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Determinants of Farmers' Adoption of Circular Economy-Based Soil Block Technology Using Rawa Pening Sediment in Temanggung Regency

Fikadhita Karunia Puteri¹, Joko Mariyono², Miranti Dian Pertiwi³

¹Universitas Diponegoro, Semarang, Indonesia, fikadhitakaruniaputeri@gmail.com

²Universitas Diponegoro, Semarang, Indonesia, jokomariyono@lecturer.undip.ac.id

³Badan Riset dan Inovasi Nasional (BRIN), Jakarta, Indonesia, mira015@brin.go.id

Corresponding Author: fikadhitakaruniaputeri@gmail.com¹

Abstract: Sedimentation in Rawa Pening Lake has become a major environmental challenge, reducing aquatic ecosystem functions while creating opportunities to recover sediment as a valuable agricultural resource through a circular economy approach. This study analyzed the determinants of farmers' adoption of Rawa Pening sediment-based soil block growing media and its implications for sustainable horticultural production in Temanggung Regency, Indonesia. A mixed-methods approach combined a cross-sectional survey of 60 chili farmers with in-depth interviews involving six key stakeholders representing producers, distributors, and government institutions. Quantitative data were analyzed using binary logistic regression, while qualitative data were examined through thematic analysis to strengthen interpretation. The logistic regression model demonstrated excellent performance, with a significant Omnibus Test ($\chi^2 = 66.521$; $p < 0.001$), satisfactory Hosmer–Lemeshow goodness-of-fit ($p = 1.000$), and a Nagelkerke R^2 of 91%, indicating strong explanatory power. Institutional support (OR = 12.691; $p = 0.041$), ease of use (OR = 4.163; $p = 0.039$), government support (OR = 2.994; $p = 0.044$), and supply chain effectiveness (OR = 3.738; $p = 0.032$) significantly increased adoption likelihood. In contrast, economic perception, sustainability, information access, and raw material availability were not statistically significant. These findings suggest that successful circular agricultural innovations depend not only on the economic value of recovered resources but also on strong institutions, supportive policies, and integrated supply chains. Transforming lake sediment into soil block growing media represents a practical resource recovery strategy for advancing sustainable horticultural production and strengthening circular economy implementation.

Keyword: Circular Economy, Technology Adoption, Soil Block, Lake Sediment, Supply Chain, Sustainable Horticulture.

INTRODUCTION

Agriculture and fisheries are fundamental sectors of Indonesia's economy, contributing substantially to food security, employment, and rural livelihoods. However, both sectors are increasingly vulnerable to environmental degradation. One of the most critical environmental challenges is the rapid sedimentation of Lake Rawa Pening in Central Java, which has reduced the lake's ecological functions and affected the livelihoods of surrounding communities. Excessive sediment accumulation has decreased water storage capacity, degraded aquatic habitats, and disrupted ecosystem services that support fisheries and agriculture. In the fisheries sector, sedimentation has reduced the productive area for floating net cages and fish harvesting, while in agriculture, sediment deposits obstruct irrigation systems, increase seasonal flooding, and reduce the availability of productive farmland, resulting in economic losses for farmers and fishers (Handayani & Setiawan, 2023; Pratama et al., 2022). Furthermore, high sedimentation rates threaten the long-term sustainability of agricultural production systems that depend on water resources supplied by the lake.

Rather than viewing sediment solely as waste requiring disposal, the circular economy promotes its recovery and reuse as a valuable resource capable of generating environmental and economic benefits. Circular economy principles emphasize closing material loops by extending resource use and transforming waste into productive inputs (Ghisellini et al., 2021). Recent studies have demonstrated that lake sediments contain substantial amounts of organic matter and essential plant nutrients, making them suitable as alternative growing media following appropriate treatment. The reuse of dredged sediments not only reduces disposal problems but also supports sustainable resource management in agriculture.

One practical application of this approach is the development of sediment-based soil block growing media. Unlike conventional nursery systems that rely on plastic polybags, soil blocks are compact growing media that eliminate the need for disposable plastic containers while maintaining seedling quality. Previous studies have shown that sediment-based soil blocks reduce plastic consumption, improve nursery efficiency, increase phosphorus and organic matter availability, and lower greenhouse gas emissions compared with conventional polybag systems. These characteristics demonstrate that soil block technology represents an innovative application of circular economy principles in horticultural production.

Temanggung Regency is one of the leading horticultural production areas in Central Java where sediment-based soil block technology has been introduced, particularly for vegetable seedling production. Chili pepper (*Capsicum annum*) is among the region's most important horticultural commodities and contributes substantially to agricultural economic output (BPS Temanggung Regency, 2024). Because chili is a strategic food commodity with highly fluctuating market prices, improving production efficiency at the farm level is essential for maintaining production stability and supporting food security (Wahyudi & Ilham, 2023).

Despite its environmental and economic advantages, the adoption of sediment-based soil block technology remains limited among horticultural farmers. Conventional polybag-based nurseries continue to dominate because they are familiar, easily accessible, and integrated into existing farming practices. This dependence contributes to higher labor requirements during seedling preparation and increases agricultural plastic waste, which conflicts with sustainable production objectives (Velis et al., 2022). These conditions suggest that the successful implementation of circular economy innovations depends not only on technological performance but also on farmers' willingness to adopt new practices and the availability of supporting supply chain systems.

Previous studies have examined the agronomic performance of sediment-based growing media, the environmental benefits of sediment recycling, and the determinants of agricultural technology adoption. However, most studies have addressed these issues separately. Limited

attention has been given to understanding how circular economy-based innovations are adopted by farmers, particularly by integrating resource recovery, innovation adoption, and supply chain perspectives within a single analytical framework. This study addresses this research gap by analyzing the adoption of Rawa Pening sediment-based soil block growing media among horticultural farmers in Temanggung Regency from a circular economy perspective. The findings are expected to provide empirical evidence for promoting sustainable agricultural innovation and improving circular resource utilization in horticultural production.

The novelty of this study lies in its integration of circular economy principles, technology adoption theory, and supply chain perspectives into a single analytical framework to explain farmers' adoption of sediment-based soil block technology. Unlike previous studies that have primarily focused on the technical performance of sediment utilization, the environmental benefits of circular resource recovery, or the socioeconomic determinants of technology adoption independently, this research simultaneously examines how institutional support, perceived technological characteristics, and supply chain effectiveness interact to influence farmers' adoption decisions. By applying this integrated perspective to the utilization of Rawa Pening sediment in horticultural production, the study extends the application of Circular Economy beyond resource recovery toward behavioral adoption analysis at the farm level. Consequently, the research contributes both theoretically, by bridging Circular Economy and agricultural technology adoption literature, and practically, by providing evidence-based insights for designing policies that accelerate the implementation of circular agriculture in developing countries.

METHOD

Research Design

This study employed an explanatory sequential mixed-methods design to examine farmers' adoption of Rawa Pening sediment-based soil block growing media within the context of the circular economy. The research combined quantitative and qualitative approaches to provide a comprehensive understanding of the economic, institutional, and supply chain factors influencing technology adoption. The quantitative component identified the determinants of adoption, whereas the qualitative component provided contextual explanations of farmers' decisions and the sustainability of sediment utilization as a circular agricultural resource.

The study was conducted from March to May 2025 in Ngadirejo Subdistrict, Temanggung Regency, Central Java, Indonesia. The research area was purposively selected because it is one of the main horticultural production centers where soil block technology utilizing sediment from Rawa Pening has been introduced and implemented. Moreover, the subdistrict represents an important production area for chili (*Capsicum annuum*), providing an appropriate setting for evaluating the economic and environmental implications of adopting circular agricultural innovations. A cross-sectional survey design was employed to collect quantitative data from farmers at a single period of observation. This design is appropriate for identifying factors associated with technology adoption and evaluating farmers' perceptions of the economic value and sustainability of sediment-based soil block growing media.

Population, Sampling, and Data Collection

The target population consisted of chili farmers who had adopted or were potential adopters of sediment-based *soil block* technology in Ngadirejo Subdistrict. Respondents were selected using purposive sampling because only farmers with prior exposure to the innovation were considered capable of evaluating its economic and technical performance. A total of 60

farmers from the Mulya III and Mulya VI farmer groups in Ndlimoyo Village participated in the quantitative survey. The sample size of 60 farmers was considered adequate for binary logistic regression because the respondents were purposively selected from the population of farmers who had prior exposure to sediment-based soil block technology, ensuring that they possessed sufficient knowledge and experience to evaluate the innovation. To complement the survey findings, six key informants representing the principal actors within the *soil block* value chain—including producers, distributors, agricultural extension officers, and local government institutions—were selected for in-depth interviews. Six key informants were purposively selected to represent the major stakeholders involved in the development and implementation of the technology. Interviews continued until no substantially new themes or insights emerged from successive interviews, indicating that thematic data saturation had been achieved. The inclusion of informants from different institutional roles further enhanced the credibility and comprehensiveness of the qualitative findings. These informants were chosen because of their direct involvement in sediment procurement, *soil block* production, technology dissemination, and institutional support.

Primary data were collected through structured questionnaires, field observations, and semi-structured interviews. The questionnaire was designed based on the conceptual framework of circular economy adoption in agriculture, while perception indicators were adapted from the Technology Acceptance Model (TAM) and Diffusion of Innovation (DOI) to ensure construct validity. Before the main survey, the questionnaire was pre-tested on 16 farmers to evaluate the clarity, consistency, and reliability of the measurement items.

Secondary data were obtained from the Central Bureau of Statistics (BPS), agricultural extension services, local government agencies, and published scientific literature concerning horticultural production, circular economy, and sediment utilization. Data triangulation was achieved by integrating survey responses, interview findings, field observations, and documentary evidence.

Variable Measurement

The dependent variable was the adoption of sediment-based *soil block* growing media, measured as a binary variable in which adopters were coded as one (1) and non-adopters as zero (0). The explanatory variables were selected to represent the major dimensions affecting the adoption of circular agricultural innovations. Although several perception indicators were adapted from TAM and DOI, the variables were operationalized to reflect the economic, environmental, institutional, and supply chain dimensions of circular economy implementation in horticultural farming.

Table 1. Table of variable

Variable	Operational Definition
Economic Perception (X_1)	Farmers' perceptions regarding production cost reduction, labor efficiency, profitability, and economic benefits derived from sediment-based <i>soil block</i> technology.
Sustainability (X_2)	Farmers' perceptions of environmental benefits, sediment reutilization, reduction of plastic waste, and resource conservation associated with <i>soil block</i> technology.
Institutional Support (X_3)	Support provided by farmer groups, extension services, cooperatives, and local institutions in promoting and facilitating technology adoption.
Ease of Use (X_4)	Farmers' perceptions regarding the simplicity, practicality, and operational feasibility of applying <i>soil block</i> technology during seedling production.
Government Support (X_5)	Availability of government assistance, training programs, policy incentives, and extension activities related to the technology.

Variable	Operational Definition
Access to Information (X_6)	Farmers' access to technical information, demonstrations, extension activities, and communication networks concerning <i>soil block</i> technology.
Supply Chain Effectiveness (X_7)	Farmers' perceptions of the efficiency of sediment procurement, production, distribution, and marketing systems supporting <i>soil block</i> technology.
Raw Material Availability (X_8)	Availability, accessibility, and continuity of sediment resources required for sustainable <i>soil block</i> production.

Data Analysis

The quantitative data were analyzed using descriptive statistics and binary logistic regression. Descriptive statistics were employed to summarize respondents' socioeconomic characteristics and describe the distribution of farmers' perceptions toward sediment-based *soil block* technology. Prior to regression analysis, the measurement instrument was evaluated through validity and reliability testing. Item validity was assessed using the Pearson product-moment correlation coefficient, with items considered valid when the correlation coefficient exceeded 0.30. Instrument reliability was evaluated using Cronbach's alpha, where coefficients greater than 0.70 indicated satisfactory internal consistency.

Binary logistic regression was employed because the dependent variable represents two mutually exclusive outcomes, namely adoption and non-adoption of sediment-based *soil block* technology. Compared with ordinary least squares regression, logistic regression provides consistent maximum likelihood estimates for binary response variables and allows the probability of technology adoption to be estimated as a function of multiple explanatory variables.

The logistic regression model is expressed as:

$$\ln\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \varepsilon$$

Where:

P_i = probability that farmer i adopts sediment-based *soil block* growing media;

β_0 = intercept;

$\beta_1 - \beta_8$ = regression coefficients;

$X_1 - X_8$ = explanatory variables;

ε = error term.

The influence of each explanatory variable was interpreted using the odds ratio:

$$OR = e^{\beta_i}$$

Where an odds ratio greater than one indicates that an increase in the explanatory variable increases the likelihood of adoption, while an odds ratio less than one indicates a lower probability of adoption. Model adequacy was evaluated using the Omnibus Test of Model Coefficients and the Hosmer–Lemeshow goodness-of-fit test. The explanatory power of the model was assessed using Nagelkerke's pseudo- R^2 , whereas the predictive accuracy of the model was evaluated through the classification table. The significance of individual regression coefficients was examined using the Wald test at a 5% significance level.

Qualitative data obtained from interviews were analyzed using the interactive model developed by Matthew B. Miles, A. Michael Huberman, and Johnny Saldaña, consisting of data condensation, data display, and conclusion drawing. Thematic analysis was subsequently applied to identify the economic, institutional, and supply chain factors that facilitate or constrain the adoption of sediment-based *soil block* technology. Finally, the quantitative and

qualitative findings were integrated through methodological triangulation to provide a comprehensive explanation of farmers' adoption behavior within the framework of the circular economy.

RESULT AND DISCUSSION

Socioeconomic Profile of Respondents

Table 2. Socioeconomic Characteristics of Respondents

Characteristics	Category	Frequency	Percentage (%)
Age (years)	≤40	15	25.0
	41–60	39	65.0
	>60	6	10.0
Land Area	<0.5 ha	57	95.0
	≥0.5 ha	3	5.0
Land Ownership	Owned	17	28.3
	Rented	43	71.7
Education	No formal education	1	1.7
	Elementary school	30	50.0
	Junior high school	19	31.7
	Senior high school	8	13.3
	College	2	3.3
Farming Experience	≤10 years	6	10.0
	11–20 years	26	43.3
	21–30 years	11	18.3
	>30 years	17	28.3
Monthly Income	< IDR 1.5 million	31	51.7
	IDR 1.5–3.0 million	24	40.0
	> IDR 3.0 million	5	8.3

The survey involved 60 chili farmers from Ndlimoyo Village, Ngadirejo Subdistrict. Most respondents were within the productive age group (41–60 years), cultivated less than 0.5 ha of land, and relied on rented farmland. The majority had over ten years of farming experience but relatively low educational attainment and household income. These characteristics indicate that respondents represent resource-constrained smallholders, whose technology adoption decisions are strongly influenced by production risks and institutional support rather than by financial capacity alone.

The socioeconomic profile provides an important context for understanding the adoption of sediment-based *soil block* technology. Small-scale farmers generally have limited ability to absorb production risks, making them more dependent on institutional assistance, reliable input supply, and practical innovations. Consequently, the adoption of circular agricultural technologies is shaped not only by economic incentives but also by the governance mechanisms that reduce uncertainty throughout the production process.

Model Performance

Table 3. Logistic Regression Model Performance

Indicator	Value
Omnibus Test (χ^2)	66.521
Sig.	<0.001
Hosmer–Lemeshow	1.000
Nagelkerke R ²	0.910

Source: Primary data analysis (2025).

The logistic regression model exhibited excellent predictive performance. The significant Omnibus test confirmed that the explanatory variables jointly influenced farmers' adoption decisions, whereas the non-significant Hosmer–Lemeshow statistic indicated a satisfactory model fit. Furthermore, the Nagelkerke R^2 value of 0.910 suggests that the model explains 91% of the variation in adoption behavior. These results demonstrate that adoption is primarily determined by a combination of institutional, technological, and supply chain factors rather than by random individual decisions. Although this level of explanatory power is relatively high compared with many behavioral adoption studies, it is likely attributable to the inclusion of theoretically relevant predictors representing institutional support, technological characteristics, and supply chain effectiveness, which collectively capture the major determinants of farmers' adoption decisions. In addition, the purposive selection of respondents who had prior exposure to sediment-based soil block technology may have reduced unexplained variation by focusing on a relatively homogeneous group of potential adopters. Therefore, the high explanatory power should be interpreted as reflecting both the strong relevance of the selected explanatory variables and the characteristics of the study sample. Nevertheless, caution should be exercised when generalizing these findings beyond the study area, and future research involving larger and more diverse samples is recommended to further validate the robustness of the model.

Determinants of Circular Technology Adoption

Table 4. Binary Logistic Regression Results

Variable	B	P-Value	Odds Ratio
Economic Perception	-0.028	0.941	0.973
Sustainability	-1.215	0.080	0.297
Institutional Support	2.541	0.041	12.691
Ease of Use	1.426	0.039	4.163
Government Support	1.097	0.044	2.994
Information Access	-0.506	0.209	0.603
Supply Chain Effectiveness	1.319	0.032	3.738
Raw Material Availability	0.130	0.610	1.139

Source: Primary data analysis (2025).

The regression results indicate that institutional support, ease of use, government support, and supply chain effectiveness significantly increased farmers' likelihood of adopting sediment-based *soil block* technology. Institutional support had the largest effect (OR = 12.691), indicating that farmers receiving stronger organizational support were substantially more likely to adopt the innovation. This finding highlights the critical role of farmer organizations and extension services in reducing uncertainty associated with circular agricultural technologies. Ease of use also significantly influenced adoption, suggesting that operational simplicity remains an important determinant of farmers' technology acceptance. The transition from conventional polybags to *soil block* media reduces nursery preparation time and labor requirements, thereby increasing production efficiency. Likewise, government support enhanced adoption through training, extension, and facilitation programs, while an effective supply chain ensured the continuous availability and distribution of sediment-based growing media. Together, these findings indicate that circular innovations require supportive governance and coordinated logistics in addition to technical feasibility.

Interestingly, economic perception, sustainability perception, information access, and raw material availability did not significantly influence farmers' adoption of sediment-based soil block technology. These findings suggest that farmers do not automatically adopt environmentally beneficial technologies simply because they recognize their economic or ecological advantages. Instead, adoption depends on the extent to which institutional

arrangements and supply chain systems reduce implementation risks and improve operational reliability. From the perspective of the Technology Acceptance Model (TAM), perceived benefits alone may be insufficient to encourage adoption when farmers remain uncertain about implementation support or the continuity of technology provision. Likewise, Diffusion of Innovation (DOI) theory suggests that the successful diffusion of an innovation is influenced not only by its perceived relative advantage but also by the availability of communication channels, institutional support, and a supportive social system.

This finding is consistent with the results reported by Firdaus et al. (2024). Their study found that several socioeconomic factors, including age, household size, off-farm income, and land tenure status, did not have a significant effect on farmers' adoption decisions. These findings suggest that farmers' adoption behavior is not always determined by economic or demographic considerations. Instead, adoption decisions may be driven more by other factors, such as perceived usefulness, ease of use, access to information, or confidence in the technology itself. Therefore, the findings of Firdaus et al. (2024) provide empirical support for the present study by reinforcing the conclusion that economic perception alone is not a significant determinant of farmers' adoption of sediment-based soil block technology.

The insignificant effect of sustainability perception indicates that environmental awareness does not necessarily translate into behavioral adoption. Although farmers may recognize the environmental benefits of utilizing lake sediment and reducing plastic waste, their adoption decisions remain primarily driven by practical considerations related to production continuity, technical assistance, and institutional reliability. This finding supports the view that pro-environmental attitudes alone are often insufficient to change farming practices unless accompanied by enabling institutional conditions and reduced implementation uncertainty.

These findings indicate that farmers' positive perceptions of sustainability do not necessarily translate into actual adoption behavior. This may be explained by previous research suggesting that the adoption of agricultural innovations is not determined solely by sustainability-related values but is also influenced by other, more dominant factors. Rizzo et al. (2024) argued that innovation complexity, high levels of innovation aversion, and low perceived behavioral control are among the primary barriers to farmers' adoption of sustainable innovations. Consequently, although farmers may recognize the importance of sustainability, they may still be reluctant to adopt an innovation if it is perceived as complex, risky, or beyond their capacity to implement effectively. Therefore, in the context of this study, sustainability perception alone was insufficient to directly influence farmers' adoption behavior, as its effect may have been overshadowed by technical and psychological barriers that play a more decisive role in the adoption process.

Similarly, the non-significant effect of economic perception suggests that anticipated economic benefits were not the dominant consideration in farmers' decisions. Because the technology was still at an early stage of dissemination, many farmers may not yet have perceived its long-term financial advantages with sufficient certainty, leading them to place greater emphasis on institutional guidance and supply chain support than on expected profitability.

These findings are broadly consistent with international studies on sustainable agricultural innovation, which report that institutional capacity, extension services, and collaborative networks frequently exert stronger influences on technology adoption than economic or environmental perceptions alone, particularly during the early stages of innovation diffusion. Consequently, the present study reinforces the argument that successful implementation of Circular Economy practices in agriculture requires not only environmentally sound technologies but also institutional and organizational mechanisms that facilitate farmers' confidence in adopting new production systems.

Integrating the Findings within the Circular Economy Framework

Table 5. Relationship Between Empirical Findings and Circular Economy Principles

Significant Finding	Circular Economy Principle	Practical Implication
Institutional support	Collaborative governance	Strengthens coordination among farmers, producers, and extension agencies.
Ease of use	Resource efficiency	Improves labor productivity and nursery efficiency.
Government support	Enabling policy	Accelerates diffusion of circular agricultural innovations.
Supply chain effectiveness	Closed-loop resource flow	Ensures continuous transformation of lake sediment into productive inputs.

Source: Primary data analysis (2025).

The findings demonstrate that the adoption of sediment-based soil block technology is driven primarily by institutional and structural factors rather than by individual economic perceptions. This supports the argument that circular economy implementation in agriculture requires coordinated governance capable of connecting waste recovery, technology dissemination, and input distribution. In the case of Rawa Pening, lake sediment is transformed from an environmental burden into a productive agricultural resource, but this transformation depends on institutions that facilitate processing, distribution, and farmer participation.

The integration of quantitative and qualitative evidence further reinforces this interpretation. While logistic regression identifies institutional support and supply chain effectiveness as significant determinants, interview findings reveal that farmers also consider trust, perceived production risks, and market certainty before adopting the innovation. These factors explain why the perceived economic benefits alone were insufficient to stimulate adoption. Therefore, successful implementation of circular agriculture requires not only technological innovation but also governance mechanisms that reduce transaction costs, strengthen farmer confidence, and ensure the long-term sustainability of circular supply chains.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that the adoption of Rawa Pening sediment-based soil block growing media is primarily driven by institutional support, ease of use, government support, and supply chain effectiveness, whereas economic perception, sustainability, information access, and raw material availability do not significantly influence farmers' adoption decisions. These findings indicate that the successful implementation of circular agricultural innovations depends not only on the perceived benefits of the technology but also on the availability of governance mechanisms that reduce adoption risks and ensure the continuity of resource flows. The study contributes to the circular economy literature by showing that the utilization of Rawa Pening sediment as growing media represents a practical form of resource recovery and waste valorization, whose success relies on the integration of institutional capacity, policy support, and supply chain management. Therefore, strengthening farmer organizations, extension services, and sustainable supply chain networks is essential to accelerate the adoption of sediment-based soil block technology and promote sustainable horticultural production. Future studies are recommended to examine the long-term economic and environmental impacts of circular agricultural innovations across different regions and agricultural commodities.

This study makes several important theoretical contributions to the literature on circular agriculture and technology adoption. First, it extends the application of Circular Economy by

integrating resource recovery, technology adoption, and supply chain perspectives into a unified analytical framework for explaining farmers' adoption behavior. While previous studies have often examined these dimensions independently, this research demonstrates that the successful implementation of circular agricultural innovations depends on the interaction between institutional support, technological characteristics, and supply chain effectiveness. The findings therefore contribute to a more comprehensive understanding of how Circular Economy principles are translated into actual technology adoption at the farm level.

From a practical perspective, the study provides empirical evidence that institutional support and supply chain coordination play a more influential role in promoting the adoption of sediment-based soil block technology than economic considerations alone. These findings suggest that policymakers, agricultural extension agencies, and local governments should prioritize strengthening institutional collaboration, expanding farmer training programs, and improving market and distribution networks to accelerate the implementation of circular agriculture. Moreover, the successful utilization of Rawa Pening sediment as a productive agricultural input demonstrates the potential of resource recovery strategies to simultaneously address environmental degradation and support sustainable horticultural production, offering a practical model that can be adapted in other regions facing similar environmental challenges.

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