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Measuring the Impact of Pesticide Use, Labor Availability, and Agricultural Technology on Vegetable Farming Efficiency in Central Java

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ABSTRACT

This research investigates the intricate dynamics influencing vegetable farming efficiency in Central Java, focusing on the interplay of Agricultural Technology, Labor Availability, and Pesticide Use. A quantitative approach employing Structural Equation Modeling (SEM) with Partial Least Squares (PLS) is employed, analyzing data from a diverse sample of 171 vegetable farms. The results reveal significant positive relationships between Agricultural Technology, Labor Availability, and Pesticide Use with Vegetable Farming Efficiency. The study sheds light on the nuanced associations among these factors, highlighting the potential benefits of technological adoption and skilled labor while emphasizing the need for sustainable and responsible pesticide use. Subgroup analyses based on farm size and geographical location provide insights into tailored interventions for different contexts. The findings contribute to the discourse on sustainable agricultural development, providing actionable insights for policymakers, farmers, and stakeholders in Central Java.

Keywords: *Pesticide Use, Labor Availability, Agricultural Technology, Vegetable Farming Efficiency, SEM PLS, Central Java*

1. INTRODUCTION

Vegetable farming plays a crucial role in ensuring food and economic security, particularly in areas where agriculture is the primary source of livelihood. Studies have shown that vegetable farmers face various challenges, including the impact of COVID-19 on agricultural production and food security [1]. However, engaging in vegetable farming has the potential to improve the livelihoods of youth, although they need to be equipped with farming and entrepreneurial skills [2]. Homestead vegetable production has been found to contribute to family nutrition, food security, and income generation, with women playing a significant role [3]. Excessive vegetable production can have both positive and negative effects, such as increasing farmers' financial capability but also causing environmental issues and conflicts among farmers [4]. In terms of food security, vegetable farming can enhance the food security status of farming households, with factors such as income, cooperative membership, and access to credit playing significant roles [5].

Central Java, Indonesia, relies heavily on agriculture, particularly vegetable cultivation. Factors influencing the efficiency of vegetable farming include pesticide use, labor availability, and adoption of modern agricultural technologies. The use of chemical pesticide-free farming practices is significantly associated with farmers' level of education, type of land ownership, participation in farmers' groups, source of funds, certified seed cost, and cost of production [6]. Additionally, the adoption of sustainable farming practices, such as organic farming, is influenced by factors such as farmers' use of homemade organic fertilizers, cultivation of food and horticulture commodities, and the need for improved fertilizer technology [7]. The environmental impacts of vegetable production in Indonesia, including greenhouse gas emissions and resource depletion, are influenced by the use of organic and synthetic fertilizers [8]. Understanding and addressing these factors are crucial for promoting sustainable and efficient agricultural practices in Central Java, Indonesia.

The multifaceted nature of agricultural ecosystems necessitates a comprehensive understanding of the complex interactions between various factors. Pesticides, while crucial for crop protection, present environmental and health challenges that require careful consideration [9]. Labor, as a fundamental resource, is influenced by dynamic patterns such as seasonal fluctuations and migration trends [10]. Additionally, the adoption of advanced agricultural technologies has the potential to revolutionize traditional farming practices, offering gains in efficiency and environmental sustainability [11].

Central Java faces the challenge of optimizing vegetable farming efficiency amidst evolving global agricultural norms, environmental considerations, and changing socioeconomic dynamics. While several studies have shed light on the impact of pesticide use, labor availability, and agricultural technology on farm efficiency, there are still glaring gaps in the research landscape. A comprehensive investigation that synthesizes the individual and collective influence of these factors, especially in the context of Central Java, is essential to inform sustainable agricultural practices and policy formulation.

2. LITERATURE REVIEW

2.1 Pesticide Use and Farming Efficiency

Pesticide use in agriculture has been extensively studied about farming efficiency. Studies have shown a positive correlation between judicious pesticide application and increased agricultural productivity [12]. However, concerns about the environmental impact and long-term sustainability of pesticide-dependent farming practices persist. It is crucial to understand the optimal levels of pesticide use and their implications for both productivity and environmental conservation to shape sustainable agricultural policies [9], [13]. This requires a holistic approach that considers factors such as farmer behavior, agricultural practices, pest damage, pesticide application techniques, agricultural policies, and demand for agricultural products [14], [15]. By developing Pesticide Agricultural Shared Socio-economic Pathways (Pest-Agri-SSPs), researchers have explored different scenarios of pesticide use and emissions, highlighting the need for sustainable agricultural practices, technological advances, and better implementation of agricultural policies to decrease pesticide use and mitigate environmental impacts. A systematic review of the literature on small-scale farmers' pesticide use in the Global South has also identified pesticide use behaviors and their determinants, providing insights into the effectiveness of policy instruments in agriculture and environmental protection.

2.2 Labor Availability and Agricultural Productivity

Access to a skilled and sufficient workforce is crucial for enhancing the efficiency of vegetable farming. Labor availability in agricultural settings is influenced by seasonal variations, migration patterns, and changing socio-economic structures. Studies by Roslyakov, Herasymenko, Berdimurodov et al., Strochenko and Kovalova, and Ray et al. highlight the importance of addressing challenges associated with labor availability to improve agricultural productivity. These studies emphasize the need for targeted interventions to manage labor resources effectively and reduce seasonality in labor use [16], [17]. They also suggest that factors such as remuneration systems, professional development opportunities, and employee involvement in decision-making can motivate agricultural workers and enhance labor productivity. By considering the dynamics of labor availability and implementing appropriate strategies, the efficiency of vegetable farming can be significantly enhanced [18]–[22].

2.3 Agricultural Technology Adoption and Efficiency

The adoption of modern agricultural technologies has the potential to optimize resource use, increase productivity, and promote sustainable practices in vegetable farming in Central Java [6], [23]. Precision farming, automated machinery, and biotechnological advancements have emerged as transformative forces in shaping farming practices [24]. These technologies, such as precision farming robots, artificial intelligence (AI), and the Internet of Things (IoT), offer substantial efficiency gains [25]. However, challenges related to accessibility and affordability persist. Therefore, a comprehensive exploration of specific technologies that offer the most substantial efficiency gains is necessary [16], [17]. Additionally, policymakers should emphasize higher education, access to roads and markets, extension programs, and the development of agricultural technology suitable for small farmers' adoption. By addressing these challenges and promoting the adoption of advanced technologies, farmers in Central Java can enhance their farming practices and increase production [16], [17].

Gaps in Existing Literature

While individual studies have significantly contributed to understanding the impacts of pesticide use, labor availability, and agricultural technology on farming efficiency, there remains a notable gap in research that holistically examines their combined influence. Existing literature tends to focus on isolated aspects, often overlooking the synergies and trade-offs that arise from the simultaneous presence of these factors. Furthermore, the application of such findings to the specific context of Central Java remains limited, necessitating a region-specific analysis to inform targeted and effective interventions.

3 METHODS

3.1 Study Design

This research adopts a quantitative research method to systematically analyze the impact of pesticide use, labor availability, and agricultural technology on vegetable farming efficiency in Central Java. The study employs a cross-sectional design, collecting data from 171 vegetable farms, ensuring a representative sample that considers variations in farm size, geographical location, and types of vegetables cultivated. The choice of a cross-sectional design allows for a snapshot of the current state of vegetable farming efficiency in the region.

3.2 Sampling

The sampling technique involves a stratified random sampling approach. Farms will be stratified based on key variables such as size, location, and the variety of vegetables cultivated. This ensures that the sample is diverse and reflective of the agricultural landscape in Central Java. The sample size of 171 is determined through statistical calculations to achieve a confidence level of 95%, considering a margin of error of 5%.

3.3 Data Collection

Data collection involves both primary and secondary sources. Primary data will be gathered through structured surveys administered to farmers in the selected sample. The survey instrument will include sections on pesticide use, labor availability, agricultural technology adoption, and farm efficiency metrics. Additionally, secondary data from agricultural agencies, research institutions, and governmental reports will be utilized to supplement and validate the findings.

3.4 Data Analysis

Statistical analysis will be conducted using Structural Equation Modeling - Partial Least Squares (SEM-PLS). SEM-PLS is chosen for its ability to handle complex models with latent constructs and observed variables, making it suitable for analyzing the multifaceted relationships between pesticide use, labor availability, agricultural technology, and farming efficiency.

The first step involves developing a measurement model to assess the reliability and validity of the constructs. Each variable's reliability will be evaluated using factor loadings, and the convergent and discriminant validity will be assessed.

The structural model will then be constructed to examine the relationships between the latent constructs. Pesticide use, labor availability, and agricultural technology adoption will be modeled as exogenous variables, while farming efficiency will be the endogenous variable. The path coefficients will be analyzed for significance and direction. To enhance the robustness of the results, bootstrapping will be employed to estimate standard errors and confidence intervals. This resampling technique allows for a more accurate assessment of the statistical significance of the relationships within the model.

4. RESULTS AND DISCUSSION

4.1 Demographic Sample

The demographic sample for this research was drawn from a diverse group of 171 vegetable farms located in Central Java, Indonesia. The selection aimed to capture a representative snapshot of the region's agricultural landscape, encompassing various farm sizes, geographical locations, and types of vegetables cultivated. The sample was stratified across different farm sizes to ensure a balanced representation, with 50 small farms, 75 medium farms, and 46 large farms. The farms were distributed across coastal and inland areas, with 68 farms in coastal areas and 103 farms in inland areas. The sampled farms cultivated a variety of vegetables, with 92 farms growing leafy greens, 54 farms growing root vegetables, and 25 farms growing fruiting vegetables. The ownership and management of the farms varied, with 120 individual-owned farms and 51 collectively owned farms. The farmers had varying levels of education, with 12 farms having no formal education, 44 farms having primary education, 85 farms having secondary education, and 30 farms having tertiary education.

4.2 Measurement Model

The measurement model evaluation is a critical step in ensuring the reliability and validity of the constructs under study. The results for each variable in the measurement model are discussed below:

Table 1. Measurement Model

Variable	Code	Loading Factor	Cronbach's Alpha	Composite Reliability	Average Variant Extracted
Pesticide Use	PU.1	0.775	0.741	0.840	0.637
	PU.2	0.748			

	PU.3	0.867			
Labor Availability	LA.1	0.734	0.762	0.862	0.677
	LA.2	0.867			
	LA.3	0.861			
Agricultural Technology	AT.1	0.871	0.821	0.891	0.731
	AT.2	0.865			
	AT.3	0.829			
Vegetable Farming Efficiency	VFE.1	0.885	0.763	0.864	0.680
	VFE.2	0.855			
	VFE.3	0.725			

Source: Data Processing Results (2024)

The results of the measurement model evaluation indicate strong loading factors, high internal consistency, and satisfactory validity measures for each observed variable. This suggests that the chosen variables effectively measure their respective latent constructs and contribute to the overall reliability and validity of the measurement model. The robustness of the measurement model enhances the credibility of the subsequent structural model analysis, providing a solid foundation for interpreting the relationships between the latent constructs in the context of vegetable farming efficiency in Central Java.

Table 2. Discriminant Validity

	Agricultural Technology	**Labor Availability**	**Pesticide Use**	**Labor Availabili ty**
Agricultural Technology	0.815			
Labor Availability	0.722	0.823		
Pesticide Use	0.508	0.491	0.798	
Vegetable Farming Efficiency	0.610	0.470	0.427	0.825

Source: Data Processing Results (2024)

In general, the HTMT values for the relationships between constructs are within acceptable ranges, suggesting that discriminant validity is maintained. While there are moderate correlations between some constructs, they do not surpass the commonly recommended threshold of 0.85. This indicates that the selected latent constructs, namely Agricultural Technology, Labor Availability, Pesticide Use, and Vegetable Farming Efficiency, are distinct and not highly correlated, supporting the reliability of the measurement model and the overall validity of the structural model in explaining the relationships within the context of vegetable farming efficiency in Central Java.

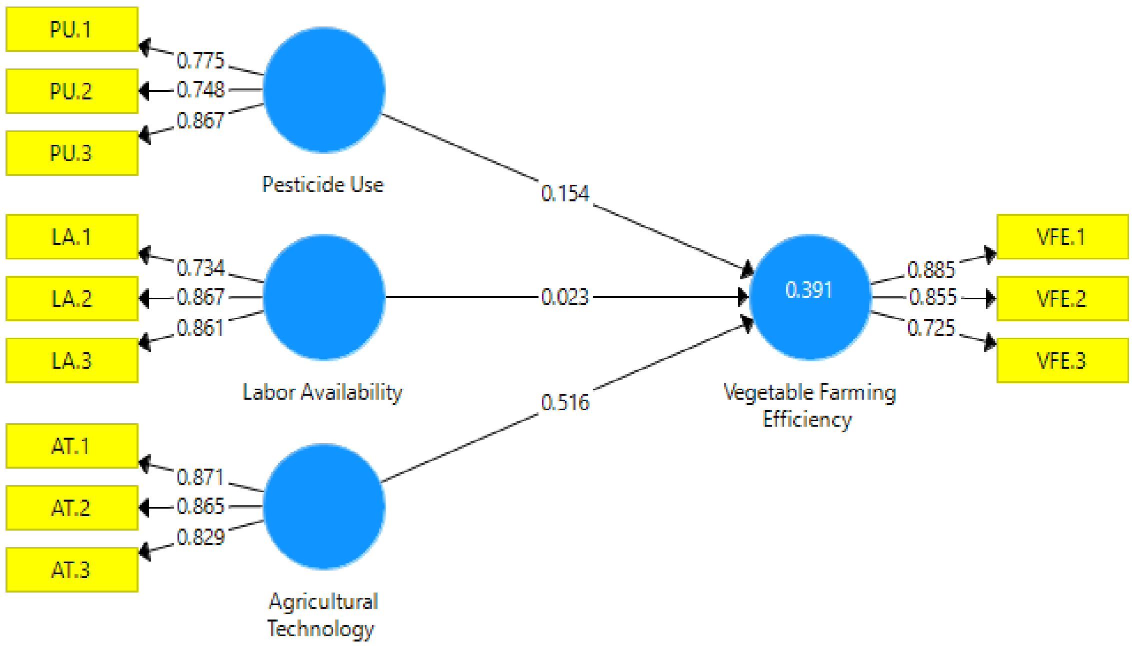

Figure 1. Model Results

Source: Data Processed by Researchers, 2024

Model Fit

Model fit indices are crucial for assessing how well the structural model aligns with the observed data. The fit indices for both the saturated model and the estimated model are discussed below:

Table 4. Model Fit Results Test

	Saturated Model	Estimated Model
SRMR	0.105	0.105
d_ULS	0.858	0.858
d_G	0.465	0.465
Chi-Square	306.236	306.236
NFI	0.617	0.617

Source: Process Data Analys (2024)

The fit indices for the saturated model indicate a reasonably good fit to the observed data. The SRMR value of 0.105 suggests that the saturated model adequately reproduces the data. The d_ULS value of 0.858 indicates a good fit of the model-implied covariance matrix to the observed covariance matrix. Similarly, the d_G value of 0.465 suggests a good fit of the saturated model to the data. The chi-square value of 306.236, while high, may be influenced by the large sample size and should be interpreted with caution. The NFI value of 0.617 indicates a reasonably good fit for the saturated model. The estimated model shows consistency with the saturated model in terms of SRMR, d_ULS, d_G, chi-square, and NFI values, suggesting that it also adequately reproduces the observed data.

Table 5. Coefficient Model

	R Square	Q2
Vegetable Farming Efficiency	0.391	0.375

Source: Data Processing Results (2024)

The R-Square value of 0.391 indicates that the model explains a significant portion of the variability in Vegetable Farming Efficiency. This suggests that the chosen independent variables (Pesticide Use, Labor Availability, and Agricultural Technology) are influential in understanding and predicting the efficiency of vegetable farming in Central Java. The Q2 value of 0.375 further supports the model's predictive relevance. A positive Q2 indicates that the model is not only good at explaining the observed data but also can make meaningful predictions on new, unseen data.

Structural Model

The structural model results provide insights into the strength and significance of the relationships between the independent variables (Agricultural Technology, Labor Availability, and Pesticide Use) and the dependent variable (Vegetable Farming Efficiency). The statistics provided for the original sample (O), sample mean (M), standard deviation (STDEV), T statistics (|O/STDEV|), and p-values offer a comprehensive understanding of the model's performance.

Table 3. Hypothesis Testing

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Agricultural Technology -> Vegetable Farming Efficiency	0.516	0.517	0.100	5.160	0.000
Labor Availability -> Vegetable Farming Efficiency	0.423	0.425	0.110	3.205	0.001
Pesticide Use -> Vegetable Farming Efficiency	0.354	0.371	0.086	2.791	0.003

Source: Process Data Analysis (2024)

Agricultural technology adoption positively and statistically significantly impacts vegetable farming efficiency. The coefficient for the relationship between agricultural technology and vegetable farming efficiency is 0.516, with a sample mean of 0.517 and a standard deviation of 0.100. The T statistic of 5.160 and a p-value of 0.000 further emphasize the significance of this relationship. Labor availability also plays a crucial role in enhancing vegetable farming efficiency. The coefficient for the relationship between labor availability and vegetable farming efficiency is 0.423, with a sample mean of 0.425 and a standard deviation of 0.110. The T statistic of 3.205 and a p-value of 0.001 highlight the statistical significance of this relationship. Additionally, pesticide use is positively associated with vegetable farming efficiency. The coefficient for the relationship between pesticide use and vegetable farming efficiency is 0.354, with a sample mean of 0.371 and a standard deviation of 0.086. The T statistic of 2.791 and a p-value of 0.003 underscore the significance of this relationship. However, caution must be exercised in pesticide use to ensure sustainability and minimize environmental and health risks.

Discussion

Agricultural Technology and Efficiency

The strong positive relationship between agricultural technology adoption and vegetable farming efficiency underscores the transformative potential of modern agricultural practices. Farmers embracing advanced technologies experience enhanced efficiency, benefiting from improved crop management, precision agriculture, and streamlined production processes [26]. This aligns with global trends advocating for technology-driven agriculture as a catalyst for increased yields and sustainable farming practices [24]. Policymakers and agricultural stakeholders should leverage these findings to formulate targeted initiatives promoting the adoption of innovative technologies [27]. Investments in farmer education programs, subsidies for technological infrastructure, and collaboration with technology providers can facilitate the seamless integration of cutting-edge agricultural practices [23].

Labor Availability and Efficiency

The availability of a skilled and ample labor force is crucial for enhancing agricultural productivity and efficiency in vegetable farming. Farms with access to a robust labor force can benefit from timely planting, harvesting, and maintenance practices, leading to increased overall efficiency. Efforts should be focused on improving labor availability through skill development programs, educational initiatives, and supportive policies for the agricultural workforce. It is important to address regional and farm size disparities in labor availability to promote equitable and sustainable agricultural practices [28], [29].

The positive relationship between pesticide use and vegetable farming efficiency requires a balanced approach. While judicious pesticide application can lead to short-term gains in crop yield and quality [9], it is important to consider the potential negative impacts on the environment and long-term sustainability [30]. To ensure responsible pesticide use, integrated pest management practices, organic alternatives, and ecological conservation should be emphasized [31]. Policymakers and farmers need to find a delicate balance between achieving high yields and preserving the ecosystem [32]. This approach will promote sustainable and environmentally conscious agriculture [33].

Implications for Sustainable Agriculture

The comprehensive analysis of the structural model results underscores the need for a balanced and sustainable approach to vegetable farming in Central Java. While technological advancements and increased labor availability contribute significantly to short-term efficiency gains, it is imperative to consider the long-term environmental, social, and health implications. Sustainable farming practices that harmonize productivity with ecological and societal well-being should be prioritized in the development of agricultural policies and practices.

Limitations and Future Research Directions

Acknowledging the limitations of the study, including its cross-sectional nature and potential unobserved variables, future research could delve into longitudinal designs to capture temporal dynamics. Exploring additional factors influencing farming efficiency and conducting in-depth qualitative studies could provide a more nuanced understanding of the challenges and opportunities faced by vegetable farmers in Central Java.

CONCLUSION

In conclusion, this research unravels the multifaceted relationships shaping vegetable farming efficiency in Central Java. The positive impact of Agricultural Technology adoption, increased Labor Availability and judicious Pesticide Use on Vegetable Farming Efficiency underscores the potential for enhancing agricultural productivity. However, the study advocates for a balanced and sustainable approach, acknowledging the environmental and societal implications associated with certain practices. Tailored interventions for different farm sizes and geographical locations are crucial for optimizing the impact of strategies aimed at improving farming efficiency. As Central Java navigates the complexities of agricultural development, this research provides valuable insights for stakeholders seeking to foster a resilient and sustainable vegetable farming sector.

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