of the world, it is essential to secure its availability to ensure national stability (Susanto et al., 2021). At the same time, increased productivity, rather than increased harvested area, is the primary contributor to higher production rates. Therefore, optimizing rice productivity in paddy fields presents an opportunity to increase national grain production (Chien et al., 2022). The modernization of agriculture involves a shift from traditional to more advanced methods, including land management, the use of superior seeds, inorganic fertilizers and pesticides, production facilities, and harvest management (Giang, 2022). However, obstacles to increasing food availability remain, such as limited land expansion, water resource degradation, and declining fertility levels in agricultural land (Hamidi et al., 2022).

Over-intensification of agriculture without regard for sustainable agriculture principles, such as high cropping intensity, monoculture, and excessive inorganic fertilizer use, has also led to stagnation in rice productivity growth and instability in production due to pests, diseases, and climate stress (Khomiuk et al., 2020). To ensure sustainable production, appropriate agricultural technology must be applied to maintain the productivity of irrigated land for crop planting (Liu et al., 2020). Also, all developing nations must prioritize sustainable agricultural development in light of increasing tourism development. Likewise, regardless of acknowledging the use of sustainable agricultural technologies to enhance productivity (Hamidi et al., 2022; Giang, 2022; Khomiuk et al., 2020), research lacks evidence regarding empirical testing but the influence of sustainable agricultural technologies on staple foods productivity. It may also challenge the government and farmers (Rokicki et al., 2021). Hence, to address this literature gap, this study aims to describe the implementation of sustainable agricultural technologies, including the system of rice intensification, organic farming, and integrated pest management, specifically for rice farming in a developing nation (Indonesian) context.

Rice is a major agricultural commodity in Indonesia, and efforts to improve its productivity date back to 1968 when the green revolution program was initiated to modernize agriculture through technology-based intensification (Limpo et al., 2022). Indonesia is one of the largest rice producers globally, with rice being a staple food for its population (Ekananda, 2022). According to the data provided by the United States Department of Agriculture (USDA), the total rice production in Indonesia in 2021/2022 is projected to be around 37.5 million metric tons. However, it's important to note that this is a projection, and the actual production can vary based on various factors such as weather, pests, diseases, and other socio-economic factors. Moreover, Indonesia's rice production is concentrated in the western and central parts of the country, particularly on the islands of Java, Bali, and Sumatra. Among these regions, Java is the largest rice-producing island, accounting for most of Indonesia's rice production. Other regions producing significant rice amounts include Sulawesi, Kalimantan, and Papua (Susanto et al., 2021).

However, the program's success in providing food for the growing population came at a high cost to the environment, including soil erosion, greenhouse gas emissions, deforestation, and water contamination, among other issues (Pramananda et al., 2022). As a result, there has been a growing interest in sustainable agricultural technologies to mitigate these impacts and increase rice production in recent years. One such technology is the System of Rice Intensification (SRI), which involves using fewer seeds, transplanting young seedlings, and applying organic fertilizers and weed control methods (Meesala & Rasala, 2022). SRI has shown promising results in increasing rice yield and reducing water usage and greenhouse gas emissions in Indonesia (Arsil et al., 2022). Likewise, organic farming is an agricultural approach that prioritizes environmental sustainability, animal welfare, and human health (Gong et al., 2022). It is used by farmers to intensify rice production in Indonesia (Grimm et al., 2023).

2. AIMS AND OBJECTIVES

Hence, to address this literature gap, the current study aims;

- To examine the influence of sustainable agricultural technologies, including the system of rice intensification, organic farming, and integrated pest management, in enhancing rice productivity.
- To investigate the moderating role of farmers' education to augment the influence of sustainable agricultural technologies (i.e., the system of rice intensification, organic farming, and integrated pest management) on enhanced rice productivity.

3. RESEARCH SIGNIFICANCE

Another sustainable technology is Integrated Pest Management (IPM), which involves using natural predators and non-chemical methods to control pests and diseases (Falkenberg et al., 2022). IPM has been successful in reducing the use of pesticides and increasing rice yield in Indonesia (Rahmawasiah et al., 2022). Overall, the use of sustainable agricultural technologies in rice production in Indonesia has the potential to increase productivity, reduce negative environmental impacts, and improve the livelihoods of farmers (Santoso et al., 2023). However, there is a need for more research, policy support, and technical assistance to encourage their widespread adoption (Sani et al., 2022).

4. STRUCTURE OF REVIEW

4.1 Sustainable Agricultural Technologies

Sustainable agricultural technologies refer to a wide range of tools, methods, and practices designed to promote more environmentally responsible and socially equitable agricultural production systems (Krauss et al., 2022). These technologies aim to improve agricultural productivity while reducing negative impacts on the environment and improving the livelihoods of farmers and communities (Yazdanpanah et al., 2021). Some examples of sustainable agricultural technologies include precision agriculture, agroforestry, conservation agriculture, the system of rice intensification, organic farming, integrated pest management, and water management technologies. These are just a few examples of sustainable agricultural technologies that can help to promote more sustainable and socially responsible agricultural practices (Bhat et al., 2022). By adopting these technologies, farmers can improve their productivity while also protecting the environment and improving the livelihoods of their communities (Arsil et al., 2022). The technologies utilized in this research for sustainable agriculture development in Java, Bali, and Sumatra Province, Indonesia, are those that have been introduced and applied at the farmer level. Hence, the three technologies implemented in the study are the System of Rice Intensification (SRI), organic farming, and integrated pest control management. Besides, the criteria for sustainable agriculture development include environmental feasibility, productivity, economic feasibility, cultural acceptability, and technical feasibility for farmers.

4.2 System of Rice Intensification and Enhance Rice Productivity

SRI is a rice cultivation technique that enhances rice productivity by changing the management of plants, soil, water, and nutrients. It has been proven to increase rice productivity by 50% and, in some places, more than 100%. SRI has been implemented in several districts in Java, Sumatra, Bali, West Nusa Tenggara, and East Nusa Tenggara, mostly promoted by Non-Governmental Organizations (NGOs). In Bali, the SRI method has been used with organic fertilizer and more efficient irrigation water, making better soil, plants, and water management based on environmentally friendly rules (Arsil et al., 2022). The increase in the prices of chemical fertilizers and pesticides and the deterioration of the resource environment due to their continuous use have encouraged farmers in several places to practice the SRI method (Bhat et al., 2022). SRI technology utilizes machines that are manipulable to grow potential rice crops by creating suitable growth conditions. The concept of synergy is applied in SRI, where all the technology components work together to yield results greater than the sum of their individual parts.

Studies have identified several crucial components of SRI, including early transplantation of young seedlings, planting one stem per planting hole, wide planting distances, maintaining moist soil conditions without flooding, and using organic fertilizers and local microorganisms (Meesala & Rasala, 2022). Moreover, SRI is an alternative rice farming system that focuses on maximizing the productivity of rice fields through the optimal management of plants, soil, water, and nutrients. SRI differs from conventional rice farming in several ways, including changes in transplanting, irrigation, and nutrient management practices. SRI promotes the use of younger seedlings with only a few leaves, which are transplanted one at a time with wider spacing between them (Mboyerwa et al., 2022). During planting, the land is kept wet but not flooded, which saves water by 46%. These seedlings are adaptable and less stressed because their roots are short, and planting does not need to be too deep. Farmers prepare for the production of high-quality young seeds from the outset, aiming to quickly grow large seeds in a 50g/m2 nursery without nutrient competition, which are ready for planting at the age of 7-10 days (Shivay et al., 2022). Transplanting these young seedlings reduces shocks and enhances their ability to produce stems and roots during vegetative growth. This allows each plant to have more space and resources, leading to the development of a stronger and more productive root system. SRI also emphasizes intermittent flooding rather than continuous flooding, which can help increase soil aeration and reduce water consumption.

Research has shown that SRI can lead to significant increases in rice productivity. Furthermore, SRI can also contribute to improved soil health, reduced greenhouse gas emissions, and increased resilience to climate change (Shivay et al., 2022). By promoting more sustainable and environmentally friendly farming practices, SRI can help to support the long-term viability of rice farming and enhance food security for communities that depend on rice as a staple crop. In summary, the SRI is an alternative rice farming system that focuses on maximizing productivity through changes in planting, irrigation, and nutrient management practices. SRI has been shown to lead to significant increases in rice yields, as well as reduced environmental impact and improved resilience to climate change. Hence, it is posited that;

H1: There is a positive influence of the system of rice intensification on enhanced rice productivity.

4.3 Organic Farming and Enhance Rice Productivity

Organic farming is based on the principles of agroecology, which emphasizes the interdependence of ecological, social, and economic systems in farming (Aulakh et al., 2022). It aims to produce food in an environmentally friendly, socially responsible, and economically viable way. One of the primary goals of organic farming is to improve soil fertility and biodiversity (Manta et al., 2023). Organic farmers use various practices, including crop rotation, cover cropping, and intercropping, to improve soil health and structure. They also use natural fertilizers, such as compost and animal manure, to build soil fertility and promote the growth of healthy crops (Sani et al., 2022). In addition, organic farmers use natural pest control methods, such as beneficial insects, to manage pests and diseases. It is an agricultural approach that prioritizes environmental sustainability, animal welfare, and human health (Gong et al., 2022).

Additionally, organic farming has been found to have a positive relationship with rice productivity, particularly in the long term (Matsuoka et al., 2022). Organic farming practices, such as using organic fertilizers, cover cropping, crop rotation, and natural pest control methods, can improve soil fertility and enhance the overall health of the farming system (Handayani et al., 2022). Research has shown that organic farming can increase rice yields by up to 50% compared to conventional farming methods in the long term (Tien et al., 2022). This is because organic farming practices enhance soil fertility by increasing soil organic matter, nutrient availability, and soil structure. These factors can improve the growth and development of rice plants, leading to higher yields. In addition, organic farming can also improve the resilience of rice farming systems to environmental stresses, such as drought and flooding (Vergura et al., 2020). Organic farming practices can improve water retention in the soil, reduce erosion, and promote the growth of beneficial microorganisms, which can help rice plants to withstand environmental stresses. Overall, organic farming can enhance rice productivity by improving soil fertility, increasing resilience to environmental stresses, and improving the quality of rice crops (Grimm et al., 2023). This can lead to higher yields and improved food security for farmers and consumers alike. Hence, it is posited that;

H2: There is a positive influence of organic farming on enhanced rice productivity.

4.4 Integrated Pest Management (IPM) and Enhance Rice Productivity

IPM is an approach to pest management that emphasizes using a range of pest control methods to manage pests in an environmentally and economically sustainable way. The goal of IPM is to minimize synthetic pesticides by using a combination of cultural, biological, and chemical control methods (Falkenberg et al., 2022). IPM is based on a thorough understanding of the pest and its life cycle, as well as the ecology of the farming system. This understanding allows farmers to choose the most appropriate pest management strategies based on the specific conditions of their farming system (Desneux et al., 2022). Besides, biological control methods involve the use of natural enemies, such as predators and parasites, to control pest populations. These can include releasing beneficial insects, such as ladybugs or lacewings, into the farming system to feed on pests (Zhang et al., 2022). At the same time, IPM is a flexible approach to pest management that can be adapted to different farming systems and pest pressures. It has been shown to be effective in reducing pest populations and increasing crop yields while minimizing the negative impact on the environment and human health (Rahmawasiah et al., 2022).

IPM can be an effective strategy for managing pests in rice production, leading to improved productivity and reduced environmental impact. Rice is a staple food for millions of people around the world, and pests such as stem borers, leaf folders, and brown planthoppers can cause significant yield losses if left unmanaged (Balié et al., 2021). IPM strategies can help to reduce pest populations and prevent the spread of pests while minimizing the use of synthetic pesticides. IPM for rice production typically involves a combination of cultural, biological, and chemical control methods (Bažok, 2022). Research has shown that IPM strategies can significantly improve rice yields while reducing the use of synthetic pesticides. For example, in one study conducted in Indonesia, IPM strategies for controlling stem borers and leaf folders resulted in a 10-40% increase in rice yields compared to conventional pest management practices (Hajjar et al., 2023). In summary, IPM can be an effective strategy for managing pests in rice production, leading to improved productivity and reduced environmental impact. By using a range of control methods and prioritizing the use of non-chemical approaches, IPM can help to promote sustainable and environmentally responsible rice production. Hence, it is posited that;

H3: There is a positive influence of integrated pest management on enhanced rice productivity.

4.5 Farmers Education as a Moderator

Sustainable agricultural technologies, such as precision agriculture, integrated pest management, the system of rice intensification, and organic farming, have the potential to significantly improve rice productivity (Hajjar et al., 2023). However, the impact of these technologies on rice productivity may be influenced by a variety of factors, including farmers' education level. Thus, farmers' education can serve as a moderator between the association of sustainable agricultural technologies and rice productivity, influencing the adoption and effectiveness of these technologies. Farmers' education can influence the adoption of sustainable agricultural technologies by improving farmers' knowledge and understanding of these technologies (Khan et al., 2022). Farmers who are more educated may be more likely to adopt sustainable agricultural technologies as they have a better understanding of the potential benefits of these technologies. Additionally, education can help farmers to understand the importance of sustainable agricultural practices and the potential long-term benefits of adopting these practices (Luo et al., 2022). This can help to overcome barriers to adoption, such as lack of knowledge or awareness.

In addition to influencing adoption, farmers' education can also influence the effectiveness of sustainable agricultural technologies. Farmers who are more educated may be better equipped to implement these technologies effectively by understanding how to use tools such as sensors or mapping systems, for example (Hanson et al., 2022). Additionally, education can help farmers to better understand the complex interactions between different aspects of agricultural production, such as soil health, nutrient management, and pest control (Diana et al., 2022). This can help to optimize the use of sustainable agricultural technologies and improve their impact on rice productivity. Hence, farmers' education can serve as an important moderator between the association of sustainable agricultural technologies and rice productivity. Education can influence the adoption and effectiveness of sustainable agricultural technologies by improving farmers' knowledge and understanding of these technologies. However, the relationship between farmers' education and sustainable agricultural technologies is complex and influenced by a variety of other factors. Hence, it is posited that;

H4: Farmers' education moderates the association of sustainable agricultural technologies with enhanced rice productivity such that the relationship is stronger in the case of higher values of farmers' education.

4.6 Theoretical Framework

The purposive literature review, logical arguments, and sustainable technology intrusion in agriculture provide the base for the current study's theoretical framework, as presented in figure 1.

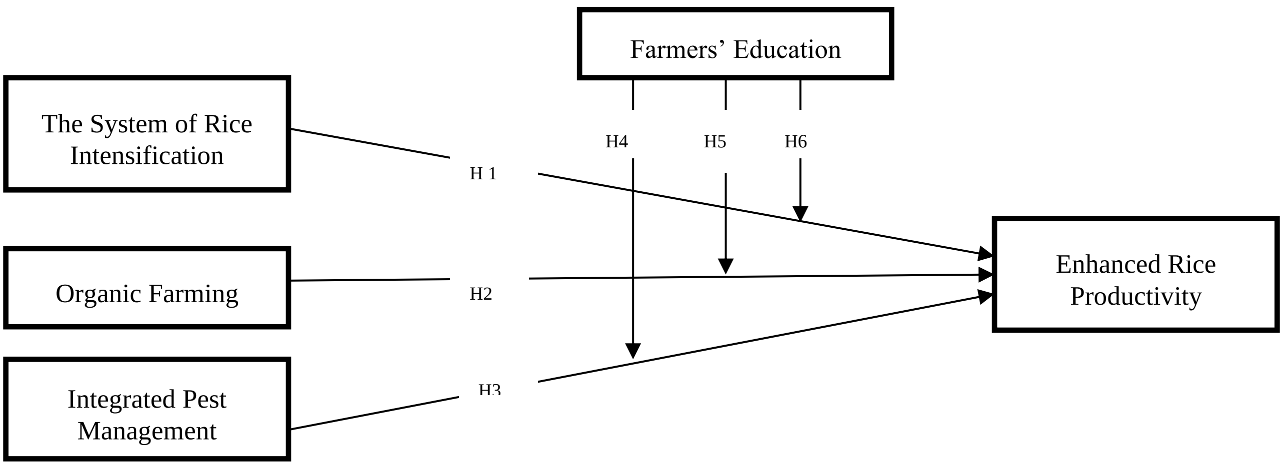


Figure 1: Theoretical Framework of the Study

5. RESEARCH METHOD

When conducting a survey using convenience sampling to collect data from farmers in South Sulawesi provinces of Indonesia for measuring the association of sustainable agricultural technologies with rice productivity, we took the following several steps: Clearly defined the research question and objectives of the survey, such as "What is the association between the use of sustainable agricultural technologies and rice productivity among farmers in Indonesia?" The target population of the survey includes rice farmers in Indonesia. For extracting the sample, we obtained a list of potential participants from local agricultural extension services, farmer groups or cooperatives. After defining the population and deciding on sample size and technique, we developed a survey instrument that includes questions related to the use of sustainable agricultural technologies, rice productivity, and demographic information of the farmers. We also ensured that the questions were clear and relevant to the research objectives. We approached the rice farmers who were requested to participate in the survey. They were also informed about the anonymity of their response. We also explained the purpose of the survey and the importance of their participation. Those who showed a willingness to participate in the survey were handed over the study questionnaire.

The big question comprised three parts, including the demographic characteristics of the farmers. The second part consisted of documentation for taking formal consent from the projected participants. Finally, the third part included the study items consisting of six items each for the system of rice intensification, organic farming, and farmers' education. Besides, five items each were adapted from the existing studies for measuring farmers' education and integrated pest management. This whole data collection procedure in early of 2022, we were able to collect 567 responses after receiving all the questionnaires, a-pretest the survey instrument with a small group of farmers to ensure that the questions are understandable and relevant to the target population. We analyze the data using appropriate statistical methods to determine the association between the use of sustainable agricultural technologies and rice productivity.

5.1 Pre-Test

When conducting a survey using convenience sampling, it is important to acknowledge the limitations of this sampling method, such as potential bias in the sample selection and the inability to generalize the findings to the broader population in the sample selection and the inability to generalize the findings to the broader population (Gupta et al., 2021). Convenience sampling is a non-probability sampling technique that can lead to potential bias in sample selection (Etikan et al., 2016). Here are some ways in which we adapted to avoid bias in the sample selection during convenience sampling: First, we defined the target population clearly and precisely before selecting a convenience sample. This helped us identify the characteristics of the population and ensure that the sample was representative. We also approached the potential participants randomly rather than relying on self-selection. Finally, we validated the sample by comparing the characteristics of the sample to those of the target population. There were no significant differences. Hence, the sample is regarded as a true representative.

5.2 Demographic Characteristics of Farmers

The participants' demographic characteristics demonstrate that the respondents (81.2%) were male and 18.8%) were female, indicating a large difference in both genders' distribution. The mean age of the participants was 41 years, with a standard deviation of 12. The participants' education level distribution indicated that the majority of the respondents were senior high school or below (83.2%), and undergraduates (16.8%).

6. RESULTS

In the following study stage, the impact of participants' demographic characteristics on the dependent variables was evaluated. It was found that the participants' age had a significant effect on their perceptions of enhanced rice productivity. Therefore, it was controlled before conducting the regression analysis. To establish the reliability and validity of the study measures, the researchers used "Cronbach's α (CA)" and "composite reliability (CR)" values (Henseler et al., 2015; Noor et al., 2022). The findings indicated that all CR and CA values were within the recommended range of above 0.70, indicating the measures' well-established validity and reliability (see Table 1). Additionally, the "Average Variance Extracted (AVE)" values were above the suggested threshold of 0.50 based on the study variables' factor loadings above 0.70 (see Figure 2). Therefore, the results supported the "convergent validity" of the study constructs (Hair et al., 2017). To ensure the discriminant validity of the constructs, researchers have suggested evaluating the Heterotrait-Monotrait (HTMT) ratio (Henseler et al., 2015). As per the results presented in Table 2, the HTMT ratio values were below 0.5.980, indicating no problem of multicollinearity among the study variables (Hair et al., 2017).

6.1 Hypothesis Testing

To test the hypothesis, the authors calculated the "Coefficient of Determination (R2)" for the influence of sustainable agricultural technologies, including the system of rice intensification, organic farming, and integrated pest management, on enhanced rice productivity. The R2 value for enhanced rice productivity was 0.759, indicating a variance of 75.9% in rice productivity based on sustainable agricultural technologies and their interaction with farmers' education.

6.2 Direct Hypotheses

Results show that sustainable agricultural technologies, including the system of rice intensification (ß = 0.360***, t = 6.455), organic farming (ß = 0.405***, t =7.123), and integrated pest management (ß = 4.005**, t =), on enhanced rice productivity. Hence, proving all direct hypotheses, i.e., H1, H2, and H3.

6.3 Moderating Hypotheses

To assess how farmers' education affects the relationship between sustainable agricultural technologies and improved rice productivity, interaction terms (FE*SRI, FE*OF, and FE*IPM) were created using a product indicator method in SmartPLS v. 4.0. The findings indicated that farmers' education plays a moderating role, and the results also revealed that FE had a significant interaction with SRI (ß = 0.218**, t =3.768), OF (ß = 0.204**, t =3.689), and IPM (ß = 0.126**, t =3.026), which increased the ERP. The R2 value for the main influence of all independent constructs on rice productivity was 0.602. However, the inclusion of the interaction terms led to an increase in the R2 value to 0.759, demonstrating a 15.7% improvement in the explanatory power of enhanced rice productivity.

Table 1: Factor Loadings, Reliability, and Validity

Constructs	Factor Loadings					AVE	CR	CA
	1	2	3	4	5			
System of Rice Intensification						0.590	0.896	0.780
SRI1	0.841							
SRI2	0.739							
SRI3	0.744							
SRI4	0.734							
SRI5	0.768							
SRI6	0.777							
Organic Farming								
OF1		0.751				0.555	0.882	0.764
OF2		0.739						
OF3		0.717						
OF4		0.796						
OF5		0.748						
OF6		0.714						
Integrated Pest Management						0.555	0.862	0.745
IPM1			0.784					
IPM2			0.737					
IPM3			0.715					
IPM4			0.740					
IPM5			0.747					
Enhanced Rice Productivity						0.584	0.894	0.782
ERP1				0.798				
ERP2				0.772				
ERP3				0.732				
ERP4				0.715				
ERP5				0.793				
ERP6				0.770				
Farmers Education						0.553	0.861	0.771
FE1					0.796			
FE2					0.795			
FE3					0.703			
FE4					0.708			
FE5					0.711			

"Note: CR, composite reliability; AVE, average variance extracted; CA= Cronbach's α."

Table 2: Heterotrait-Monotrait Ratio

Constructs	Mean	STD	1	2	3	4	5
System of Rice Intensification	3.88	1.11	**0.768**				
Organic Farming	3.96	1.05	0.406	**0.744**			
Integrated Pest Management	4.04	0.98	0.540	0.497	**0.744**		
Enhanced Rice Productivity	4.18	0.92	0.409	0.454	0.533	**0.764**	
Farmers Education	4.10	0.95	0.611	0.600	0.452	0.510	**0.743**

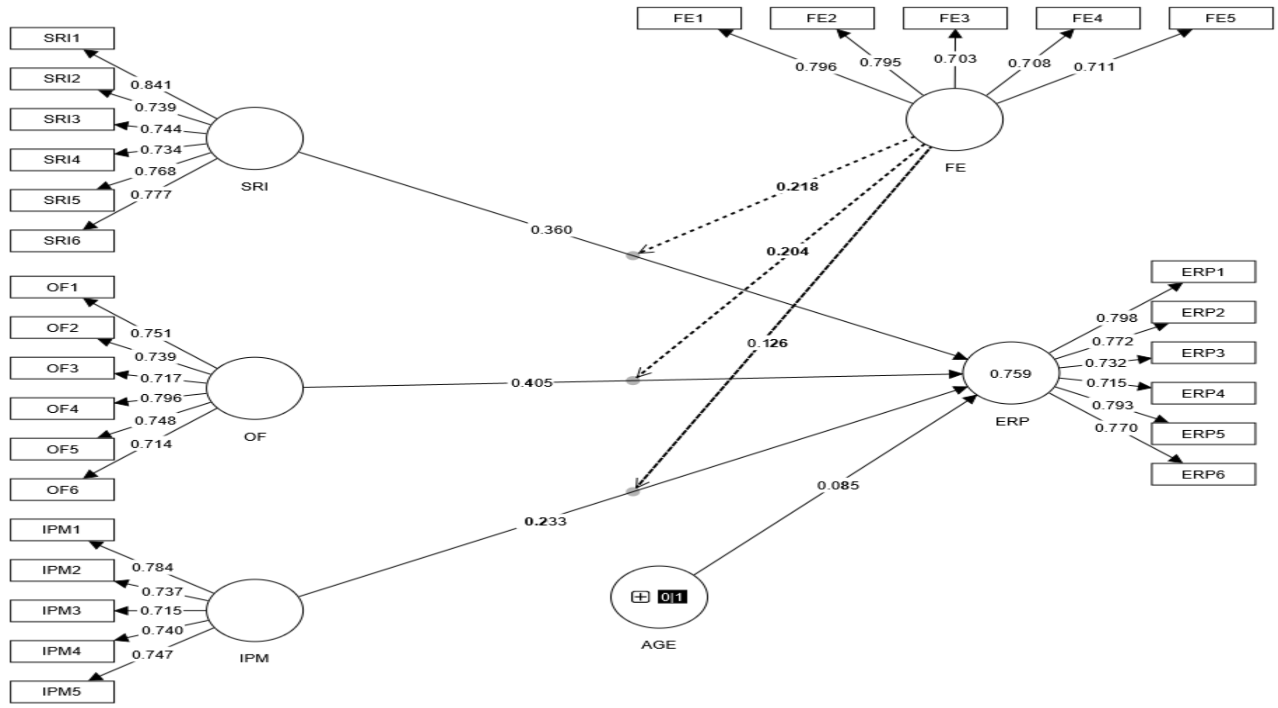
"Note: The square roots of AVEs of the constructs are shown in bold in diagonal."

Figure 3 a, b, and c demonstrates that the slope of the line representing the correlation between sustainable agricultural technologies and increased rice productivity was more pronounced for farmers with higher levels of education as opposed to those with lower levels of education. This further reveals that when farmers are highly qualified and well trained, they are in a better position to apply sustainable agricultural technologies to grow rice and other crops resulting in high productivity. These results also support this research's hypotheses 4, 5, and 6.

7. FINDINGS

7.1 Findings of the Study

The association of sustainable agricultural technologies with rice productivity is an important topic that has gained increasing attention in recent years. Sustainable agricultural technologies such as the System of Rice Intensification (SRI), Organic Farming, and Integrated Pest Management (IPM) have been shown to improve rice productivity while also reducing environmental impacts and promoting social and economic sustainability. SRI is a set of agricultural practices that focus on improving the growth and productivity of rice plants (Arsil et al., 2022). In the current study, SRI has been shown to significantly increase rice productivity while reducing water consumption and greenhouse gas emissions. This further reflects that SRI can improve soil health and biodiversity, leading to more sustainable and resilient agricultural systems (Meesala & Rasala, 2022).



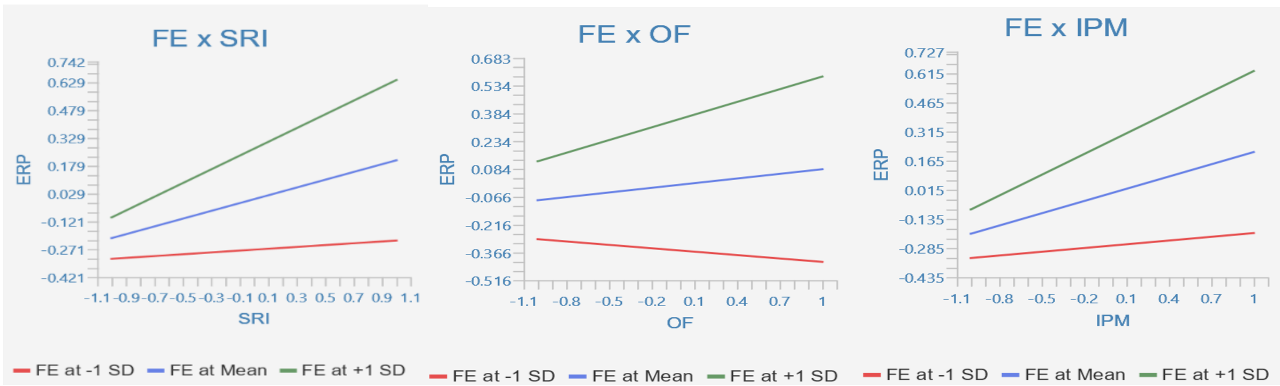


Figure 3: a, b, and c: Interaction plot for moderating effects of technical support.

Table 3: Hypothesis Testing Results

Hypothesized relationships		Std. Beta	t-value	p-value	Supported
H1	SRI→ERP	0.360	6.455	0.000	Yes
H2	OF→ERP	0.405	7.123	0.000	Yes
H3	IPM→ERP	0.233	4.005	0.000	Yes
H4	SRI*FE→ERP	0.218	3.768	0.003	Yes
H5	OF*FE→ERP	0.204	3.679	0.009	Yes
H6	IPM*FE→ERP	0.126	3.020	0.006	Yes

Where: SRI= System of Rice Intensification; OF= Organic Farming; IPM=Integrated Pest Management; ERP=Enhanced Rice Productivity; FE=Farmers Education

Organic farming is another sustainable agricultural technology associated with increased rice productivity. Organic farming practices focus on using natural resources and minimizing the use of synthetic inputs such as fertilizers and pesticides (Krauss et al., 2022). In the current study, organic farming has been shown to improve soil health, biodiversity, and water retention, leading to increased rice productivity. IPM is a third sustainable agricultural technology that has been associated with increased rice productivity. IPM is an approach to pest management that focuses on minimizing the use of synthetic pesticides and instead uses a combination of cultural, biological, and chemical control methods to manage pests (Matsuoka et al., 2022). IPM has been shown to significantly reduce the use of pesticides while maintaining or even increasing rice productivity. IPM also promotes environmental sustainability by reducing pesticide residues and improving the health of the ecosystem (Tien et al., 2022).

Simultaneously results also revealed the moderating role of farmers' education between the association of sustainable agricultural technologies and enhanced rice productivity. Results specifically revealed the higher values of the interactive effect of SRI and farmers' education on enhanced rice productivity, followed by the IBM and organic fall forming. These results depict that the farmers need to be knowledgeable and educated to successfully implement sustainable agricultural technologies to extract the maximum benefits and enhance the country's socioeconomic development.

8. CONCLUSION

In conclusion, sustainable agricultural technologies such as SRI, Organic Farming, and IPM have been associated with increased rice productivity while also promoting environmental, social, and economic sustainability. These technologies can play an important role in ensuring food security and promoting sustainable agriculture in rice-producing regions. However, the adoption and implementation of these technologies require adequate farmer education to reach a large number of farmers. Therefore, it is important for policymakers, researchers, and other stakeholders to prioritize the development and dissemination of these technologies to promote sustainable agriculture and improve rice productivity.

9. CONTRIBUTIONS AND IMPLICATIONS

9.1 Theoretical Implications

The association of sustainable agricultural technologies with rice productivity has several theoretical implications that can inform agricultural research and practice. Some of these implications include the fact that sustainable agricultural technologies are complex and require a system thinking approach that considers the interactions and feedback among different components of the agricultural system. Adopting and implementing sustainable agricultural technologies require a holistic understanding of the agricultural system, including the soil, water, crops, pests, and diseases. This requires interdisciplinary research that integrates knowledge from different fields, such as agronomy, ecology, and social sciences. Moreover, sustainable agricultural technologies are not only about improving crop productivity but also about ensuring that agriculture is socially, economically, and environmentally sustainable (Matsuoka et al., 2022). The adoption and implementation of sustainable agricultural technologies require a socio-ecological approach that considers agriculture's social, economic, and environmental dimensions. This requires research that considers the socio-economic context of the farmers, including their access to resources such as land, water, and capital, and the impact of agricultural practices on the environment and society (Krauss et al., 2022).

Likewise, agricultural technologies are constantly evolving, and their effectiveness and sustainability depend on the ability of farmers to innovate and adapt to changing conditions. Additionally, the adoption and implementation of sustainable agricultural technologies require a dynamic and adaptive approach that takes into account the changing needs and conditions of the farmers. This requires research that promotes innovation and adaptation, including the development of new technologies, the improvement of existing ones, and the adoption of best practices. In conclusion, the association of sustainable agricultural technologies with rice productivity has several theoretical implications that can inform agricultural research and practice. These include the importance of systems thinking, the need for a socio-ecological approach, the importance of innovation and adaptation, the need for a participatory approach, and the importance of scaling up. Agricultural research and practice should prioritize these implications to promote sustainable agriculture and improve rice productivity.

9.2 Practical Implications

The association of sustainable agricultural technologies with rice productivity has several practical implications that can inform agricultural development initiatives. Some of these implications include the need for education and training programs. As discussed earlier, farmers' education and training are critical for effectively adopting and implementing sustainable agricultural technologies. Agricultural development initiatives should, therefore, prioritize the design and implementation of education and training programs tailored to the farmers' needs and context. These programs should provide farmers with the necessary knowledge and skills to effectively use sustainable agricultural technologies to improve rice productivity. Sustainable agricultural technologies are complex and require collaboration among different stakeholders, including farmers, researchers, and policymakers. Agricultural development initiatives should, therefore, promote communication and collaboration among these stakeholders to facilitate knowledge exchange, adoption of best practices, and innovation. This can be achieved through platforms such as farmer field schools, extension services, and research networks. At the same time, adopting and implementing sustainable agricultural technologies require an enabling policy environment that supports innovation, encourages investment and promotes the dissemination of knowledge and best practices. Agricultural development initiatives should, therefore, prioritize advocacy and engagement with policymakers to create a supportive policy environment that promotes sustainable agriculture.

Likewise, sustainable agricultural technologies are context-specific, and what works in one context may not work in another. Agricultural development initiatives should, therefore, prioritize context-specific approaches that take into account the local environment, culture, and socio-economic conditions of the farmers. This can help to ensure that sustainable agricultural technologies are appropriate, effective, and sustainable. Sustainable agricultural technologies are constantly evolving, and agricultural development initiatives should prioritize research and innovation to identify new technologies, improve existing ones, and promote continuous learning.

This can help to ensure that sustainable agricultural technologies remain relevant, effective, and sustainable in the face of emerging challenges such as climate change, pest and disease outbreaks, and changing market conditions. Hence, it can be stated that the association of sustainable agricultural technologies with rice productivity has several practical implications that can inform agricultural development initiatives. These include the need for education and training programs, the importance of communication and collaboration, the need for an enabling policy environment, the importance of context-specific approaches, and the need for research and innovation. Agricultural development initiatives should prioritize these implications to promote sustainable agriculture and improve rice productivity.

10. FUTURE RESEARCH WORK

To fully understand the relationship between farmers' education and sustainable agricultural technologies, it is important to consider the broader context in which these technologies are being adopted and implemented. In this regard, government policies, market incentives, and access to resources such as credit or land can all influence the adoption and effectiveness of sustainable agricultural technologies and can be empirically tested concerning rice production. Therefore, it is important to take a holistic approach to understand the factors that influence the adoption and effectiveness of these technologies. Additionally, the current study investigates the influence of three sustainable agricultural technologies to investigate rice productivity. In contrast, studies can also consider other constructs, including precision agriculture, as predictors of rice productivity.

11. LIMITATIONS

Despite several procedural and theoretical strengths, the current study also has some limitations. For instance, the relationship between farmers' education and sustainable agricultural technologies may be complex and influenced by factors other than the interactive effect. Likewise, access to information and training programs may be limited in some areas, which can limit the impact of education on the adoption and effectiveness of sustainable agricultural technologies. Additionally, cultural and social factors may also shape farmers' attitudes and beliefs about sustainable agricultural practices. For example, farmers may be more likely to adopt sustainable agricultural practices if they are perceived as socially desirable or if they align with traditional farming practices.

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