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Sustainability Analysis of Shallot Farming in Pidie Regency

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Abstract: Shallots (Allium cepa L.) in Pidie Regency represent a strategic horticultural commodity characterized by high risk due to price volatility and a capital-intensive cost structure. This study aims to analyze the economic sustainability status, identify leverage factors, and formulate policy interventions for shallot farming in Pidie Regency. Primary data were collected through structured interviews with 145 respondents selected via simple random sampling. Data were analyzed using the Multi-Dimensional Scaling (MDS) ordination technique with the Rap-BawangMerah model. The results indicated that the economic sustainability index reached 64.56%, placing it in the "Moderately Sustainable" category. The ordination model is valid and stable, supported by a coefficient of determination (R^2 = 0.942), a stress value of 0.151, and a low Monte Carlo simulation deviation of 0.81 points. Leverage analysis confirmed that the farmers' average income (RMS = 4.59) and financial viability (RMS = 3.56) were the two most dominant leverage attributes. This study demonstrates the occurrence of an economic trap phenomenon, where farming profits only suffice for basic working capital without generating long-term capital accumulation. Policy recommendations are directed toward strengthening Village-Owned Enterprises (BUMDes) as market guarantors (off-takers), facilitating communal deferred-sale systems, and substituting chemical inputs with self-produced organic variants to reduce production costs.

Keywords: *Shallot, Economic Sustainability, Multi-Dimensional Scaling, Leverage Factors.*

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I. INTRODUCTION

The agricultural sector contributes 12.53% to the national GDP and absorbs 28.21% of the workforce (1). Within this sector, shallots (Allium cepa L.) represent a primary horticultural commodity that significantly influences macro-inflation. Despite stable national consumption at 2.86 kg/capita/year (2), sharp price volatility frequently occurs, such as a 55.8% spike in April 2024, which increases farmers' financial risks. Biologically, the shallow fibrous root system of shallots (15–20 cm) and the high sensitivity of their vegetative organs demand intensive input management to maintain bulb (bulbus) quality (3) (4).

Pidie Regency is the largest shallot production center in Aceh Province; however, abundant regional production does not automatically guarantee farmers' economic welfare. Previous studies have highlighted low marketing efficiency resulting from long distribution chains and severe dependence on middlemen (5). Furthermore, the phenomenon of market glut during peak harvest periods often forces selling prices below production costs (6), thereby hindering capital accumulation, eroding financial resilience, and triggering chronic debt cycles as chemical input costs dominate 60%–70% of total operational expenditures (7).

The economic dimension serves as the primary foundation for adopting environmentally friendly technologies and achieving long-term sustainability across ecological and social dimensions (8) (9). In imperfect markets, smallholder behavior deviates from classic profit-maximization assumptions, shifting instead toward survival strategies and the safety-first principle driven by risk-aversion behaviors to secure basic domestic needs (10) (11). Consequently, farmers possess short-term absorptive capacity against temporary price shocks but lack long-term adaptive capacity for independent structural investments (12). Agricultural economic sustainability must therefore be evaluated through integrated indicators of formal capital access, cost efficiency, income growth, and competitiveness against market shocks (13) (14).

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To systematically quantify this level of sustainability, Multi-Dimensional Scaling (MDS) serves as a robust multivariate statistical technique to reduce data dimensionality by mapping the similarities or dissimilarities of attributes into a low-dimensional geometric space (15). This technique is operationally applied through the Rapid Appraisal for Sustainability (RAPS) method, such as Rapfish, which successfully converts qualitative ordinal scale data into a standardized quantitative index ranging from 0% to 100% (16) (17).

Three research gaps persist in the existing literature regarding this topic. First, previous studies in Pidie Regency were limited to partial income and marketing efficiency analyses without measuring a composite economic index (5) (9). Second, similar sustainability studies in Aceh Province (18) relied primarily on outdated macro-secondary data, which fails to reflect recent price fluctuations (2024–2025). Third, there is a distinct lack of quantitative mapping regarding leverage factors within the local shallot supply chain.

To bridge these scientific gaps, the novelty of this study lies in utilizing the MDS-based Rap-BawangMerah ordination technique restricted to the economic dimension with 7 comprehensive attributes using recent primary data (2025). This approach allows for the objective mapping of leverage factors via Root Mean Square (RMS) values validated through Monte Carlo simulations. The economic status of shallot farming in Pidie is hypothesized to fall within the "Moderately Sustainable" category due to a pseudo-equilibrium, with the average income of farmers serving as the primary leverage attribute (13) (19).

II. METHODOLOGY

This study was purposefully conducted in Pidie Regency, Aceh Province, as a major center for shallot production. Field data collection was carried out from September to October 2025, aligning with the planting and harvesting phases. The population encompassed all farmers across four districts with the highest harvested areas (Simpang Tiga, Pidie, Batee, and Peukan Baro), totaling N = 228 individuals. The sample size was calculated using the Slovin formula at a 5% error margin, yielding 145 respondents selected via simple random sampling.

$$n = \frac{\mathrm{N}}{1 + \mathrm{N}\,(e)^2}$$

Where:

n = sample size

N = population size

e = error margin (5%)

$$n = \frac{\mathrm{N}}{1 + \mathrm{N}\,(e)^2} = \frac{228}{1\ +\ 225\ (0{,}05)^2}$$

$$n = \frac{228}{1 + 0{,}570} = \frac{228}{1{,}570} = 145{,}22 = 145$$

Primary data were gathered through field observations, structured questionnaires, and in-depth interviews, while secondary data were sourced from the Pidie Regency Agriculture Office and BPS. The instrument utilized a Likert scale (0–3) to generate ordinal data. Data analysis employed the MDS ordination technique via the Rap-BawangMerah approach based on Rapfish for Excel software using the ALSCAL algorithm (16).

The computational model required adherence to three assumptions: ordinal data scale (0–3), zero missing values, and consistent Euclidean distances. The procedure was executed in five stages: (1) scoring input attributes into a 145 x 7 matrix; (2) MDS ordination utilizing two-dimensional Euclidean distances; (3) leverage analysis via a jackknife procedure to calculate RMS values; (4) Monte Carlo validation with 250 random iterations within a range of ≤ 1 and a difference tolerance threshold of < 5% (20) and (5) Goodness-of-Fit testing based on S-stress (S < 0.25) (21) R^2 parameters. Index values were categorized into unsustainable (0.00–25.00), less sustainable (25.01–50.00), moderately sustainable (50.01–75.00), and highly sustainable (75.01–100.00) (16).

III. RESULTS

➢ *Respondent Characteristics*

The respondent profile reflects the demographic characteristics of the farmers directly involved in this study. Theoretically, individual characteristics correlate strongly with cognitive capacity and strategic decision-making processes in farm management to optimize economic performance. The exploration of respondent characteristics focused on four main indicators: age level, formal educational background, farming experience, and the number of household dependents.

Table 1 Respondent Characteristics Based on Age in the Study Area, 2025

No	Age (Years)	Number of Individuals	Percentage (%)
1	< 15	0	-
2	15 – 30	13	8.97
3	31 - 45	74	51.03
4	46 - 60	52	35.86
5	≥ 61	6	4.14
	Total	145	100

Source: Primary Data (processed), 2025

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Table 2 Respondent Characteristics Based on Education Level in the Study Area, 2025

No	Education Level	Number of Individuals	Percentage (%)
1	Elementary School	37	25.52
2	Junior High School	26	17.93
3	Senior High School	53	36.55
4	Diploma	20	13.79
5	Bachelor's Degree	9	6.21
	Total	145	100

Source: Primary Data (processed), 2025

Table 3 Respondent Characteristics Based on Farming Experience in the Study Area, 2025

No	Experience (Years)	Number of Individuals	Percentage (%)
1	< 10 Years (Beginner)	117	80.69
2	10 - 20 Years (Experienced)	27	18.62
3	> 20 Years (Highly Experienced)	1	0.69
	Total	145	100

Source: Primary Data (processed), 2025

Table 4 Respondent Characteristics Based on Number of Dependents in the Study Area, 2025

No	Number of Dependents	Number of Individuals	Percentage (%)
1	≤ 3 Individuals (Small Family)	87	60
2	4 – 5 Individuals (Medium Family)	58	40
3	≥ 6 Individuals (Large Family)	0	-
	Total	145	100

Source: Primary Data (processed), 2025

➢ *Sustainability Index of Shallot Farming in Pidie Regency*

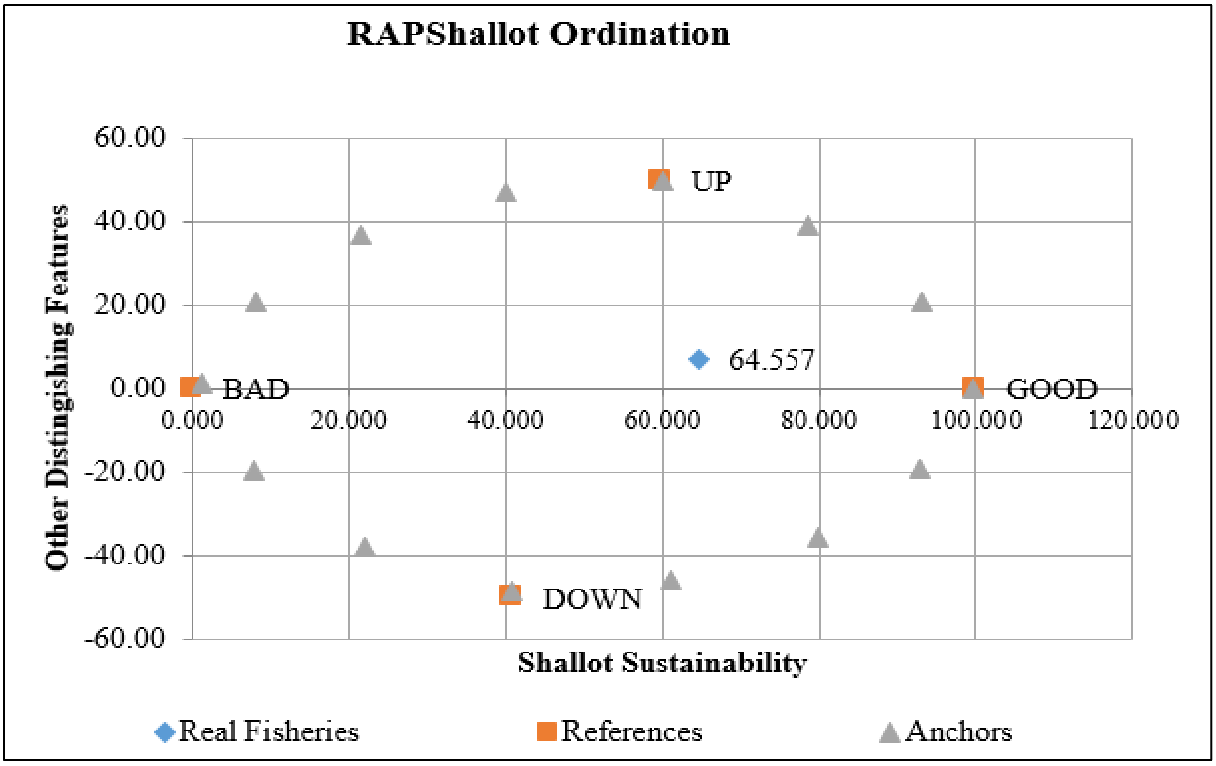

Fig 1 Sustainability Status Index of the Economic Dimension of Shallot Farming

The results of the MDS ordination using the RAP-Bawang Merah approach showed that the economic sustainability index of shallot farming in Pidie Regency is 64.56 (Table 5). This value places the economic status of farming in the "Moderately Sustainable" category (50.01–75.00).

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➢ *Leverage Analysis*

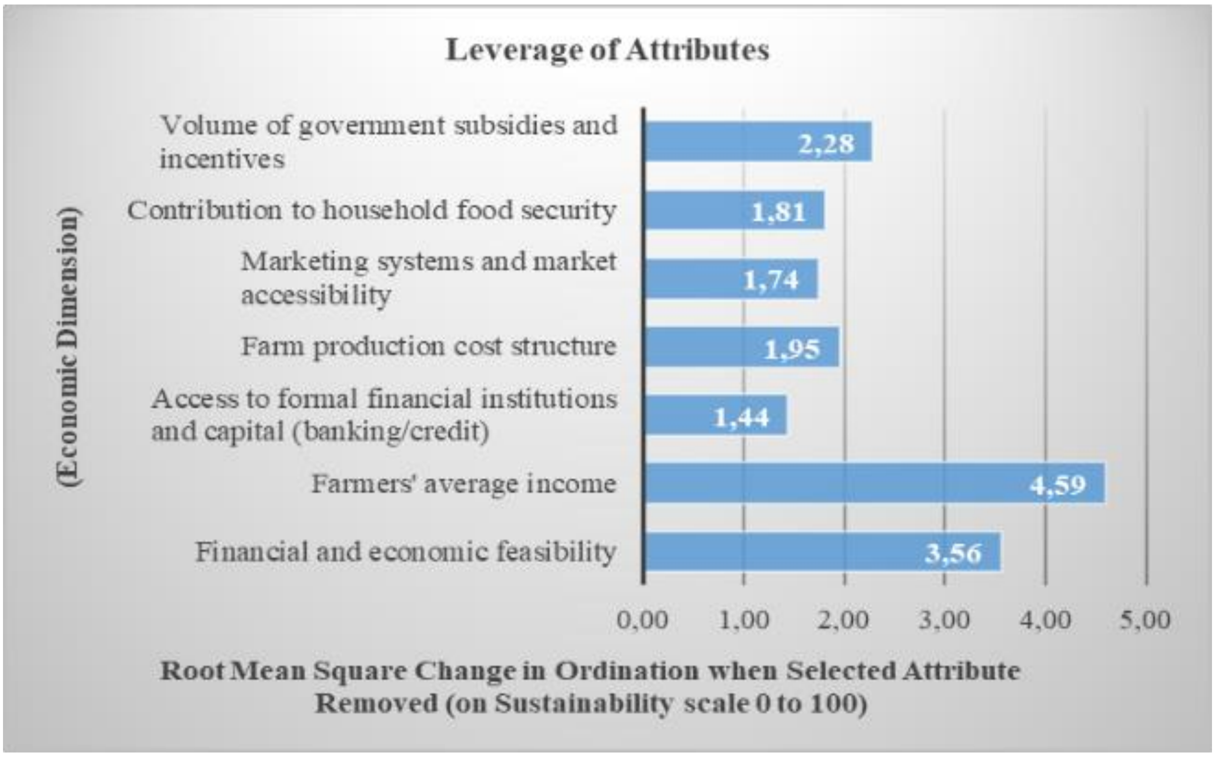

Fig 2 Leverage Analysis Chart for the Economic Dimension of Shallot Farming

Sensitivity analysis revealed that out of the seven economic attributes tested, two attributes recorded the highest Root Mean Square (RMS) values, identifying them as the main leverage factors for sustainability: 1) Farmers' Average Income (RMS: 4.59) and 2) Financial and Economic Viability (RMS: 3.56).

➢ *Validity and Goodness-of-Fit Test*

Table 5 MDS Analysis Results for Shallot Farming Sustainability in Pidie

Dimen sion	Index (%)	Status	Monte Carlo	Stress	R^2
Economic	64.56	Moderately Sustainable	63.752	0.151	0.942

Source: Primary Data (processed), 2025

Statistical parameters demonstrated a high level of confidence in the model. The R^2 value of 0.942 indicates that 94.2% of the variance can be explained by the model. A stress value of 0.151 ($S < 0.25$) indicates satisfactory data mapping accuracy. Furthermore, the discrepancy between the MDS index value (64.56) and the Monte Carlo value (63.75) was only 0.81, confirming that the analytical results are stable and free from data entry or systematic errors.

IV. DISCUSSION

➢ *Demographic Characteristics and Economic Behavior of Farmers*

Farmer characteristics influence mindsets and managerial decision-making in agriculture. The profile of the 145 respondents shows that shallot farming in Pidie Regency relies heavily on the mature productive age group (31–60 years) at 86.89%, dominated by the 31–45 age cohort (51.03%). This structure indicates secure economic sustainability due to a balance between physical capacity and managerial maturity (22). Age affects cognitive ability in risk management in a U-shaped pattern; mature productive farmers process market information more rationally and schedule planting times effectively to mitigate climate risks (23). However, the study detected a generational renewal crisis, as young farmer participation (<30 years) stands at only 8.97%. This low figure confirms an aging farmer phenomenon driven by high perceptions of financial risk in horticultural commodities, potentially hindering future digital agricultural modernization (24) (25).

Regarding social capital, 56.55% of the farmers possess secondary to higher education backgrounds (High School, Diploma, Bachelor’s degree). Formal education enhances the absorptive capacity of farmers, accelerating the adoption of IoT-based technologies and precision management of input expenditure (26) (27). The transformation from subsistence farming to profit-oriented commercial agribusiness requires adequate literacy support (28). Conversely, the presence of 43,45% of farmers with only elementary or junior high school education triggers risk-aversion behavior and psychological barriers toward complex new methods (29) (30).

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The structure of farming experience is overwhelmingly dominated by beginners (experience < 10 years) at 80.69% (117 individuals), while highly experienced farmers (> 20 years) account for only 0.69%. The influx of new actors proves that shallot farming possesses strong economic attractiveness in Pidie Regency. However, this condition increases technical vulnerability, as beginner farmers are still in an active learning-by-doing phase, lacking established intuition for pest and disease management or extreme weather mitigation (31). Positively, beginners exhibit high cognitive flexibility and lower resistance to the introduction of smart farming ecosystems (32).

The household dependent variable is dominated by small-scale families (≤ 3 individuals) at 60.00% and medium-scale families (4–5 individuals) at 40.00%. Small households benefit from low domestic expenditure margins, allowing harvest income to be reinvested for capital accumulation (33). However, a lack of internal labor forces them to allocate substantial cash outlays for external hired labor, particularly during synchronized planting and harvesting periods that trigger local labor shortages (34). The results indicate that a medium family size (4–5 individuals) is the most efficient structure, as it successfully substitutes external labor requirements with family labor without disrupting farm capital liquidity (35).

➢ *Economic Sustainability Status and Model Validity*

The MDS ordination analysis of the Rap-BawangMerah model indicates that the economic sustainability index of shallot farming in Pidie Regency reaches 64.56% ("Moderately Sustainable" category). The mathematical validity of the model is highly robust based on Goodness-of-Fit parameters, with a coefficient of determination (R^2 = 0.942), meaning that 94.2% of field data variance is successfully explained by the model. A low stress value of 0.151 (S < 0.25) confirms the spatial configuration stability of the model (good fit) (21) (36). The Monte Carlo validation test yielded a value of 63.75, showing a minimal deviation (0.81 index points) from the actual MDS value. This gap, well below the significant threshold (< 2.00 points), proves that the model is free from scoring and human errors, confirming its reliability as a basis for regional policy (37).

The index of 64.56% reflects an economic resilience state in a transitional phase. Although farming has surpassed minimum viability and generates profit, farmers remain constrained within an economic trap. Net operational profits are consumed by domestic subsistence needs and recurring input capital cycles, which restricts adaptive capacity for independent investments in post-harvest technologies such as cold storage or mechanization (19). Consequently, farming stability depends heavily on volatile external market prices.

A degradation of the index below the 50.00% threshold would trigger systemic risks. Negative cash flow from market shocks forces farm decapitalization through the liquidation of productive assets or informal debt traps via the ijon system (38). This condition would accelerate productive labor shifts to urban centers, induce agricultural labor scarcity, and hasten the aging of rural farming demographics (39). At a macro level, declining economic performance among producers of this strategic commodity directly impacts local food vulnerability and regional inflation fluctuations.

A comparison across production centers reveals that the Pidie Regency index (64.56%) falls below that of Brebes Regency in Central Java, which reaches 70%–75% (40). This disparity is driven by a more mature market ecosystem, information integration, and institutionalized farmer groups in Brebes. However, the Pidie index outperforms the highland production center of Alahan Panjang in West Sumatra, which ranges between 55%–60%, due to that region's high sensitivity to logistical distribution costs toward external wholesale markets (41). Pidie Regency maintains a competitive advantage in regional distribution logistics but remains vulnerable to price disparities in local markets.

➢ *Leverage Factors Analysis*

Sensitivity analysis using the X-axis RMS parameter confirms that Farmers' Average Income and Financial Viability are the two most sensitive attributes affecting the sustainability index, recording RMS values of 4.59 and 3.56, respectively. These two attributes dominate significantly over government subsidy size (RMS: 2.28), production cost structure (RMS: 1.95), food security contributions (RMS: 1.81), marketing systems (RMS: 1.74), and access to formal financial institutions, which recorded the lowest RMS value (1.44). This finding challenges the common assumption that positions formal banking credit constraints as the primary bottleneck for smallholders.

The farmers' average income attribute recorded the highest RMS value (4.59) because the income structure of shallot farming is characterized by a high risk-high return profile. Thin net profit margins render farming highly elastic to operational selling price changes. Net income serves as the primary psychological driver for smallholders to persist in a risky agricultural sector (42). This variable correlates linearly with reinvestment capability; the absence of financial buffer stocks due to narrow income margins deprives farmers of the capital needed to purchase high-quality seeds and restore soil fertility for subsequent seasons (43).

Financial viability represents the second leverage factor (RMS: 3.56), reflecting the technical input-output allocation efficiency measured through R/C or B/C ratios. Upfront investment in superior seeds and pesticides constitutes a high sunk cost at the beginning of the season. If production volumes fail to meet minimum targets due to poor land management, the R/C ratio falls below 1.0 (44). Given that chemical input costs command a dominant share, technical cultivation efficiency at the field level acts as the absolute determinant of financial viability, rather than external capital assistance alone (45) (46) (47).

The sensitivity of income validates the application of the Cobweb Theory in regional horticultural agriculture. A production time lag exists wherein farmers make current acreage allocation decisions based on adaptive expectations of past high prices (48). Consequently, peak harvest periods trigger an oversupply/market glut that depresses selling prices

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below production costs (38). The oligopsonistic structure of the local market exacerbates these fluctuations through price information asymmetry, where farmers bear the heaviest economic burden when prices collapse yet receive unfair economic surpluses when prices rise (49) (36).

Conversely, the lowest RMS score for access to formal financial institutions (1.44) indicates that the economic sustainability of farming is inelastic relative to banking access. Farmers operate independently through self-financing or by utilizing informal credit networks from family and middlemen. Rigid bureaucratic procedures and physical collateral requirements act as primary barriers to formal financing schemes like KUR within seasonal horticulture sectors (46). Farmers favor informal financial institutions due to the speed of fund disbursement when the planting season arrives, despite the consequence of higher interest burdens (50). The leverage test results demonstrate that current banking credit models are insufficiently inclusive to act as a significant driver for agricultural sustainability.

V. CONCLUSION

Shallot (Allium cepa L.) farming in Pidie Regency is in a "Moderately Sustainable" state, with a composite index of 64.56%. The farming system has surpassed basic viability but remains confined within an economic trap that impedes long-term capital accumulation. The mathematical validity of the ordination model is robust, supported by Goodness-of-Fit parameters (R^2 = 0.942, Stress = 0.151) and Monte Carlo simulations (0.81 point deviation), which confirms the first hypothesis. Based on the leverage test, the economic resilience of farming is determined by two primary leverage factors with the highest RMS values: farmers' average income (RMS: 4.59) and farm financial viability (RMS: 3.56). This confirms the second hypothesis, demonstrating that the primary determinants of economic sustainability in Pidie Regency are not driven by upstream variables but depend heavily on commodity price controls and technical input cost efficiency at the field level.

RECOMMENDATIONS

To elevate the sustainability status to highly sustainable (> 75.00), it is recommended to strengthen trading systems through regional regulations that direct BUMDes or Agricultural Cooperatives in Pidie Regency to act as market guarantors (off-takers). This policy should be integrated with initial capital injections, formal partnerships with Bulog, and the provision of communal cold storage facilities to support the Warehouse Receipt System (SRG) as a deferred-sale instrument during harvest gluts (51). The Agriculture Office, alongside Agricultural Extension Officers (PPL), must promote cost-structure efficiency programs by substituting synthetic chemical inputs with self-produced organic inputs (local compost and bio-pesticides) to reduce operational cash expenses (52) (37). For future research, it is suggested to integrate this economic analysis with the ecological dimension to assess soil degradation rates, as well as the social dimension to evaluate the role of social capital and youth generational renewal holistically.

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