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Analysis of the Corn Supply Chain to Increase Farmers' Profits in Napis Village

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Abstract
Bojonegoro Regency, particularly Napis Village in Tambakrejo District, is a major corn-producing center in East Java that faces supply chain challenges such as limited access to capital, fluctuations in input costs, and low bargaining power among farmers due to their dependence on informal middlemen. This study aims to identify the factors affecting farmers' profits, develop and validate a Dynamic Systems model based on actual data from 2021–2025, and formulate strategies for strengthening a sustainable supply chain. A combined PLS-SEM and Dynamic Systems (STELLA) approach was applied using data from 60 respondents. The PLS-SEM analysis confirmed that access to capital is the most dominant factor influencing profits (path coefficient = 0.504; T-statistic = 4.947; P-value = 0.000). Simulations of three scenarios (2026–2030) showed that the scenario involving labor substitution through the adoption of collective corn planting technology managed by Gapoktan (Scenario 3) was the best option because it reduced operating costs by Rp4.36 billion without increasing farmers' debt burden. Gapoktan-based supply chain restructuring breaks farmers' financial dependence on middlemen and restores farmers' bargaining power in determining corn selling prices.
Keywords: Access to Capital, Corn Supply Chain, Farmer Profitability, PLS-SEM, System Dynamics.

I. PENDAHULUAN

Bojonegoro Regency is one of the major corn- Bojonegoro Regency is one of the major corn-producing regions in East Java. The village of Napis in Tambakrejo Subdistrict is a key corn supplier, with a harvested area of 698 ha, total production of 4,048 metric tons, and productivity of 5.8 metric tons per hectare in 2024 (Satu Data Bojonegoro, 2024). This production potential has not yet fully translated into stable profits for farmers due to high operating costs, the need for substantial initial capital, fluctuations in fertilizer prices, and weak bargaining power within the supply chain.

Corn farmers bear the costs of seeds, fertilizer, pesticides, labor, and harvesting each growing season. Farmers' net income amounts to Rp26,506,000 per season, but when divided by is the four-month growing season, the monthly profit only about Rp6,626,500 below Bojonegoro Regency's 2024 minimum wage of Rp2,832,924, while farmers bear the full risk of crop failure and price fluctuations. Dependence on middlemen or brokers exacerbates this situation: partner farmers are bound by a loan system that ties capital to the obligation to sell their harvest, resulting in a structural decline in their bargaining power.

Previous studies have examined agricultural supply chains and farmer profitability separately, but none have integrated supply chain analysis, PLS-SEM for identifying dominant factors, and Dynamic Systems for simulating longterm policies into a single integrated framework for the case of corn in Bojonegoro. This study addresses this gap with the following objectives: (1) to empirically identify the factors influencing farmers' profits; (2) to build and validate a Dynamic Systems model based on 2021–2025 data; and (3) to formulate strategies for strengthening a sustainable supply chain through policy scenario simulations.

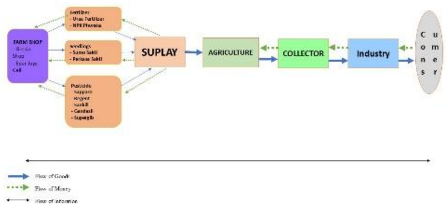

Figure 1 Mapping the Corn Supply Chain

II. THEORY

A. Corn

Corn (Zea mays L.) is an annual food crop of the Gramineae family with a growth cycle of 80–150 days, encompassing vegetative and generative phases that determine the quality and quantity of the harvest. This crop requires optimal agroecological conditions, including temperatures of 21–34°C, rainfall of 200–300 mm per season, good soil drainage, and the use of certified high-yielding varieties. Proper fertilizationin terms of both dosage and timing is a critical factor in corn cultivation, with urea and NPK fertilizers constituting the largest component of input costs and directly influencing production yields (García Lara & Serna Saldivar, 2019).

In the context of this study, the characteristics of corn cultivation in Napis Village have direct implications for farmers' cost and profit structures. Land productivity of 5.8 metric tons per hectare indicates adequate technical potential; however, farmers' ability to implement recommended agricultural practices particularly applying fertilizer at the recommended dosage is highly dependent on the availability of working capital. Limited capital forces farmers to reduce input doses, which in turn lowers productivity and narrows profit margins. This causal relationship serves as the theoretical basis for why access to capital is considered a dominant factor in this research model.

B. Supply Chain Management

Supply Chain Management (SCM) is an integrated approach to efficiently planning, implementing, and controlling the flow of materials, information, and finances from the source of raw materials to the end consumer (Guritno & Harsasi, 2022). (Chopra, 2019) defines a supply chain as a network of facilities and distribution channels that encompasses the procurement of raw materials, product transformation, and distribution to consumers. In the agricultural sector, supply chains have unique characteristics: seasonality, perishable products, and production fragmentation, which create information asymmetry and disparities in bargaining power among stakeholders (Guritno & Harsasi, 2022).

This asymmetry in bargaining power is the main problem facing the corn supply chain in Napis Village. Two farming models operate in parallel: independent farmers, who finance all their input needs on their own and are free to choose their marketing channels; and partner farmers, who are tied to collectors as providers of pre-planting capital and as the sole buyers of their harvest. (Hermanto & Swastika, 2016) found that farmers with access to formal credit have incomes 20–25% higher than those who rely on informal credit. This finding reinforces the argument that improving access to capital through supply chain restructuring is a targeted intervention to increase the profits of corn farmers in Napis Village.

C. Economic Analysis of Farming Operations

Agricultural economic analysis is an approach to assessing the feasibility and profitability of agricultural production activities from a financial perspective (Lantarsih, 2016). The profit from corn farming is calculated using the following basic equation:

$$\pi = TR - TC = (P \times Q) - (TFC + TVC) \qquad (1)$$

where π = profit (Rp), TR = total revenue, TC = total cost, P = selling price (Rp/kg), Q = production quantity (kg), TFC = fixed costs, and TVC = variable costs, which include fertilizer, pesticides, seeds, planting labor, and harvesting costs.

Applying this formula to the context of Napis Village reveals an important dynamic: an increase in TC does not always have a negative correlation with π. When additional input costs are directed toward applying the correct fertilizer dosage, the value of Q increases proportionally, causing TR to grow faster than TC. Conversely, farmers forced to reduce input doses due to capital constraints experience a significant decline in Q, causing TR to fall more sharply than TC. It is this dynamic that explains why access to capital is a key variable influencing the profitability of corn farming a hypothesis empirically tested via PLS-SEM in this study.

D. PLS-SEM

Partial Least Squares Structural Equation Modeling (PLS-SEM) is a multivariate analysis method that simultaneously estimates the measurement model (outer model) and the structural model (inner model) to test the relationships among latent variables (Jr et al., 2016). PLS-SEM was chosen for this study based on three considerations: first, the limited sample size (n = 60) still meets the requirements for PLS SEM, unlike CB-SEM, which requires a large sample; second, the model is predictive in nature, designed to identify the dominant factors influencing profit, in line with the orientation of PLS-SEM; third, the distribution of agricultural field data tends to be non-normal, and PLS-SEM does not require the assumption of normality (Ghozali & Latan, 2012).

The measurement model (outer model) was evaluated based on: convergent validity (AVE ≥ 0.50), where

$$AVE = \Sigma\lambda^2 / (\Sigma\lambda^2 + \Sigma(1-\lambda^2)) \qquad (2)$$

with λ = the factor loading of the indicator; reliability based on Composite Reliability (CR ≥ 0.70) and Cronbach's Alpha ($\alpha \geq 0.70$); and discriminant validity using the Fornell-Larcker criterion. The structural model (inner model) was tested using bootstrapping (500 subsamples) for path coefficients (β), T-statistics (> 1.96), and P values (< 0.05). The estimated structural path equation is:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \zeta \quad (3)$$

where Y = farmers' profits (latent dependent variable), X_1 = access to capital, X_2 = market access, X_3 = production costs, X_4 = land productivity (latent independent variable), β_1–β_4=path coefficients for each variable, and ζ=model residuals. The suitability of PLS-SEM for this study is also supported by the nature of the variables that cannot be directly observed (latent) access to capital, access to markets, production costs, and land productivity which require a structural equation modeling approach capable of simultaneously estimating latent variables.

E. Dynamic Systems

Dynamic Systems is a quantitative modeling methodology for understanding the behavior of complex systems that change over time through feedback, accumulation, and delay mechanisms (Murnawan & Saves, 2025). A Causal Loop Diagram (CLD) maps cause-and effect relationships in the form of reinforcing loops (R) and balancing loops (B). The CLD is then translated into a Stock and Flow Diagram (SFD) that can be numerically simulated using the basic accumulation equation (Prahasta, 2018):

$$\text{Stock}(t) = \text{Stock}(t-dt) + (\text{Inflow} - \text{Outflow}) \times dt \quad (4)$$

where Stock(t) = the accumulated value of the variable at time t (Business Balance in Rupiah or Land Area in hectares), Inflow = the rate of increase (corn sales revenue), Outflow = the rate of decrease (operating costs), and dt = the simulation time interval (1 year). Model validation uses the Mean Comparison test

$$E1 = |\bar{S} - \bar{A}| / \bar{A} \times 100\% \quad (5)$$

(valid if E1 ≤ 5%) and the Error Variance test

$$E2 = (S_s / A_s) \times 100\% \quad (6)$$

(valid if E2 ≤ 30%), where $\bar{S}$ = the simulation mean and $\bar{A}$ = the actual mean.

The choice of the Dynamic Systems approach in this study is based on its ability to capture the nonlinear dynamics among supply chain variables capital,input costs, productivity, and profits which simultaneously influence one another over the 2026–2030 period. The ability to simulate these long-term policy scenarios cannot be replaced by regression analysis or SEM alone. Thus, the integration of PLS-SEM (identification of dominant factors) and Dynamic Systems (simulation of intervention impacts) forms a comprehensive and complementary methodological framework.

F. Food Security

Food security is defined as a condition in which the food needs of all segments of society are met, as reflected in the sustainable availability of sufficient, safe, nutritious, equitable, and affordable food (FAO, 2008). This concept encompasses four pillars: availability, access, utilization, and stability. In Indonesia, corn holds a strategic position as the second most important food commodity after rice and as the primary raw material for the national animal feed industry; therefore, the continuity of its supply has a direct impact on the pillar of food availability (Yulinda & Murnawan, 2025).

The connection between food security and the main topic of this study lies in the causal relationship between farmer profitability, supply chain sustainability, and the availability of corn as a food commodity. When farmers' profits are unstable due to supply chain asymmetry as is the case in Napis Village farmers tend to reduce their planted area or switch to other crops, thereby directly threatening the pillars of regional food availability and stability. Conversely, strengthening the supply chain to increase farmers' profits will encourage land expansion and increased productivity, which in turn will sustainably strengthen regional food security. Thus, this study contributes to the strengthening of a production-based food security system, rather than being merely an economic analysis of farming operations.

III. METHOD

A. Type of Research

This study employs a quantitative-modeling approach using primary data in the form of structured questionnaires administered to 60 corn farmers in Napis Village and secondary data consisting of historical production figures and land area data from the Bojonegoro Regency Statistics Agency (BPS). The questionnaire measured four latent variables access to capital, access to markets, production costs, and land productivity (each with 4 indicators) which were analyzed using SmartPLS 3.0. Outer model testing included convergent validity (AVE ≥ 0.50) and reliability (Composite Reliability and Cronbach's Alpha ≥ 0.70), while the inner model was tested using bootstrapping with 500 subsamples to generate path coefficients, T statistics, and P-values as the basis for hypothesis acceptance.

The dynamic system model was built using STELLA 10.0.6 with stock variables (farm balance and land area), flow variables (inputs and outputs), and auxiliary variables including selling price, and costs of fertilizer, pesticides, seeds, and labor, which were calibrated using field data. Model validation was performed by comparing simulation outputs with actual data from 2021 2025 using the E1 test (Mean Comparison, valid ≤ 5%) and the E2 test (Error Variance, valid ≤ 30%). After the model was validated, three policy intervention scenarios were simulated for the 2026–2030 period based on the dominant factors obtained from the PLS-SEM analysis.

B. Research Design

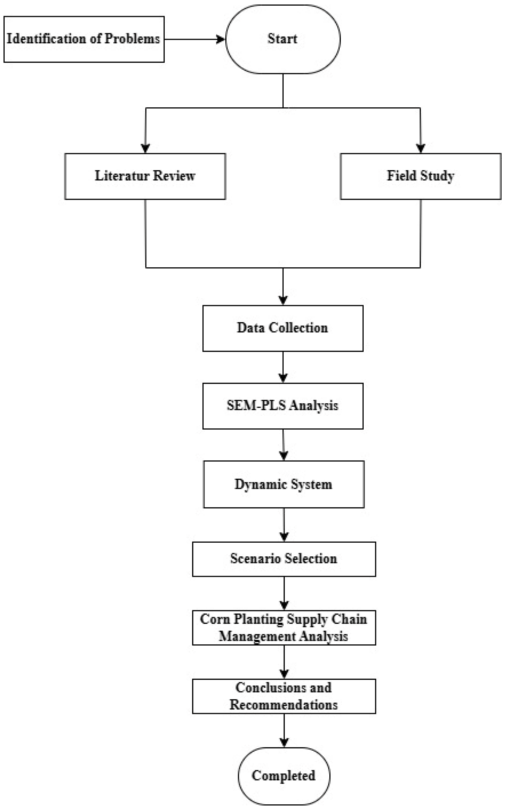

Figure 2 Flowchart

IV. RESULTS AND DISCUSSION

A. Analysis of the Existing Supply Chain

The current situation in Napis Village reflects a conventional supply chain structure with the following flow: farmers → collectors → industry → consumers. Farmers bear the highest economic risk but receive the smallest margin.

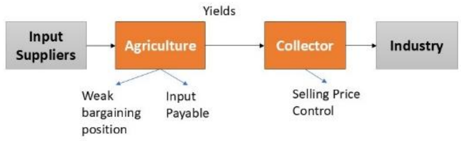

Figure 3 Previous Supply Chain

The main problem lies not in the physical distribution of corn, but in the pre-planting financing structure: partner farmers receive fertilizer and seeds from collectors at a markup; thus, once a debt obligation is established, their freedom to choose marketing channels is lost, and the selling price is unilaterally determined by the collector.

B. Results of the SEM-PLS Analysis

Testing of the outer model showed that all variables met the criteria for validity (AVE > 0.50) and reliability (Composite Reliability > 0.70). The bootstrapping results for the inner model are presented in Table 1.

Table 1 Path Coefficients

Relationship Paths	Path Coefficient (O)	T-Statistik	P-Value
Access to Capital → Profit	0,504	4,947	0,000
Market Access → Profit	0,236	2,246	0,025
Production Costs → Profit	0,165	1,417	0,157
Land Productivity → Profit	0,267	2,157	0,031

Table 1 shows that access to capital, market access, and land productivity have a significant effect on profits, while production costs do not (P-value = 0.157). Access to capital (X1) proved to be the most dominant factor, with the highest coefficient (0.504) and the lowest P-value (0.000): a one-unit increase in access to capital is correlated with a 0.504-unit increase in profit, after controlling for other factors. The dominance of access to capital confirms the qualitative finding that capital constraints force farmers into the informal financing ecosystem of middlemen, which depresses the selling price of corn.

C. Validation of the Dynamic System Model

The model was validated by comparing simulation results with actual data from 2021 2025.

Table 2 Summary of Dynamic System Model Validation

Variables	Average Data	Simulation Average	E1	E2	Status
Corn Production (Tons)	3.865	3.865	0%	0%	Valid
Harvest Area (Ha)	677	677	0%	0%	Valid

Source: Processed data (2026)

The values of E1 and E2 = 0% were obtained because historical data on land area and annual production were entered directly as actual values into the STELLA function. This serves to verify the model's structural fit to actual behavior patterns, rather than as an independent prediction; therefore, the model is deemed valid and suitable for policy simulation.

D. Policy Scenario Simulations (2026–2030)

Based on the dominant factor of access to capital, three intervention scenarios were designed with the following general assumptions: normal weather conditions, a corn selling price of Rp5,300/kg, and full market absorption of production.

Scenario 1 Full Loan Financing: Farmers obtain 100% of their capital needs from formal bank loans, allowing them to purchase inputs according to the recommended dosage without a markup by middlemen, but they bear the principal and interest payments.

Table 3 Simulation Results for Scenario 1: Cumulative Profit

Year	Base Model	Scenario 1
2026	Rp16.826.415.000	Rp18.327.158.100
2027	Rp17.089.007.000	Rp18.613.172.180
2028	Rp17.351.599.000	Rp18.899.186.260
2029	Rp17.614.191.000	Rp19.185.200.340
2030	Rp17.876.783.000	Rp19.471.214.420
Total	Rp86.757.995.000	Rp94.495.931.300

Source: Processed data (2026)

Table 3 compares the profits between the base model and the loan capital intervention scenario over a five-year period. In 2026, the base model's profit is Rp16,826,415,000, while the intervention scenario's profit is higher at Rp18,327,158,100. This difference is consistent with an average profit of approximately Rp1,547,587,260. In 2030, the base model reaches Rp17,876,783,000 and the scenario reaches Rp19,471,214,420. Status The total accumulated cost for the base model is Rp86,757,995,000, while the scenario using borrowed capital reaches Rp94,495,931,300, meaning the scenario successfully increases profits by Rp7,737,936,300 over five years.

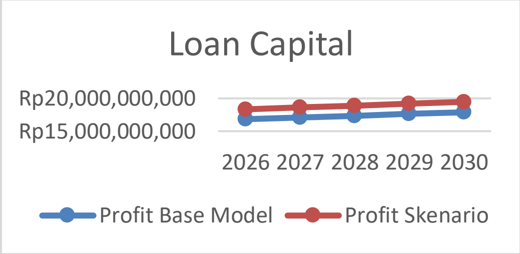

Figure 4 Scenario 1

Based on the simulation results and the profit table, it can be seen that there is a gradual increase in profits from year to year. This increase is due to farmers being able to maximize their capital by purchasing fertilizer to increase the fertilizer dosage, thereby boosting corn productivity.

Scenario 2 Borrowed Capital + 5% Inflation: A combination of borrowed capital and a 5% annual inflation trend across all input cost components, serving as a stress test of the farm's financial resilience.

Table 4 Operating Costs for Scenario 2 vs. Base Model

Year	Base Model	Scenario 2
2026	Rp6.339.885.000	Rp6.656.879.250
2027	Rp6.438.753.000	Rp6.760.690.650
2028	Rp6.537.621.000	Rp6.864.502.050
2029	Rp6.636.489.000	Rp6.968.313.450
2030	Rp6.735.357.000	Rp7.072.124.850
Total	Rp32.688.105.000	Rp34.322.510.250

Source: Processed data (2026)

The simulation results in Table 4 show a rise in operating costs under this combined scenario, reaching Rp 6,656,879,250 at the beginning of the year (2026) with an inflation rate of 5%. The total accumulated cost for the base model over the simulation period was Rp 32,688,105,000, while the scenario reached Rp 34,322,510,250, a difference of Rp 1,634,405,250. The cost increase due to inflation, coupled with the obligation to pay bank interest, places financial pressure on farmers.

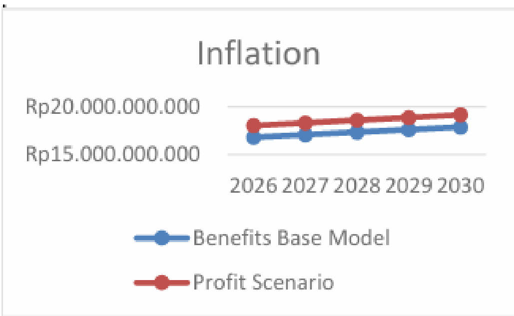

Figure 5 Scenario 2

The results of the profit simulation for this scenario are shown in Table 4 and Figure 5, where farmers' profits increase despite very high operating costs. This occurs because the rise in operating costs reduces the farmers' planting season, leading to a corn shortage. The corn shortage can drive up selling prices, so the costs incurred are offset by the higher selling prices.

Scenario 3 Adoption of Collective Planting Equipment: Substitution of manual labor with corn planters collectively purchased through the Gapoktan and rented on a rotating basis to member farmers. There is no new debt burden.

Table 5 Operating Costs: Scenario 3 vs. Base Model

Tahun	Base Model	Skenario 3
2026	Rp6.339.885.000	Rp5.493.960.000
2027	Rp6.438.753.000	Rp5.579.628.000
2028	Rp6.537.621.000	Rp5.665.296.000
2029	Rp6.636.489.000	Rp5.750.964.000
2030	Rp6.735.357.000	Rp5.836.632.000
Total	Rp32.688.105.000	Rp28.326.480.000

Source: Processed data (2026)

Table 5 shows a comparison between the base model and a labor substitution scenario through the adoption of corn planting technology. This scenario reduces the number of workers by renting modern corn planting equipment that is more effective to use. The total production cost for the base model is recorded at Rp 32,688,105,000, while the intervention scenario is lower, at Rp 28,326,480,000. The scenario successfully reduces production costs by Rp 4,361,625,000 over the five-year simulation period.

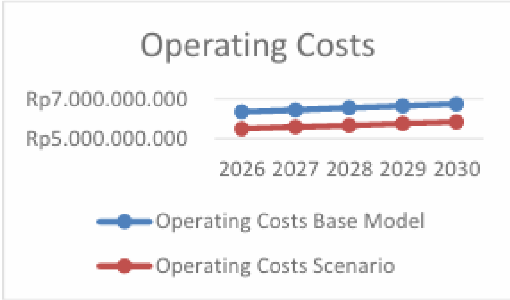

Figure 6 Scenario 3

Based on the simulation results and the operational cost comparison table, it can be seen that there has been a gradual increase in production input costs from year to year. This increase is primarily due to the expansion of cultivated land area, which directly impacts the demand for inputs such as fertilizer, seeds, pesticides, labor, and overall land preparation costs.

Table 6 Scenario Evaluation

Scenario	Intervention Description	Weaknesses & Risks
Scenario 1 (Full Loan)	By using the full loan amount, farmers can increase fertilizer application rates to boost productivity, thereby raising income and generating high profits	Debt dependency and the risk of interest burdens in the event of a crop failure.
Scenario 2 (Loans + Inflation)	A 5% inflation rate for production inputs causes operational costs to balloon, leading to a shorter growing season; as a result, there will be a corn shortage, but the selling price will still rise	This is highly dependent on unpredictable market scarcity conditions.
Scenario 3 (Replacing Labor with the Adoption of Planting Machinery)	Labor efficiency through the use of modern farming equipment	Pure internal efficiency without the external burden of new debt.

Based on the evaluation results in Table 6, Scenario 3 (Replacing labor with the adoption of planting machinery) was selected as the primary policy recommendation. This decision was based on the fact that the associated risks are very low.

Replacing labor with modern planting machinery can reduce farmers' operating costs. Scenario 3 has proven effective in protecting farmers' profit margins by improving operational cost efficiency, without increasing farmers' cash flow burdens due to bank interest risks.

E. Proposal for a Sustainable Supply Chain

The integration of SEM-PLS and Dynamic Systems results provides a foundation for restructuring the supply chain with Gapoktan (Farmers' Group Associations) serving as the central hub for managing capital, inputs, and marketing. In this new model, the chain of financial dependence on middlemen is completely severed: Gapoktan provides capital through partnerships with formal banks and distributes subsidized fertilizer through official channels.

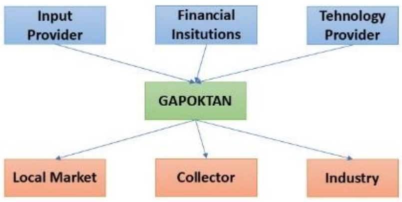

Figure 7 Sustainable Supply Chain

Scenario 3 is implemented through the collective procurement of a corn planter as a shared asset of the Gapoktan, which is leased on a rotating basis. Downstream, the entire harvest is collected at the Gapoktan's warehouse and sold directly to large-scale animal feed manufacturers. The large supply volume creates economies of scale that enhance bargaining power in price negotiations, shifting control from middlemen to farmers.

V. CONCLUSION

This study integrates supply chain analysis, PLS-SEM, and Dynamic Systems an approach that has never been applied to the corn supply chain in Bojonegoro Regency. The three main conclusions are as follows:

(1) Access to capital is the most dominant factor influencing farmers' profits (coefficient = 0.504; T-statistic = 4.947; P-value = 0.000). Limited capital forces farmers to turn to informal financing from middlemen, who unilaterally set selling prices. Market access and land productivity are also significant, while production costs are not significant in this model.

(2) The Dynamic System model was successfully validated with E1 = 0% and E2 = 0% because historical data was entered directly into STELLA. Simulations of three scenarios for 2026–2030 indicate that Scenario 3 (adoption of collective corn planter technology via Gapoktan) is the top recommendation: it saves Rp4.36 billion in operating costs with the lowest financial risk, without increasing farmers' debt burden.

(3) The reconstruction of the supply chain based on Gapoktan breaks farmers' dependence on informal middlemen, restores their bargaining power in setting selling prices, and supports regional food security.

Limitations of the study include: (a) the sample was limited to 60 respondents from a single village; (b) the model assumes normal climatic conditions without disaster risks; (c) market price dynamics have not been modeled endogenously. Practical recommendations: local governments should strengthen farmers' access to formal credit; the Department of Agriculture should facilitate mechanization units within Gapoktan; and banks should develop agricultural microcredit based on the crop planting cycle.

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