Plantation Management Model with Utilization of Palm Oil Waste

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ABSTRACT

Background: The purpose of the study was to assess how effective the use of organic and liquid fertilizers derived from palm oil mill waste as an alternative to improve soil quality and control Ganoderma.

Methods: In this study, the DEA Model was used to assess effectiveness, the TAM Model to assess technology acceptance and the ISM Model to analyze policies that support the management of palm oil mill waste into organic fertilizer.

Result: The results showed that using organic fertilizer obtained from palm oil mill waste significantly improved soil quality. Compared with conventional methods, this treatment also succeeded in reducing the level of Ganoderma attacks by 40% and increasing production yields by 15%.

Key words: Ganoderma, Model, Oil palm waste, Oil palm, Plantation management.

INTRODUCTION

In Indonesia, the use of chemical fertilizers has reached an alarming level because it can cause severe dependency. There are several problems with the use of inorganic fertilizers that have a negative impact on the sustainability of agricultural land. In the long term, this dependency will have a negative impact on the sustainability of oil palm plantations (Galib *et al.,* 2022). Basically, the quality of soil fertility can be improved through fertilization. Therefore, fertilization cannot be limited to inorganic fertilizers alone.

The imbalance of fertilizer use in oil palm plants has also been reported to reduce the frequency of pest and disease attacks such as ganoderma. Ganoderma attacks are reported to occur more frequently in oil palm plantations (Widiastuti *et al.,* 2016; Semangun, 2000). Because ganoderma spreads through the soil, its control is considered difficult. As a result, the rootstock becomes damaged (Syahputra and Purba, 2015). Synthetic fungicides used to control ganoderma are considered inefficient and can cause environmental pollution (Wiratmoko *et al.,* 2018).

One type of liquid fertilizer that is very useful is palm oil mill liquid waste (Mulia Raja *et al.,* 2021; Yacob *et al.,* 2022). Utilization of palm oil mill liquid waste can be useful in suppressing the development of ganoderma. Such as palm oil agro-industrial biomass waste originating from upstream activities, namely in plantations in the form of fronds, leaves and trunks of oil palm trees (Saswattecha *et al.,* 2016; Sheehy *et al.,* 2021). Therefore, this study aims to develop a model that can optimize the use of factory liquid waste in controlling Ganoderma, taking into account its impact on social, economic, institutional and environmental aspects. This study seeks to integrate the use of factory waste with Ganoderma control strategies.

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MATERIALS AND METHODS

In this quantitative study, the DEA model was used to analyze the efficiency value of liquid waste utilization. The data processing program is STATA 13. The analysis study used the Technology Acceptance Model (TAM). Perceived ease, perceived usefulness and user perception of technology were measured using a Likert scale. Data processing and collection in this study were carried out in 2020-2023 over a period of one year. The research was conducted at PT Padasa Enam Utama, located in North Sumatra province, Indonesia.

RESULTS AND DISCUSSION

Efficiency level of PT padasa enam utama oil palm plantation

At the PT Padasa Enam Utama Oil Palm Plantation for the 2020-2023 period, the processing results using the DEA model and with the assistance of Stata 13 software were obtained as in Fig 1.

Based on the data in Fig 1 provided, PT. Padasa Enam Utama shows consistent efficiency with an efficiency value

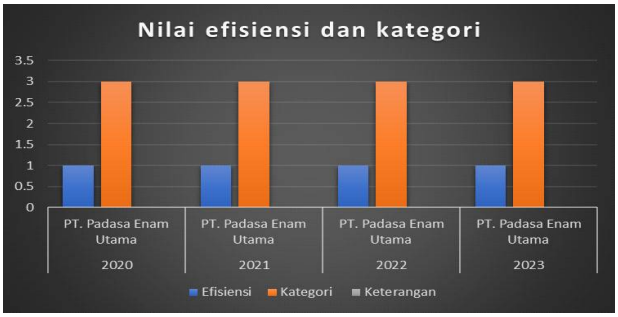
of 1 for four consecutive years (2020-2023). Overall, PT. Padasa Enam Utama has demonstrated how PKS waste management can work together with operational efficiency, compliance with ISPO standards and innovation (Rahmawati and Novani, 2024). Consistent high efficiency, effective Ganoderma disease control and commitment to environmental sustainability are evidence that responsible agribusiness practices can provide positive economic, social and ecological outcomes (Banu *et al.,* 2024).

Perception of PKS waste acceptance with technology acceptance model (TAM)

The purpose of this study was to evaluate respondents' responses to the technology of processing palm oil mill waste into organic fertilizer. To do this, the technology acceptance model (TAM) and the structural equation modeling-partial least squares (SEM-PLS) testing method were used. In addition, the validity and reliability of the questionnaire were tested using the average variance extracted (AVE) and composite reliability values.

Measurement model test results (Outer model) for PT padasa enam utama

Validity testing is carried out to ensure that the research tool can measure the variables correctly. Convergent validity in the partial least squares (PLS) approach with reflective indicators is assessed by the loading factor.



Source: Data processed using STATA 13 application.

Fig 1: Overview of efficiency values and efficiency categories.

Table 1: R-square test.

Variables	R square	Information
Experience	0.251	Weak
Real users	0.208	Weak

Source: Data processing results, using the SmartPLS.3 application 2024.

Structural model test results (Inner model)

After the outer model test is completed, the evaluation of the results is carried out by assessing the structural model (inner model). At this point, the determinant coefficient test (R-square, F-square, Q-square and hypothesis) is carried out.

R-square test

The following are the results of the R-Square values in this study which can be seen in the following table. This can be seen in Table 1.

According to Table 1 above, the R square value for the Experience variable is 0.251 and the R square value for the Real Users variable is 0.208. The square coefficient, also known as the coefficient of determination, measures how well the independent variables in a model can explain the variability of the dependent variable. With an R square value of 0.251, we find that approximately 25.1% of the measured variables can be explained by this model. This value indicates that the model has low or weak explanatory power for the dependent variable.

F-square test

F-square is used to analyze the level of influence of variable predictions whether weak, moderate or strong at the structural level. Leeflang *et al.* (2017) stated that a value of 0.02 indicates that the variable predictor has a small influence, a value of 0.15 indicates a medium (moderate) influence and 0.35 indicates a large influence (Henseler *et al.,* 2009). As shown in Table 2.

According to Table 2 above, the results show that the effect of intensity on actual users is not significant, because the coefficient is only 0.075 and the effect of ease of use on experience is also small, with a coefficient of 0.136. Although there is a positive effect, its effect on user experience is not significant. In contrast, there is no relationship between Perceived Usefulness and Actual Users, with a coefficient of only 0.001. This indicates that a person's perception of the usefulness of the technology or system does not affect their likelihood of becoming an actual user.

However, the experience variable appears to have a greater influence on actual users, with a coefficient value of 0.334. This indicates that the more experience a user has, the more likely they are to become an actual user.

Table 2: F-square test.

	Intensity	Ease of use	Experience	Real users	Perception of usefulness
Intensity				0.075	
User ease				0.136	
Experience					
Real users			0.334		
Perceived usefulness				0.001	

Source: Data processing results, using the smart PLS.3 application, 2024.

In this case, user experience appears to be the most significant factor influencing a person's decision to use a technology or system directly, compared to the intensity, ease of use and level of difficulty experienced by the user.

Q-square test

In PLS, the blindfolding method is used to perform the Q-square test. Q-square analysis is used to evaluate the predictive validity of exogenous and endogenous latent variables. The Q-square value obtained must be greater than zero (0). The Q-square value obtained can be seen in Table 3.

Table 3 above shows that despite its low predictive power, the model has predictive ability for the "Experience" variable, with a Q^2_predict value of 0.085. Since the Q^2_predict value is greater than zero, indicating predictive validity although not very strong, the predictive relevance of this model still meets the established criteria.

Real Users (Q^2_predict = 0.095)

The "Real users" variable has slightly greater predictive power than the "Experience" variable, according to the Q^2_predict value of 0.095. Just like the previous variable, although predictive, it is still considered weak but still predictively relevant.

Test results

Hypothesis testing is the final step in analyzing the influence between variables in a structural model. This test uses bootstrapping to produce significance values such as t-statistics, p-values and relationships between constructs. The level of significance used in the study is 5%. Based on the bootstrapping test results, it was found that five hypotheses were accepted, while one hypothesis was rejected. A more detailed explanation can be found in the following Table 4.

These results indicate that the perceived usefulness of a system or application does not affect the user's decision to use it.

User intention perception towards real users

The results of statistical analysis with T statistic of 2.395 and p-value of 0.017 indicate a significant relationship between the intensity of user intention (Behavioral Intention to Use/BIU) and the actual application (Actual Use/AU) of palm oil mill waste management technology into organic fertilizer. Organic agricultural production is lower than that projected for conventional farming due to the smaller area of organic farming and lower productivity compared to conventional farming and the greater proportion of land used for organic farming (Ghanem *et al.,* 2024).

A p-value of less than 0.05 confirms that the intention to use technology significantly affects the actual adoption of the technology in the field (Cintya Mawar and Adiati, 2024; Tiwari *et al.,* 2020). This means that the stronger the user's intention to utilize technology, the more likely this technology is to be adopted and applied in everyday practice (Bagheri *et al.,* 2024). In the context of waste management technology acceptance, the management of PT Padasa Enam Utama views technology adoption as strategic to improve operational efficiency and reduce environmental damage.

Perceived user ease (PEU) of real users (AU)

The results of the statistical analysis show that the T-statistic value of 3.213 and the p-value of 0.001 in the relationship between perceived ease of use (PEU) and actual use (AU) in the technology of managing palm oil mill waste into organic fertilizer indicate a very significant relationship. With a p-value far below the threshold of 0.05, it can be concluded that the perception of ease of use of technology significantly affects the adoption and implementation of technology in operational practices. This means that the easier a technology is to use for the management of PT Padasa Enam Utama, the more likely the technology will be adopted in the management of palm oil mill waste (Wijaya *et al.,* 2023).

Real user perception (AU) -> user experience (PU)

The results of the statistical analysis show that the T-statistic is 5.69 with a p-value of 0.000 in the relationship between actual use (AU) and Experience perceived usefulness (PU) in the context of palm oil mill waste management technology into organic fertilizer indicates a very significant relationship. The p-value which is far below the threshold of 0.05 indicates that the perceived benefits of the technology significantly affect the level of technology adoption in real practice. In other words, the greater the benefits perceived by the user, the higher the tendency to actively apply the technology in operations (Shrestha and Vassileva, 2019). In this case, the management of PT Padasa Enam Utama assessed that the perception of

Tabel 3: Uji Q-square.

	Q^2_predict	Predictive relevance
Experience	0.085	Yes
Real users	0.095	Yes

Source: Data processing results, using the Smart PLS.3 application, 2024.

Table 4: Path coefficient results.

Hypothesis	T-statistics	P values	Information
Intensity (BIU) -> Actual users (AU)	2.395	0.017	Accepted
Ease of use (PEU) -> Actual users (AU)	3.213	0.001	Accepted
Real users (AU) -> Experience (PU)	5.691	0.000	Accepted
Perceived usefulness (ATU) -> Actual users (AU)	0.181	0.857	Rejected

Source: Smart PLS 3 data processing (2024).

the usefulness or benefits of technology greatly influences the decision to adoption.

Perceived usability (APU) -> Real users (AU)

The results of the statistical analysis show that the T-statistic value of 0.181 with a p-value of 0.857 in the evaluation of the relationship between Perceived Usefulness (Attitude Toward Using/ATU) and actual use (AU) for palm oil mill waste management technology indicates that there is no significant relationship between the perception of the usefulness of technology and the level of application of the technology in practice. The p-value which is far above the significance limit of 0.05 indicates that a positive attitude towards the usefulness of technology does not directly contribute to the level of technology adoption in the field. Overall, these statistical results suggest that a more comprehensive understanding of technology is needed.

Policy approach with ISM model

Reachibility matrix (RM)

After compiling the SSIM, the next step is to convert it into a reachability matrix (RM), which is a numerical representation of the SSIM. This matrix serves to identify direct and indirect relationships between elements. The results of the Reachability Matrix are explained in the following Table 5.

The reachability matrix presented shows that almost all variables directly affect each other. Except for variable 4, which is the availability of green open land, each variable is indicated by a value of 1 in each position. The other variables have a strong correlation with each other. This shows that policies, management support, budget allocation and other factors must support each other in the process of processing toxic waste into organic fertilizer (Saenimun'im *et al.,* 2023). However, variable 4 has a value of zero in several places, indicating that the availability of green open land does not have a direct impact on the policies of the Environmental Service (Perubahan *et al.,* 2012).

In addition, all other variables are influenced by the policy and management support variables (variables 1 and 2), which are important roles. In addition, the similarity of perception among stakeholders (variable 7) has a strong correlation with all components, which shows how important it is to have the same perspective on how to run the program. Overall, this matrix shows that the production of organic fertilizer from toxic waste is highly dependent on good cooperation between policy owners (Kaldarboyevich *et al.,* 2023).

Conical matrix (Level determination)

Conical matrix is created by grouping components with the same level of relatedness. This matrix is very helpful in determining important elements or priority actions that must be considered in a complex system. Table 6 below presents the results of the conical matrix study.

The results of the conical matrix analysis that assesses the processing of palm oil mill waste into organic fertilizer found seven main factors that are very important for the success of this system. Each variable has a strength value of 1; this indicates that they contribute significantly to the process of transforming toxic waste into organic fertilizer. The most commonly used phenolic compounds are gallic acid, chlorogenic acid and catechin; the main vitamins are ascorbic acid and niacin (Bhattacherjee *et al.,* 2023). Citric acid and malic acid are the most abundant organic acids found in plants and they are also suitable for use as organic matter in oil palm plantations. In addition, the level of dependence of each variable shows the same value, namely 1, which indicates that there is a strong correlation between these variables. In contrast, one of the variables, the availability of open green land, has a lower strength value, namely 0, indicating that this variable does not function as the main driver of the system, but is more dependent on external factors.

Cross impact matrix diagram in classification model (MICMAC)

The ISM diagram is used in this study to describe the important variables that affect the processing of palm oil mill waste into organic fertilizer. Seven variables were evaluated: Environmental Agency policy, management support, budget allocation, availability of open green land, availability of infrastructure, uniformity of organizational structure and perception of the same stakeholders. Each

Table 5: Reachibility matrix.

Variables	1	2	3	4	5	6	7
1. There is a policy/permit from the environmental service in the form of regulations related to the processing of toxic waste into fertilizer.	1	1	1	1	1	1	1
2. There is full support from the management in the application of toxic waste into organic fertilizer.	1	1	1	1	1	1	1
3. Budget allocation as a priority in supporting waste processing into organic.	1	1	1	1	1	1	1
4. Availability of green open land.	0	1	1	1	1	1	1
5. Availability of supporting infrastructure.	1	1	1	1	1	1	1
6. Uniformity of organizational and institutional structures.	1	1	1	1	1	1	1
7. Similar perceptions of stakeholders.	1	1	1	1	1	1	1

Source: Processed results with ISM-professional application (2024).

of these variables has a different level of dependence and driving force. Fig 2 shows the location of each variable and its level of driving force.

The analysis results show that the three main variables environmental policy (A1), management support (A2) and budget allocation (A3) have high driving force and low dependency. That is, these variables are the main drivers of the system and they do not depend too much on other variables to function. In addition, significant driving factors include uniform organizational structure (A6), common stakeholder perception (A7) and availability of infrastructure (A5). Although the variable of green open land availability (A4) shows a lower driver resource, Fig 3 shows the level of each variable and its shortcomings in decision making.

In the graph above, the variables are divided into several levels. Variables at level 1 (marked in red) show a greater driving role and variables at level 2 (marked in blue) show a supporting role. The Environmental Service Policy (A1) is at level 1 and indicates that government policies and regulations, especially those related to the environmental service, serve as the main basis for the toxic waste management system into organic fertilizer. Bioformulation is also desirable because it can improve growth parameters and crop yields in both normal and sodic soils. Halo-Mix demonstrated the highest efficacy in soil fertility metrics, including nitrogen, phosphorus and potassium levels. Sodic soil pH was slightly neutralized and organic carbon content increased (Tomar *et al.,* 2025).

In addition, the signs at level 1 are management support (A2), budget allocation (A3), availability of infrastructure (A5) and common perception of stakeholders (A7). This shows that this system cannot operate effectively without (A2, A3, A5, A7) support. Each of these variables supports each other and is very important for running operations optimally. In contrast, the availability of open green land (A4) is at level two. This variable plays an important role in maintaining environmental balance, although it is not at the most important level. Overall, this diagram shows the hierarchy of variables related to the use of palm oil waste to produce organic fertilizer. Including the use of mold, by adding mold concentrations to the mixture, the nutritional value, antioxidant activity, flavonoids, polyphenols, beta-carotene, fatty acids and amino acids significantly increased (Hasanuddin Asriani *et al.,* 2025). With 8% mold, the measured parameter

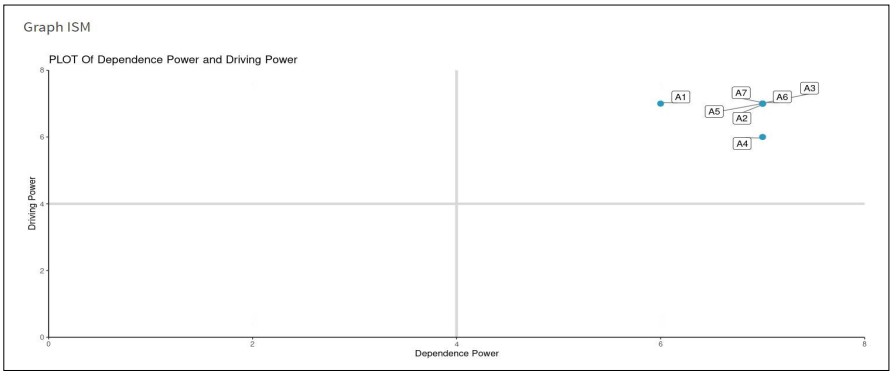


Fig 2: MICMAC image processed with the ISM-professional application.

Table 6: Conical matrix.

Variables	1	2	3	4	5	6	7	Driver power	Rank	Dependence Hierarchy	Hierarchy
1. There is a policy/permit from the environmental Service in the form of regulations related to the processing of toxic waste into fertilizer.	1	1	1	1	1	1	1	7	1	6	2
2. There is full support from the management in the application of toxic waste into organic fertilizer.	1	1	1	1	1	1	1	7	1	7	1
3. Budget allocation as a priority in supporting waste processing into organic.	1	1	1	1	1	1	1	7	1	7	1
4. Availability of green open land.	0	1	1	1	1	1	1	6	2	7	1
5. Availability of supporting infrastructure.	1	1	1	1	1	1	1	7	1	7	1
6. Uniformity of organizational and institutional structures.	1	1	1	1	1	1	1	7	1	7	1
7. Similar perceptions of stakeholders.	1	1	1	1	1	1	1	7	1	7	1

Source: Processed results with ISM-professional application (2024).

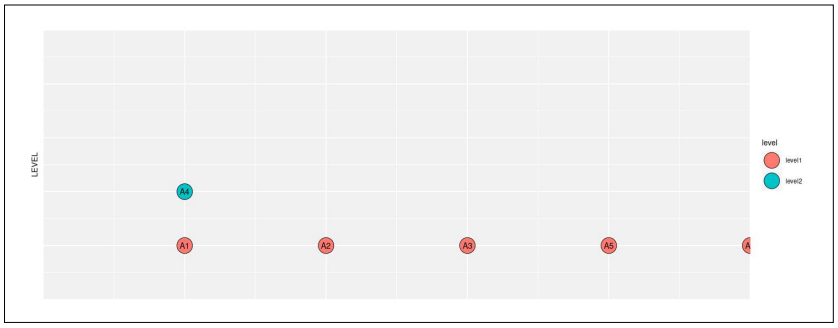


Fig 3: Graph level.

values were the best. The variables at level 1 are the main drivers that affect the process, while the variables at level 2 help the system to last.

CONCLUSION

Based on the results of data processing and wetting, the following conclusions can be drawn:

1. Utilization of palm oil mill (PKS) waste as organic fertilizer at PT. Padasa Enam Utama has proven effective in suppressing the spread of Ganoderma disease, while replacing the use of chemical fertilizers. The implementation of this strategy has not only succeeded in maintaining plant productivity, but also contributed to increasing the company's income. Thus, this approach offers a sustainable solution that is environmentally friendly, supports circular economy practices and makes a significant contribution to the sustainability of agribusiness in the long term.
2. The policy of implementing factory waste management technology into organic fertilizer at PT. Padasa Enam Utama focuses on increasing the ease of use of technology and the intensity of employee intention to use it through technology acceptance.
3. The success of processing palm oil mill waste into organic fertilizer is highly dependent on the synergy between supportive policies, strong institutional encouragement, especially from management policies and budget allocation, acting as the main drivers of the success of managing palm oil mill waste into organic fertilizer.

Conflict of interest

All authors declared that there is no conflict of interest.

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