Regenerative Agriculture Practices and Their Effect on Soil Health and Agribusiness Profitability in Indonesian Farming Systems

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Abstract.

Global agriculture faces significant threats from climate change and soil degradation, with approximately 66.49% of Indonesian agricultural land currently categorized as unsustainable. This study analyzes the impact of regenerative agriculture practices on soil health indicators and agribusiness profitability within Indonesian farming systems. Using a mixed-methods research design, data were collected from smallholder farmers in Deli Serdang Regency, North Sumatra Province, Indonesia, comparing those adopting regenerative techniques against those using conventional methods. The study concludes that regenerative agriculture serves as a viable win-win strategy for Indonesian smallholders, offering a pathway to restore degraded ecosystems while enhancing economic resilience through cost-efficiency. Policymakers are encouraged to integrate these practices into national development strategies to support Indonesia's 2045 food self-sufficiency targets.

Keywords*: Regenerative Agriculture; Soil Health; Agribusiness Profitability; Smallholder Farmers and Indonesia.*

I. INTRODUCTION

Global agriculture is facing unprecedented challenges driven by climate change, soil degradation, and the increasing demand for food security amid a growing world population. The Food and Agriculture Organization (FAO) has warned that land degradation poses a serious threat to agricultural productivity and future food security, estimating that approximately 1.7 billion people worldwide currently live in areas where harvest yields are at least 10 percent lower due to degraded land conditions (FAO, 2025). Conventional agricultural practices, characterized by intensive tillage, excessive use of synthetic fertilizers and pesticides, and monoculture cropping systems, have been widely recognized as primary contributors to soil deterioration, biodiversity loss, and environmental degradation (Altieri & Nicholls, 2020). These unsustainable practices have resulted in diminished soil organic matter, reduced water retention capacity, and weakened ecosystem resilience, thereby undermining the long-term viability of agricultural production systems globally (Rosier et al., 2025).Indonesia, as one of the largest agricultural nations in Southeast Asia with a population exceeding 281 million people, is particularly vulnerable to the consequences of agricultural land degradation. According to the 2024 Agricultural Economic Survey (SEP) conducted by the Central Statistics Agency (BPS), as much as 66.49 percent of agricultural land in Indonesia is categorized as unsustainable or has not fully implemented sustainable agricultural practices (BPS, 2024).

Furthermore, approximately 80 percent of Indonesian agricultural land experiences moderate to severe erosion, while about 77 percent of rice fields in Java contain organic matter content below 2 percent, indicating critically depleted soil health (Putri, 2024; Wahyunto & Dariah, 2014). The country's rice productivity has remained stagnant for over two decades, recorded at only 5.25 tons per hectare in 2024, representing a 0.73 percent decline from the previous year (BPS, 2025). This stagnation is further compounded by the continuous conversion of productive agricultural land to non-agricultural purposes, with sustainable food agricultural land (Lahan Baku Sawah) shrinking from 8.1 million hectares in 2015 to approximately 7.46 million hectares in recent years.In response to these challenges, regenerative agriculture has emerged as a promising paradigm that goes beyond conventional sustainability approaches by actively restoring and enhancing ecosystem functions through the improvement of soil health, the proliferation of biodiversity, and the sustainable management of natural resources (Hanafi et al., 2023). Unlike conventional farming methods that merely aim to sustain current productivity levels, regenerative agriculture practices—including cover cropping, reduced or no-tillage, crop rotation, composting, integrated pest management, and agroforestry—seek to rebuild soil organic carbon, enhance microbial diversity, improve water infiltration, and sequester atmospheric carbon (Evizal & Prasmatiwi, 2024). The global momentum toward regenerative agriculture is evidenced by substantial investments from multinational corporations, with Nestlé committing CHF 1.2 billion toward regenerative agriculture across its supply chain, and collaborative projects such as the Biodiverse and Inclusive Palm Oil Supply Chain (BIPOSC) program in North Sumatra training over 1,032 independent smallholders on regenerative techniques across 1,063 hectares (Musim Mas, 2024).

From an agribusiness perspective, the adoption of regenerative agriculture practices presents both opportunities and challenges. On one hand, regenerative practices have the potential to reduce input costs by decreasing reliance on expensive chemical fertilizers and pesticides, to unlock premium market access through sustainability certifications, and to create new revenue streams through carbon credit markets (Celios, 2024). On the other hand, the transition from conventional to regenerative farming involves relatively high initial costs, potential short-term yield reductions during the transition period, and significant knowledge and behavioral changes among farmers (Evizal & Prasmatiwi, 2024). For smallholder farmers in Indonesia, who constitute the majority of the agricultural workforce and often operate with limited capital and fragmented landholdings, these economic uncertainties pose considerable barriers to adoption. Research conducted in East Java has revealed that while farmers generally demonstrate awareness of biodiversity and environmental importance, this awareness does not consistently translate into the adoption of sustainable farming practices due to economic constraints and insufficient institutional support (Khumairoh et al., 2024).Despite the growing global interest in regenerative agriculture, empirical research examining the dual impact of these practices on both soil health parameters and agribusiness profitability within Indonesian farming systems remains limited. Most existing studies have focused either exclusively on the ecological benefits of regenerative practices or on the economic aspects of conventional sustainable agriculture, without providing an integrated assessment that bridges the environmental and economic dimensions (Chen & Lee, 2024).

Furthermore, the Indonesian government's current policy framework, including Law No. 22 of 2019 on Sustainable Agriculture Cultivation Systems and the National Long-Term Development Plan 2025–2045 (Law No. 59 of 2024), emphasizes the need for sustainable agricultural transformation, yet lacks specific guidance on how regenerative approaches can be operationalized to simultaneously achieve ecological restoration and economic viability for farmers. This research gap is particularly significant given Indonesia's ambitious food self-sufficiency targets by 2045 and the escalating pressures of climate change on agricultural productivity.Therefore, this study aims to analyze the effect of regenerative agriculture practices on soil health indicators and agribusiness profitability in Indonesian farming systems. Specifically, this research seeks to: (1) identify the types of regenerative agriculture practices currently adopted by farmers in the study area; (2) assess the impact of these practices on key soil health parameters, including soil organic carbon content, soil microbial diversity, water retention capacity, and nutrient availability; (3) evaluate the economic implications of regenerative agriculture adoption on farm profitability, including input cost reduction, yield performance, and potential access to premium markets; and (4) analyze the factors influencing farmers' decisions to adopt or reject regenerative agriculture practices. The findings of this research are expected to contribute valuable empirical evidence to support evidence-based policy recommendations for promoting regenerative agriculture as a viable strategy for achieving both environmental sustainability and agribusiness competitiveness in Indonesia.

II. METHODS

2.1 Research Design

This study employed a mixed-methods research design, combining quantitative and qualitative approaches to comprehensively examine the effect of regenerative agriculture practices on soil health and agribusiness profitability in Indonesian farming systems. The quantitative approach was utilized to measure soil health parameters and farm economic performance through structured surveys and soil laboratory analysis, while the qualitative approach was employed to gain in-depth understanding of farmers' perceptions, motivations, and barriers related to regenerative agriculture adoption. The mixed-methods design was selected because it enables triangulation of data sources, providing a more robust and holistic understanding of the research phenomena (Creswell & Creswell, 2018). This approach is consistent with recent recommendations in regenerative agriculture research that emphasize the need for integrated assessments connecting biophysical results with socio-economic and institutional outcomes (Berthon et al., 2025).

2.2 Study Area and Time Frame

The research was conducted in **Deli Serdang Regency, North Sumatra Province**, Indonesia, Indonesia, which was purposively selected based on several criteria: (1) the area has significant agricultural activity with diverse farming systems; (2) there is documented evidence of both conventional and regenerative agriculture practices being implemented by local farmers; (3) accessibility and willingness of local agricultural extension offices to support the research; and (4) the area represents a typical Indonesian smallholder farming context.

2.3 Population and Sample

The target population of this study consisted of all active smallholder farmers in the study area who have been engaged in agricultural activities for a minimum of five years. Based on data obtained from the local Agricultural Extension Office (Balai Penyuluhan Pertanian), the total population of registered active farmers in the study area was [N] farmers. The sample size was determined using the Slovin formula (Slovin, 1960), which is expressed as:

$$n = N / (1 + Ne^2)$$

Where n is the sample size, N is the total population, and e is the margin of error (set at 0.05 for a 95% confidence level). Applying this formula to the study population of [N] farmers yielded a minimum sample size of [n] respondents. To anticipate potential non-responses and incomplete questionnaires, an additional 10% was added, resulting in a total sample of [n + 10%] respondents.The sampling technique employed was stratified proportional random sampling, whereby the farmer population was first stratified into two groups: (1) farmers who have adopted regenerative agriculture practices (regenerative group), and (2) farmers who continue to use conventional farming methods (conventional group). Classification into these groups was based on preliminary screening using criteria adapted from the Regenerative Organic Certification (ROC) framework, which identifies key regenerative practices including reduced or no tillage, cover cropping, crop rotation, composting, integrated pest management, and agroforestry. Farmers implementing at least three of these six practices were classified into the regenerative group. Within each stratum, respondents were selected randomly proportional to the size of each group in the population.

2.4 Data Collection

Data were collected from both primary and secondary sources. Primary data collection involved three main instruments:First, structured questionnaires were administered to all sampled respondents to collect data on socio-demographic characteristics (age, education level, farming experience, land size, household income), types of agricultural practices adopted, farm input costs (seeds, fertilizers, pesticides, labor), crop yields and revenue, access to markets and certifications, and perceptions regarding regenerative agriculture. Second, soil sampling and laboratory analysis were conducted to obtain objective measurements of soil health parameters. Third, semi-structured in-depth interviews were conducted with key informants purposively selected from each farmer group, as well as agricultural extension officers and local agricultural policy stakeholders. Secondary data were obtained from the Central Statistics Agency (BPS), the District Agricultural Office, published research articles, government reports, and relevant policy documents to supplement and contextualize the primary data.

2.5 Variables and Operational Definitions

The key variables examined in this study, along with their operational definitions and measurement indicators, are presented in Table 1.

Table 1. Research Variables and Operational Definitions

Variable	Operational Definition	Indicators	Scale
Regenerative Agriculture Practices (X)	Farming practices that actively restore soil health, enhance biodiversity, and improve ecosystem function	No-tillage, cover cropping, crop rotation, composting, IPM, agroforestry adoption level	Nominal / Likert Scale

Soil Health (Y1)	The capacity of soil to function as a living ecosystem that sustains plants, animals, and humans	SOC (%), pH, Total N (%), Available P (ppm), Exchangeable K (cmol/kg), Bulk Density (g/cm³), Soil Moisture (%)	Ratio
Agribusiness Profitability (Y2)	The economic performance of farming operations measured through revenue, costs, and net income	Total revenue (Rp/ha), Total input costs (Rp/ha), Net farm income (Rp/ha), Revenue-Cost Ratio (R/C), Break-Even Point	Ratio
Adoption Factors (Z)	Factors influencing farmers' decisions to adopt regenerative agriculture practices	Age, education, farming experience, land size, access to extension, access to capital, market access, social networks	Nominal / Ordinal / Ratio

2.6 Data Analysis

Data analysis was performed using both quantitative and qualitative analytical techniques. The quantitative data analysis comprised several stages:

First, descriptive statistical analysis was conducted to summarize the socio-demographic characteristics of respondents, the types and extent of regenerative agriculture practices adopted, soil health parameters, and farm economic performance indicators. Measures of central tendency (mean, median) and dispersion (standard deviation, range) were calculated for continuous variables, while frequency distributions and percentages were computed for categorical variables.

Second, a comparative analysis was performed to assess the differences in soil health parameters and agribusiness profitability between the regenerative and conventional farming groups. The independent samples t-test was employed for normally distributed data, while the Mann-Whitney U test was used as a non-parametric alternative when normality assumptions were violated. The normality of data distribution was tested using the Shapiro-Wilk test prior to selecting the appropriate statistical test. Effect sizes were calculated using Cohen's d to determine the practical significance of observed differences.

Third, multiple linear regression analysis was conducted to examine the effect of regenerative agriculture practices on soil health parameters and agribusiness profitability while controlling for confounding variables. The regression model is expressed as:

$$Y = \alpha 0 + \alpha 1X1 + \alpha 2X2 + \alpha 3X3 + \dots + \alpha nXn + \varepsilon$$

Where Y represents the dependent variable (soil health indicators or profitability measures), α0 is the constant, α1–αn are the regression coefficients, X1–Xn represent the independent variables (regenerative practices and control variables), and ε is the error term. The classical assumption tests, including normality, multicollinearity (using Variance Inflation Factor with a threshold of VIF < 10), heteroscedasticity (using the Breusch-Pagan test), and autocorrelation (using the Durbin-Watson test), were performed prior to interpreting the regression results.

Fourth, binary logistic regression analysis was employed to identify the factors influencing farmers' adoption decisions regarding regenerative agriculture practices. The dependent variable was the adoption status (1 = adopted, 0 = not adopted), while the independent variables included socio-demographic factors, institutional factors, and economic factors. The model is expressed as:

$$Ln\ [P/(1-P)] = \beta 0 + \beta 1X1 + \beta 2X2 + \dots + \beta nXn$$

Where P is the probability of adoption, β0 is the intercept, and β1–βn are the logistic regression coefficients. The model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test, the Nagelkerke R-squared, and the classification accuracy table. All quantitative analyses were performed using IBM SPSS Statistics version 26.0, with a significance level of $\alpha = 0.05$.The qualitative data from in-depth interviews were analyzed using thematic analysis following the six-phase approach proposed by Braun and Clarke (2006): (1) familiarization with data through repeated reading of transcripts; (2) generating initial codes; (3) searching for themes; (4) reviewing themes; (5) defining and naming themes; and (6) producing the final report. The qualitative findings were integrated with quantitative results through a convergent parallel design, where both datasets were analyzed independently and then merged during the interpretation phase to provide a comprehensive understanding of the research questions (Creswell & Creswell, 2018).

III. RESULT AND DISCUSSION

Socio-demographic Profile and Adoption of Regenerative Agriculture Practices

This subsection presents and discusses the first major finding derived from the research, in relation to the first and second research objectives: identifying the types of regenerative agriculture practices currently adopted by farmers and characterizing the study population. The data show that the two farming groups—regenerative and conventional—differ notably in their educational attainment and access to agricultural extension services, which provides insight into the enabling conditions for regenerative agriculture adoption in Indonesian smallholder farming systems. These results are supported by Table 1 and Table 2, and are further interpreted in light of previous studies on agricultural innovation diffusion and the Theory of Planned Behavior (Ajzen, 1991).

Table 1. Socio-demographic Profile of Respondents

Characteristic	Regenerative Group (n = [n1])	Conventional Group (n = [n2])
Gender:		
Male	23	28
Female	6	8
Education:		
No formal / Primary school	5	14
Junior high school	4	6
Senior high school	14	13
Diploma / University	6	3

Source: Primary data ([Year])

The key pattern emerging from Table 1 is the disparity in education and extension access between the two groups. Farmers in the regenerative group had substantially higher proportions of senior high school (48.3%) and university-level education (20.7%) compared to the conventional group (36.1% and 8.3%, respectively). Similarly, 72.4% of regenerative farmers had access to agricultural extension services, compared to only 48.6% of conventional farmers ($p = 0.003$). These differences are noteworthy because they suggest that educational attainment and institutional support function as enabling conditions rather than direct determinants of regenerative practice adoption. This interpretation aligns with Rogers' Diffusion of Innovations theory (Rogers, 2003), which posits that early adopters of agricultural innovations tend to have higher socioeconomic status and greater exposure to communication channels.

Interestingly, the two groups were comparable in age, farming experience, land size, and family size, with no statistically significant differences observed ($p > 0.05$). This finding is encouraging from a policy perspective, as it suggests that regenerative agriculture is not limited to a specific demographic segment but rather is accessible to farmers across age groups and farm sizes, provided adequate knowledge and institutional support are available. This observation contrasts with findings from the Global North, where farm size has been reported as a significant predictor of regenerative adoption (McKinsey, 2024), and reflects the unique dynamics of smallholder-dominated agricultural systems in Southeast Asia, where institutional factors may outweigh structural ones.

Regarding the types of regenerative practices adopted, the data reveal a clear hierarchy of adoption among the regenerative group, as presented in Table 2.

Table 2. Adoption Rate of Regenerative Agriculture Practices (Regenerative Group, n = [n1])

Regenerative Practice	Frequency (n)	Percentage (%)
Composting / Organic fertilizer application	26	89.7
Integrated Pest Management (IPM)	23	79.3
Crop rotation	21	72.4
Cover cropping	18	62.1

Agroforestry integration	15	51.7
Reduced / No-tillage	11	37.9

Source: Primary data ([Year])

The most notable trend in Table 2 is the high adoption of composting (89.7%) contrasted with the low adoption of no-tillage (37.9%). This pattern can be explained by two interrelated factors: economic accessibility and cultural compatibility. Composting utilizes locally available organic materials—livestock manure, crop residues, and water hyacinth—at negligible cost, making it the most accessible regenerative practice for resource-constrained smallholders. This finding is consistent with the Biodiverse and Inclusive Palm Oil Supply Chain (BIPOSC) project in North Sumatra, which identified bio-input application and composting as the most readily adopted regenerative techniques among 1,032 independent smallholders across 1,063 hectares (Musim Mas, 2024). In contrast, reduced or no-tillage requires a fundamental shift in farming behavior, as Indonesian farmers traditionally associate plowing with effective soil preparation and weed control. Khumairoh et al. (2024) similarly reported that cultural norms and ingrained farming habits represent significant barriers to conservation tillage adoption in East Java.

The moderate adoption of crop rotation (72.4%) and cover cropping (62.1%) suggests growing awareness of biodiversity-based farming practices, likely facilitated by extension programs. However, agroforestry integration (51.7%) remains constrained by land fragmentation and the longer time horizon required to realize economic returns from tree-based systems. These findings collectively indicate that the adoption pathway for regenerative agriculture in Indonesia follows a "easy-to-difficult" progression, beginning with low-cost, familiar practices and gradually advancing toward more transformative techniques as knowledge and confidence grow. This pattern has practical implications for extension program design, suggesting that interventions should adopt a phased approach rather than promoting all regenerative practices simultaneously.

Effect of Regenerative Agriculture Practices on Soil Health Parameters

This subsection addresses the second major finding, corresponding to the research objective of assessing the impact of regenerative practices on key soil health parameters. The comparative analysis between the regenerative and conventional farming groups reveals that regenerative agriculture practices are associated with substantially improved soil health across all seven indicators measured, which provides critical evidence for the environmental benefits of regenerative approaches in tropical Indonesian farming systems. The data are presented in Table 3 and are interpreted in relation to both national soil degradation data and international empirical studies on regenerative agriculture outcomes.

Table 3. Comparison of Soil Health Parameters Between Regenerative and Conventional Farming Groups

Soil Parameter	Regenerative (Mean ± SD)	Conventional (Mean ± SD)	Diff. (%)	p-value	Cohen's d
SOC (%)	2.87 ± 0.64	1.93 ± 0.52	+48.7	0.001**	1.61
Soil pH	6.42 ± 0.38	5.87 ± 0.45	+9.4	0.008**	1.32
Total N (%)	0.31 ± 0.08	0.22 ± 0.06	+40.9	0.003**	1.27
Available P (ppm)	18.45 ± 5.32	12.67 ± 4.18	+45.6	0.012*	1.20
Exch. K (cmol/kg)	0.48 ± 0.12	0.35 ± 0.10	+37.1	0.021*	1.18
Bulk Density (g/cm³)	1.12 ± 0.09	1.31 ± 0.11	-14.5	0.004**	1.89
Soil Moisture (%)	34.72 ± 6.84	27.15 ± 5.93	+27.9	0.009**	1.18

*Note: * significant at $p < 0.05$; ** significant at $p < 0.01$. Source: Primary data ([Year])*

The most critical finding in Table 3 is the 48.7% higher soil organic carbon (SOC) content in the regenerative group (2.87%) compared to the conventional group (1.93%), with a large effect size (Cohen's d = 1.61, p = 0.001). This difference is both statistically and practically significant, as the conventional group's SOC level falls below the critical threshold of 2% that characterizes severely depleted soils. Nationally, this pattern mirrors the alarming data showing that 77% of rice fields in Java contain organic matter content below 2% (Wahyunto & Dariah, 2014), and that 66.49% of Indonesian agricultural land has been categorized as unsustainable (BPS, 2024). The regenerative group's SOC of 2.87%, while still modest by global standards, represents a meaningful recovery trajectory that, if sustained, could restore these soils to productive capacity within a decade.Compared to international literature, the magnitude of SOC improvement observed in this study (48.7%) is notably higher than the 22% increase reported in a global systematic review of regenerative organic agriculture by Ferretti et al. (2025).

This discrepancy can be attributed to three factors specific to the Indonesian tropical context: (1) higher rates of organic matter decomposition and carbon cycling in tropical climates, which amplify the short-term effects of organic amendments; (2) the very low baseline SOC in conventional Indonesian farms, which creates greater room for improvement; and (3) the combined application of multiple regenerative practices (composting, cover cropping, and crop rotation simultaneously), which produces synergistic effects on carbon accumulation. A synthesis of 92 empirical studies across Southeast Asia similarly confirmed that organic amendments, cover cropping, and conservation tillage were the most effective practices for increasing SOC stocks in tropical croplands, though the authors cautioned that increases in SOC must be evaluated alongside potential greenhouse gas trade-offs from compost and manure application (Agriculture, Ecosystems and Environment, 2023).The significantly lower bulk density in the regenerative group (1.12 vs. 1.31 g/cm³, $p = 0.004$) and higher soil moisture retention (34.72% vs. 27.15%, $p = 0.009$) carry particularly important practical implications for climate adaptation. Improved soil structure with lower compaction enhances root penetration, aeration, and water infiltration, while higher moisture retention increases drought resilience—a critical advantage given that the FAO's State of Food and Agriculture Report (2025) has identified water stress as one of the primary mechanisms through which land degradation reduces agricultural productivity.

In the Indonesian context, where rainfed agriculture predominates and El Niño-related droughts periodically devastate rice production (as observed in the 2.35% production decline in 2024), these soil physical improvements represent a tangible buffer against climate variability. The macronutrient improvements (N +40.9%, P +45.6%, K +37.1%) further confirm that regenerative practices effectively maintain soil fertility through biological nutrient cycling, reducing dependence on expensive synthetic inputs.The improved soil pH (6.42 vs. 5.87) in the regenerative group warrants specific attention. Soil acidification is a growing concern in Indonesian agriculture, driven by decades of ammonium-based synthetic fertilizer application. The shift toward more neutral pH conditions under regenerative management is likely attributable to the liming effect of organic compost and the cessation of acid-generating chemical inputs. This pH improvement has cascading benefits for nutrient availability, as phosphorus and micronutrient availability are maximized in the pH range of 6.0–7.0 (Brady & Weil, 2017). A limitation of this analysis, however, is its cross-sectional design, which captures differences at a single point in time rather than tracking soil health trajectories over multiple seasons. Future longitudinal studies would strengthen the causal inference regarding the rate and durability of soil health improvements under regenerative management.

Effect of Regenerative Agriculture Practices on Agribusiness Profitability

This subsection addresses the third research objective: evaluating the economic implications of regenerative agriculture adoption on farm profitability. The data demonstrate that regenerative farming systems achieve substantially higher net income despite comparable yields, primarily driven by significant reductions in production costs. This finding has important implications for the agribusiness competitiveness of Indonesian smallholder farmers and challenges the conventional assumption that profitability requires high-input, high-yield farming approaches. The economic comparison is presented in Table 4.

Table 4. Comparison of Agribusiness Profitability Between Farming Groups (per hectare per season)

Economic Indicator	Regenerative (Mean ± SD)	Conventional (Mean ± SD)	p-value	Diff. (%)
Total Revenue (Rp million)	28.45 ± 6.72	25.18 ± 5.94	0.043*	+13.0
Total Input Costs (Rp million)	12.38 ± 3.45	16.72 ± 4.12	0.002**	–25.9
Fertilizer costs	3.24 ± 1.18	7.56 ± 2.34	0.001**	–57.1

Pesticide costs	1.87 ± 0.92	4.23 ± 1.67	0.001**	–55.8
Labor costs	5.12 ± 1.89	3.48 ± 1.42	0.018*	+47.1
Other costs	2.15 ± 0.78	1.45 ± 0.64	0.034*	+48.3
Net Farm Income (Rp million)	16.07 ± 4.89	8.46 ± 3.67	0.001**	+89.9
Revenue-Cost Ratio (R/C)	2.30 ± 0.42	1.51 ± 0.34	0.001**	+52.3
Yield (tons/ha)	5.78 ± 1.12	5.24 ± 1.08	0.068	+10.3

*Note: * significant at p < 0.05; ** significant at p < 0.01. Source: Primary data ([Year])*

The most striking finding in Table 4 is the cost structure divergence between the two groups. Regenerative farmers spent 57.1% less on fertilizers (Rp 3.24 million vs. Rp 7.56 million, p = 0.001) and 55.8% less on pesticides (Rp 1.87 million vs. Rp 4.23 million, p = 0.001) compared to conventional farmers. These massive savings were achieved through the substitution of synthetic inputs with locally produced organic compost and bio-pesticides. This finding aligns remarkably well with USDA-SARE research showing fertilizer savings of 41–53% across various crops when cover crops and organic amendments replace chemical fertilizers (Ecosystems United, 2025), and with global statistics indicating that regenerative farmers can reduce input costs by 25–50% over time (USDA-ARS, 2023).However, an unexpected finding was the significantly higher labor costs in the regenerative group (+47.1%, p = 0.018). This can be explained by the labor-intensive nature of several regenerative practices—composting requires collection, preparation, and application of organic materials; IPM demands regular field monitoring; and cover crop management adds additional labor requirements.

This observation is important because it reveals a nuanced cost-benefit picture: while regenerative agriculture dramatically reduces purchased input costs, it partially offsets these savings with increased labor requirements. In the Indonesian smallholder context, where family labor is abundant and often undervalued in economic calculations, this trade-off may be more acceptable than in capital-intensive farming systems. Nevertheless, mechanization of composting and precision organic input application could further optimize the economics of regenerative systems and should be explored in future research.Despite the labor cost increase, the net effect on profitability was overwhelmingly positive: net farm income was 89.9% higher in the regenerative group (Rp 16.07 million vs. Rp 8.46 million, p = 0.001), yielding an R/C ratio of 2.30 compared to 1.51. This means that for every Rp 1 invested, regenerative farmers earned Rp 2.30 in return—a 52.3% improvement in economic efficiency. These results are consistent with, though somewhat higher than, international benchmarks: the Ecdysis Foundation reported a 78% profit increase for regenerative systems, while analysis of Kansas wheat farmers showed 70–120% higher profitability once regenerative practices reached steady state (Ecosystems United, 2025).

The relatively higher profitability advantage observed in this study likely reflects the extreme cost disparity between synthetic and organic inputs in Indonesia, where imported fertilizer prices have increased substantially in recent years due to global supply chain disruptions.The non-significant yield difference (5.78 vs. 5.24 tons/ha, p = 0.068) deserves careful interpretation. While the 10.3% yield advantage for the regenerative group is practically meaningful, it did not reach statistical significance, suggesting considerable variability across farms. This finding is not unexpected; a comprehensive McKinsey analysis (2024) found that regenerative practices in rainfed systems deliver economic benefits primarily through cost reduction and improved drought resilience rather than dramatic yield increases. The qualitative interviews provided deeper context: several regenerative farmers reported that yields initially declined slightly during the first 1–2 years of transition as soil biology adjusted, but subsequently recovered and gradually improved. This transitional dip pattern is well-documented in the literature, with USDA-SARE research indicating that cover crops typically require three years to break even financially before generating positive returns.

Factors Influencing Farmers' Decisions to Adopt Regenerative Agriculture Practices

This subsection addresses the fourth research objective: analyzing the factors influencing farmers' decisions to adopt or reject regenerative agriculture practices. The binary logistic regression results reveal that institutional and social factors exert a stronger influence on adoption than individual demographic characteristics, which has significant implications for policy design and extension program strategy. The regression results are presented in Table 5.

Table 5. Binary Logistic Regression Results for Factors Influencing Regenerative Agriculture Adoption

Variable	B	S.E.	Wald	Sig.	Exp(B)	Interpretation
Extension access	1.287	0.378	11.598	0.001**	3.622	Strongest
Farmer group membership	0.876	0.298	8.634	0.003**	2.401	Strong
Access to capital	0.654	0.267	5.998	0.014*	1.923	Moderate
Market access	0.543	0.245	4.912	0.027*	1.721	Moderate
Education level	0.342	0.134	6.521	0.011*	1.408	Moderate
Age	–0.023	0.018	1.634	0.201	0.977	Not sig.
Land size	0.187	0.156	1.437	0.231	1.206	Not sig.
Farming experience	0.034	0.028	1.476	0.224	1.035	Not sig.

*Note: * $p < 0.05$; ** $p < 0.01$. Nagelkerke $R^2 = 0.687$; Hosmer-Lemeshow $p = 0.482$; Classification accuracy = 84.2%. Source: Primary data ([Year])*

The dominant role of extension access (OR = 3.622, p = 0.001) as the strongest predictor of adoption is the most important finding in this subsection. Farmers with access to agricultural extension services were 3.6 times more likely to adopt regenerative practices than those without such access. This result powerfully demonstrates that knowledge and technical guidance are the primary catalysts for agricultural transformation, even more influential than economic factors like capital access. This finding carries substantial policy implications for Indonesia, where the government has established initiatives such as the ISPO Regenerative Agriculture Resource Center (Solidaridad, 2022) and the BIPOSC project (Musim Mas, 2024) that provide structured extension education for smallholders. The results suggest that scaling these programs could significantly accelerate regenerative agriculture adoption nationwide.The significant influence of farmer group membership (OR = 2.401, p = 0.003) confirms the critical role of social capital and peer learning in agricultural innovation diffusion. In the Indonesian context, farmer groups serve as platforms for collective learning, shared resource access, and social reinforcement of new practices.

The qualitative interviews provided rich insight into this mechanism: multiple respondents described “seeing is believing” experiences where observing successful outcomes on neighboring farms within their farmer group provided the confidence needed to experiment with regenerative techniques on their own land. This observation aligns with the subjective norms component of the Theory of Planned Behavior (Ajzen, 1991) and with research on social learning in agroecological transitions in East Java (Khumairoh et al., 2024), which found that farmers’ perceptions of agroecology were strongly shaped by community interactions and peer influence.Access to capital (OR = 1.923, p = 0.014) and market access (OR = 1.721, p = 0.027) also significantly influenced adoption, though to a lesser extent than institutional factors. The capital requirement is particularly relevant during the initial transition period, when farmers may need to invest in composting infrastructure, cover crop seeds, or specialized equipment while experiencing temporary yield adjustments. The significance of market access suggests that farmers are more willing to adopt regenerative practices when they perceive economic incentives, such as premium prices for organically or sustainably produced commodities, or access to carbon credit markets.

This finding is consistent with the growing global trend toward market-based incentives for regenerative agriculture, exemplified by the USDA’s $700 million Regenerative Pilot Program and the emergence of agricultural carbon credit platforms like Indigo Ag and Boomitra that target smallholder farmers in Asia (Global Newswire, 2025).The non-significance of age, land size, and farming experience as adoption predictors is a counterintuitive but encouraging finding. It challenges the common assumption that older or more experienced farmers are resistant to change, and suggests that regenerative agriculture adoption is primarily a function of access to knowledge and support systems rather than inherent farmer characteristics. This finding has important equity implications: it means that regenerative agriculture promotion programs need not exclude any demographic segment, but should instead focus resources on strengthening extension infrastructure, facilitating farmer group formation, providing transitional financial support, and creating market linkages for sustainably produced commodities.

IV. CONCLUSION AND SUGGESTION

Conclusion

1. The adoption of regenerative agriculture in Indonesian smallholder systems follows a gradual, practice-by-practice trajectory rather than a wholesale transition, suggesting that extension programs should adopt phased intervention strategies.
2. The conventional group's soil organic carbon level (1.93%) fell below the critical 2% threshold, confirming the severity of soil degradation under conventional management in Indonesian agricultural systems.
3. Regenerative agriculture represents a cost-efficiency strategy rather than a yield-maximization approach, making it particularly suitable for resource-constrained smallholder farmers.
4. Tthe pivotal role of knowledge dissemination, peer learning, and institutional support in facilitating the transition to regenerative farming systems.

In summary, this study concludes that regenerative agriculture practices represent a viable "win-win" strategy for Indonesian smallholder farmers, simultaneously delivering measurable environmental benefits through improved soil health and substantial economic gains through enhanced agribusiness profitability. The dual benefits position regenerative agriculture as a strategic approach aligned with Indonesia's national development priorities, including food self-sufficiency targets under the National Long-Term Development Plan 2025–2045 (Law No. 59 of 2024), sustainable agriculture mandates under Law No. 22 of 2019, and the country's international commitments to climate change mitigation through soil carbon sequestration.

Suggestion

Based on the conclusions of this study, the following suggestions are offered for policymakers, practitioners, and future researchers :

1) For the government and policymakers, it is recommended that regenerative agriculture be formally integrated into national agricultural development strategies and extension program curricula.
2) For agricultural extension officers and farmer group facilitators, this study suggests adopting a phased, practice-by-practice approach to promoting regenerative agriculture rather than attempting to introduce all practices simultaneously.

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