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DINAMIKA PERMINTAAN PRODUK BIOPESTISIDA DAN FAKTOR – FAKTOR PENENTU UTAMANYA

DYNAMICS OF DEMAND FOR BIOPESTICIDE PRODUCTS AND ITS KEY DETERMINANTS

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Abstrak

Pertumbuhan pasar organik dan tuntutan pengurangan residu mendorong kebutuhan akan input ramah lingkungan, namun adopsi biopestisida di tingkat petani masih terbatas. Studi ini menganalisis dinamika permintaan produk biopestisida dengan menilai dampak *willingness to pay* (WTP), kinerja operasional, dan Program Go Organik pada dua konteks agroekologis Desa Bendunganjati (Pacet) dan Desa Randugenengan (Dlanggu). Desain penelitian adalah survei kuantitatif eksplanatori (*cross sectional*) menggunakan stratified random sampling. Instrumen divalidasi dan reliabel. Analisis menggunakan regresi linear berganda untuk menguji pengaruh faktor penjelas terhadap permintaan maupun intensitas penggunaan serta pendekatan *exponential smoothing* untuk prediksi permintaan bulanan. Hasil menunjukkan *willingness to pay* berpengaruh positif dan signifikan terhadap permintaan, Program Go Organik berpengaruh negatif dan signifikan sehingga mengindikasikan kemungkinan substitusi ke praktik pembuatan Biopestisida sedangkan kinerja operasional positif namun tidak signifikan. Model signifikan secara simultan, menandakan variasi permintaan dijelaskan oleh tiga variabel tersebut. Untuk peramalan, dengan alfa yang lebih besar memberikan jejak paling mendekati data aktual dan menghasilkan prediksi periode berikut lebih akurat dibanding alfa yang lebih kecil. Temuan ini menegaskan bahwa penguatan WTP berbasis bukti efikasi dan desain ulang implementasi Program Go Organik agar mendorong, bukan mensubstitusi permintaan komersial lebih krusial daripada perbaikan operasional semata. Rekomendasi manajerial meliputi demoplot terukur, kemasan ekonomis, SOP visual, pengelolaan stok dan *lead time*, serta integrasi materi biopestisida dalam modul Program Go Organik
Kata kunci: Biopestisida, Willingness to Pay, Kinerja Operasional, Program Go Organik, Exponential Smoothing.

Abstract

The growth of the organic market and the demand for residue reduction are driving the need for environmentally friendly inputs, but biopesticide adoption at the farmer level remains limited. This study analyzes the dynamics of biopesticide demand by assessing the impact of willingness to pay (WTP), operational performance, and the Go Organic Program in two agroecological contexts: Bendunganjati Village (Pacet) and Randugenengan Village (Dlanggu). The research design was a quantitative explanatory survey (cross-sectional) using

stratified random sampling. The instruments were validated and reliable. The analysis used multiple linear regression to test the influence of explanatory factors on demand and usage intensity, and an exponential smoothing approach to predict monthly demand. The results show that Willingness to Pay has a positive and significant effect on demand, the Go Organic Program has a negative and significant effect, indicating a possible substitution to biopesticide production practices, while operational performance is positive but not significant. The model is simultaneously significant, indicating that the variation in demand is explained by the three variables. For forecasting, a larger alpha provides the closest trace to the actual data and produces more accurate predictions for the following period than a smaller alpha. These findings confirm that strengthening WTP based on evidence of efficacy and redesigning the implementation of the Go Organic Program to encourage, rather than substitute, commercial demand is more crucial than operational improvements alone. Managerial recommendations include measurable demonstration plots, packaging economy, visual SOPs, stock and lead time management, and the integration of biopesticide materials into the Go Organic Program module.
Key Words: *Biopesticides, Willingness to Pay, Operational Performance, Go Organic Program, Multiple Linear Regression, Exponential Smoothing.*

INTRODUCTION

Demand for biopesticides is increasing as the global push toward a more sustainable and safer food system. This trend is driving the expansion of organic farming and policy pressure to reduce reliance on synthetic pesticides (Fitriyani, Putra, et al., 2024). Recent data from the FiBL consortium indicates that by 2023, global organic land will reach approximately 99 million hectares (2.6% of the total), while the global organic retail market will exceed €136 billion. Although volume growth has slowed due to inflation, the long-term trend remains upward, driven primarily by rising prices and consumption in North America and Europe. The expansion of the organic market is indirectly driving a preference for biological control inputs, including biopesticides, due to their compliance with organic standards and Integrated Pest Management (IPM) practices (Willer, 2025). Biopesticide adoption in the field still faces obstacles, meaning their share remains small in the rapidly growing pesticide market. The main obstacles frequently reported include limited product availability, relatively high commercial product prices, complex licensing and registration processes, varying perceptions of effectiveness, and limited local production facilities. To accelerate use, operational intervention by farmers, willingness to pay, and organic programs are needed to support demand (Hernandez-Tenorio et al., 2022).

At the technical level, formulation and stability challenges are critical determinants of operational performance throughout the supply chain. Bibliometric studies of biopesticide formulations show that degradation of active ingredients by light, oxygen, and temperature reduces viability or efficacy. Therefore, formulation innovation using nanoemulsions, microencapsulation, and controlled release is a crucial research and development agenda to extend shelf life, improve stability, and facilitate field application (Putra et al., 2025). This dimension is directly related to the operational performance of producers and distributors, where the better the formulation (stability, ease of distribution, packaging), the lower the risk of stock-outs, remaining expiration, and efficacy complaints which ultimately lowers the total cost per unit of crop protection (Hernandez-Tenorio et al., 2022). From the perspective of policy design and supply chain coordination, the network equilibrium model in the biopesticide supply chain shows that a government subsidy scheme that is well-targeted, for example, there is an emphasis on R&D rather than excessive price subsidies, where this strategy can encourage improvements in product quality while maintaining the profitability of actors in the long term (Fitriyani, Rizkina, et al., 2024). Farmers' environmental safety preferences have also been shown to be a driver of manufacturing R&D investment decisions, suggesting that policies that foster green preferences at the user level have a positive impact on the supply side. These results confirm that operational performance, as measured by supply, production and distribution efficiency, and quality and efficacy, is not solely an internal company issue, but rather an adaptive response to incentive structures, technology formulations, and market preferences (Jiang et al., 2024).

On the willingness to pay (WTP) side, empirical evidence shows that willingness to pay for more environmentally friendly control solutions is influenced by technological attributes (efficacy, risk, ease of use), perceived health/environmental benefits, and user income and experience. A study in Benin using a choice experiment on IPM attributes for Spodoptera frugiperda (greyak caterpillars) showed significant WTP for attributes that optimize effectiveness and better risk profiles and signaled that users are willing to pay a premium when benefits are clear and risks are perceived to be lower (Tassembédo et al., 2024). At the broader societal level, surveys on nanopesticides also found WTP related to preferences for innovations that are perceived as safer and more efficient, although understanding of risks is a limiting factor that needs to be addressed through education and credible labeling (Liu et al., 2024).

The above findings are relevant to the Indonesian context, which is currently consolidating various organic initiatives. A transdisciplinary review of the transformation of smallholder farms to organic farming in Indonesia concluded that many initiatives are underway, but various actors (state, NGOs, communities) often have misaligned orientations and targets. Consequently, policy impacts are fragmented, and barriers to adoption, ranging from yield declines during the transition, limited support from extension workers, certification costs, and marketing, remain persistent. The recommendation is for an inclusive, cross-level strategy focused on policy alignment, capacity building, and market governance (Santy & Alam, 2022). Within the framework of this research, the Go Organic Program can be positioned as a policy protector and ecosystem strengthening that includes consumer education, incentives to adopt environmentally friendly inputs including biopesticides, research and development formulation support, and facilitation of organic product markets (Waluyo et al., 2022). Recent global evidence also emphasizes that successfully achieving the target of increasing the share of organic land requires a combination of context-appropriate policy instruments such as transition subsidies, technical assistance, improved regulatory inputs, and market access, rather than a single instrument (Möhring et al., 2024).

The problematic phenomenon that occurs in Mojokerto is the low number of people who use biopesticides in their agricultural activities, this is because the community still has a historical dependence on conventional farming practices using chemical pesticides, minimal knowledge and technical community specifications, the adoption process still requires assistance even though ecosystem support actually already exists. (Ramada & Syah, 2023) also explained that the condition of farmers who on average still apply conventional farming methods that still use fertilizers and pesticides, so that there is a need for socialization and research to encourage farmers to switch to using biopesticides.

Contextually, the dynamics of biopesticide demand will be determined by the interaction of three major blocks: (1) Preferences & WTP of users (farmers, agro-dealers, and downstream consumers who appreciate organic attributes), (2) Operational performance of producers and distributors (formulation quality, supply reliability, output costs and prices), and (3) The policy environment that supports the organic transition (incentives, treatment, and institutional capacity) (Poli & Fontefrancesco, 2024). Recent literature places efficacy/stability and regulatory barriers as the main levers explaining why the share of biopesticides remains relative, but when these barriers are overcome through innovative formulations, accelerated registration, and competitive pricing and distribution strategies, market preferences tend to react positively, reflected in higher WTP for demand (Fritz et al., 2021).

In the context of research methodology, testing the hypothesis of the impact of WTP and operational performance on biopesticide demand can be developed through a regression model that includes the variables of price, perceived risk or efficacy, access to information, and product availability (operational performance proxies), as well as policy variables in the Go Organic intervention. Exponential smoothing is also used to predict biopesticide product demand data (Fritz et al., 2021). The urgency of this study is reinforced by the growing global organic market and the policy goals of various countries to expand organic practices. By synthesizing evidence on user acceptance of organic products (WTP), improving operational performance through innovation and supply chain efficiency, and consolidating more aligned Go Organic policies across actors, Indonesia has the opportunity to accelerate biopesticide adoption and improve the performance of the post-harvest economic-environmental sector. This research is expected to provide an empirical basis for WTP variables, operational performance, and the go organic program to support the popularity of biopesticide products, thereby encouraging innovation and market certainty.

This study contributes to the literature in three important ways. First, it provides empirical novelty by jointly modeling willingness to pay (WTP), operational performance, and the Go Organic Program to explain biopesticide demand at the farm level in two contrasting agroecological contexts in Indonesia, an area that remains underexplored in existing studies that often focus on either technological or policy dimensions in isolation. The finding that the Go Organic Program exerts a negative yet significant effect, indicating a substitution toward self-produced biopesticides, offers new empirical evidence on unintended demand-side dynamics of organic policy interventions. Second, the study delivers a policy contribution by demonstrating that organic transition programs need to be redesigned to complement rather than crowd out commercial biopesticide markets, thereby informing more coherent subsidy design, extension strategies, and regulatory support. Third, from a demand modeling perspective, this research integrates econometric analysis with short-term forecasting using exponential smoothing, showing how preference-based variables and policy environments translate into observable demand trajectories. By linking behavioral drivers with predictive demand modeling, this study extends the practical applicability of biopesticide demand models for supply chain planning and policy evaluation in emerging organic agriculture systems.

METHOD

This research uses an explanatory quantitative approach, namely a quantitative method with the aim of explaining, testing and analyzing causal relationships and research hypotheses (Fitriyani, 2021). The survey design used two groups of farmers in two locations: Bendunganjati Village, Pacet District, and Randugenengan Village, Dlanggu District. The two villages were chosen because they represent different commodity contexts and input access. Pacet tends towards upland horticulture with shallots as its main product, while Dlanggu is dominated by dryland rice in the lower plains with long beans as its main product, allowing for a comparison of factors determining biopesticide demand in contrasting ecosystems. The study period is planned for three to four months, covering pre-survey, primary data collection, and data analysis.

The target population was the farmer groups in Bendunganjati and Randugenengan villages, who are the decision-makers in the use of crop protection inputs. The sampling technique used stratified random sampling based on primary commodities or land area, followed by simple random sampling within each stratum. To complete the context, several key informants (farmer group leaders, pesticide kiosks, and extension workers) were briefly interviewed to validate the field findings.

The dependent variables of the study are the demand for biopesticide products, measured as the frequency of application per month or per season, and the quality and price of the products, which also have an influence. The main independent variables include: (i) willingness to pay (WTP) with indicators of CVM value, land ownership, income, and biopesticide product quality (Fitriyani, Putra, et al., 2024). (ii) operational performance with indicators of product suppliers, product availability, lead time, and ease of sales service. (iii) Go Organic program with indicators of participation in socialization, organic product manufacturing training, application of organic systems, and monitoring of organic products as shown in Table 1 (Möhring et al., 2024).

Table 1. Operational Definition and Measurement Scale

No	Variable	Operational Definition	Indicators	Measurement Scale
1	Biopesticide Product Demand (Y)	The level of use and application intensity of biopesticide products by farmers within a planting season or on a monthly basis as a response to pest	(1) Frequency of biopesticide application per month/season; (2) Quantity of biopesticide products used; (3) Consistency of use	Likert Scale 1–5

		control needs and preferences for environmentally friendly inputs.	during one planting period	
2	Willingness to Pay (X1)	Farmers' willingness to pay a certain price for biopesticide products based on perceived benefits, product quality, and economic capacity.	(1) Contingent Valuation Method (CVM) value; (2) Income level; (3) Land ownership/size; (4) Perceived quality of biopesticide products	Likert Scale 1–5
3	Operational Performance (X2)	Farmers' perception of the ability of biopesticide suppliers to ensure product availability, quality, and efficiency of distribution and service.	(1) Product availability; (2) Supplier reliability; (3) Distribution lead time; (4) Ease of sales and service access	Likert Scale 1–5
4	Go Organic Program (X3)	The degree of farmers' participation in and exposure to the Go Organic Program aimed at promoting environmentally friendly agricultural practices.	(1) Participation in socialization activities; (2) Training on organic or biopesticide production; (3) Implementation of organic farming systems; (4) Program monitoring and assistance	Likert Scale 1–5

Source: Processed Data (2025)

The data analysis technique used SPSS 27 with a linear multiple regression approach and an exponential smoothing approach. The linear multiple regression approach was carried out to test the influence of the variables Willingness to Pay (X1), Operational Performance (X2), and the Go Organic Program (X3) on the demand for Biopesticide Products (Y). The calculation formula can be formulated as follows: (Fitriyani, 2021),

$$Y = \alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + e$$

Information,

Y = Biopesticide Product Demand Variables

α = Constant

X1 = Willingness to Pay Variables

β1 = Coefficient of Willingness to Pay Variable

X2 = Operational Performance Variables

β2 = Coefficient of Operational Performance Variable
X3 = Go Organic Program Variables
β3 = Coefficient of Go Organic Program
e = Standard Error (5%)

An exponential smoothing approach is also used to predict demand. This model assumes that fluctuating data is used to average consistent trends and growth patterns, thus assuming a stable average fluctuation. Exponential smoothing in forecasts is calculated based on actual data plus previous forecast data to obtain the next prediction. (Suranto & Fitriani, 2024) The model equation is as seen below (Andia et al., 2024),

$Ft+1= .Xt+(1-a) .Ft$

Information,

$Ft+1$= Data forecast

a = Exponential function

Xt = Previous actual data

Ft = Previous forecast data

RESULT AND DISCUSSION

Result

The results of the research were obtained by measuring multiple linear regression tests in SPSS version 27 and calculating exponential smoothing in predicting demand for biopesticide products. Prior to conducting the Multiple Linear Regression test, instrument testing was conducted to determine the validity and reliability of the data. The results showed that all data were valid. According to (Hendijani & Saeidi, 2020) A valid instrument is considered valid if the test results have a sig value <0.05, and vice versa if the value >0.05 is declared invalid. All data in this study have a value >0.05, which means they are valid. After the validity test, a reliability test was conducted to determine whether the research data is reliable or not, as shown in Table 2.

Table 2. Reliability Test Results

Variables	Croncbach's Alpha	Decree	Informations
Willingness To Pay	0.785	0.7	Reliable
Operational Performance	0.776	0.7	Reliable
Go Organic Program	0.827	0.7	Reliable
Biopesticide Product Demand	0.705	0.7	Reliable

Source: Processed Data (2025)

In table 2, it can be seen that the Cronbach's alpha value for the Willingness To Pay variable is 0.785, Operational Performance is 0.776, Go Organic Program is 0.827, and demand for Biopesticide Products is 0.705, meaning that all variables have a Cronbach's alpha value > 0.7 so that all data are reliable and can then be tested using Multiple Linear Regression.

Multiple Linear Regression

Multiple linear regression tests were conducted to determine the influence of variables, both partially and simultaneously, and to determine the extent of the influence on all variables. The results of the T-test (Partial) can be seen in Table 3 below.

Table 3. Results of the T-Test (Partial)

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	.491	.212		2.315	.024
	Willingness_To_Pay	1.060	.190	1.052	5.570	.000
	Operasional_Performance	.286	.193	.276	1.480	.145
	Go_Organic_Program	-.468	.119	-.446	-3.915	.000
a. Dependent Variable: Biopesticide_ Product_Demand						

Source: Processed Data (2025)

From the table above, it can be seen that the Willingness To Pay variable has a partial significant influence on the Biopesticide Product Calculation variable with a sig value of 0.000 <0.05. The Operational Performance variable does not have a partial influence on the Biopesticide Product variable because it has a sig value of 0.145>0.05. The Go Organic Program variable has a significant influence on the Biopesticide Income variable because it has a sig value of 0.000 <0.05.

Table 3 also shows a standardized β value >1 for the WTP variable. According to (Ziglari, 2024) a standardized β value >1 can arise due to overlapping information between independent variables (moderate multicollinearity) or measurement scales with different sensitivity levels, even though reliability tests indicate that the instruments used are consistent (Cronbach's α >0.7). Under these conditions, the standardized coefficient captures a very sharp relative change in the dependent variable when there is a one-standard-deviation variation in WTP, especially in samples that are relatively homogeneous in operational aspects but heterogeneous in economic aspects and preference values.

After conducting the T test (Partial), the next step is the F test (simultaneous) with the results as shown in table 4.

Table 4. F-Test Results (Simultaneous)

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	37.226	3	12.409	128.415	.000[b]
	Residual	5.411	56	.097		
	Total	42.637	59			

Source : Processed Data (2025)

The table above shows that the Willingness to Pay, Operational Performance, and Go Green Program variables have a significant simultaneous influence on the demand for Biopesticide Products because they have a sig value of 0.000 <0.05. After the F test (Simultaneous) was conducted, the R^2 test (Determination) was conducted, the results of which can be seen in Table 5.

Table 5. R^2 Test Results

Model Summary[b]						
					Durbin-Watson	
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change
1	.934[a]	.873	.866	.31085	.873	128.415

Source: Processed Data (2025)

From table 4, it can be seen that the R square is 0.873 or 87.3%, meaning that more than 50% of the strength of the Biopesticide Product demand variable is influenced by the Willingness To Pay, Operational Performance, and Go Organic Program variables, while 12.7% is influenced by other variables such as Biopesticide Risk, Organic Program Support, and Ease of Product Supply.

Exponential Smoothing

The exponential smoothing approach is used to predict the amount of demand for Biopesticide products by comparing three exponential value functions, namely α = 0.1, α = 0.2, and α = 0.3 as seen in Table 6 and Figure 1 below.

Table 6. Results of Biopesticide Product Data Prediction Calculations

Period (Month)	Actual Demand	Forecast (α = 0.1)	Forecast (α = 0.2)	Forecast (α = 0.3)	Absolute Error (α = 0.3)	Squared Error (α = 0.3)	Absolute Percentage Error (%)
1	20	20.00	20.00	20.00	0.00	0.00	0.00

2	22	20.00	20.00	20.00	2.00	4.00	9.09
3	22	20.20	20.40	20.60	1.40	1.96	6.36
4	19	20.38	20.72	21.02	2.02	4.08	10.63
5	24	20.24	20.38	20.41	3.59	12.89	14.96
6	23	20.62	21.10	21.49	1.51	2.28	6.57
7	27	20.86	21.48	21.94	5.06	25.60	18.74
8	30	21.47	22.58	23.46	6.54	42.77	21.80
9	32	22.32	24.07	25.42	6.58	43.30	20.56
Accuracy Indicators							
MAD				**3.19**			
MAPE (%)				**13.6**			
MSE				**15.77**			

Source: Processed Data (2025)

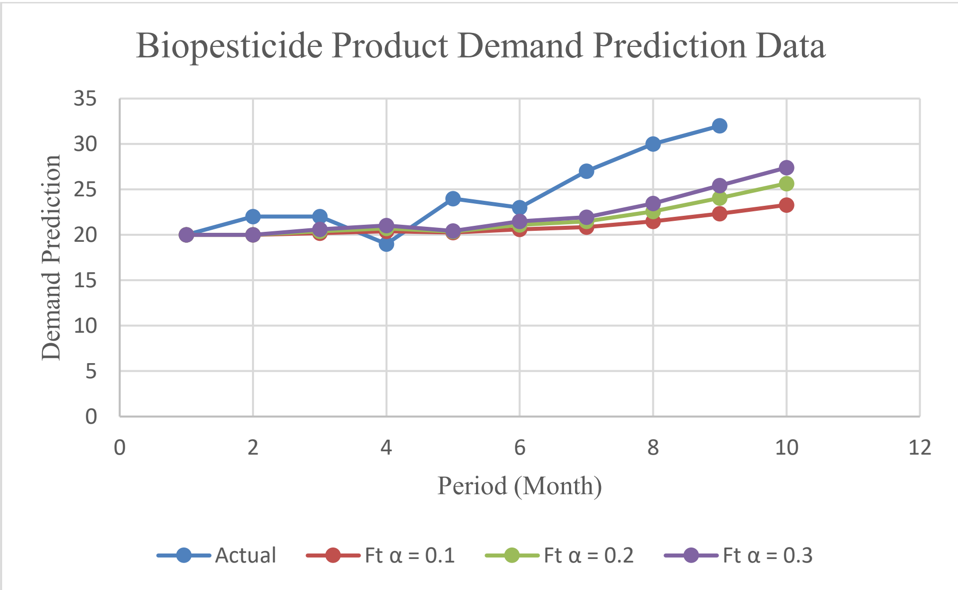

Figure 1. Biopesticide Product Demand Prediction Data

Source: Processed Data (2025)

From table 6, the predicted demand for Biopesticide products can be seen with actual data for 9 periods starting from January 2025 to September 2025, while in period 10, it can be seen that the data prediction by comparing 3 exponential value functions, namely α = 0.1, α = 0.2, α = 0.3, the results obtained are 23.291 ~ 24; 25.6541 ~ 26; 27.3954 ~ 28. Strengthened in figure 1, it can be seen that the graph in the calculation of the exponential function α = 0.3 is closer to the actual data. In line with what was conveyed by (Dibyantoro, 2023) that the use of data in the exponential value function can be said to have the best level of responsiveness if it is close to the actual data.

Discussion

Multiple Linear Regression

The first discussion on the multiple linear regression test is the T test (partial), where if it has a sig value < 0.05 then it is said to have a significant partial influence (Kilay et al., 2022). The Willingness to Pay (WTP) variable has the strongest and most significant influence on the acquisition of Biopesticide Products ($B=1.060$; $\beta=1.052$; $p<0.001$). This means that every 1 SD increase in WTP is stopped by an increase of ±1.05 SD, in line with evidence that willingness to pay determines the adoption of biological inputs (Moshkin et al., 2023). The increase in CVM reflects a willingness to pay more for benefits and efficacy, leading to increased application frequency. Income and land size or ownership factors increase WTP for biological or organic inputs, while perceived high product quality also increases WTP. This aligns with findings on farmers' WTP and supporting factors (Fitriyani, Putra, et al., 2024).

Operational Performance is positive but not significant with a value ($B=0.286$; $p=0.145$), indicating that good service quality and supply chain alone are not enough to drive demand without economic-perception levers (e.g. price, evidence of effectiveness) (Bottani et al., 2025). The insignificant relationship may be due to the fact that supplier indicators, availability, lead time, and ease of service may be considered quite good, but there are ceiling effects or variations between regions, so the net effect on demand is not yet strong. The agribusiness supply chain literature emphasizes that lead time and service reliability influence demand for biopesticide products, but their impact is often only apparent when combined with other variables such as value levers, product stock guarantees, and delivery SLAs (Zhou et al., 2024).

The Go Organic program had a negative and significant effect ($B=-0.468$; $\beta=-0.446$; $p<0.001$). This is consistent with findings that intensification, such as organic land clustering, can reduce pesticide dependence. Conversely, certain patterns actually encourage increased licensed applications on surrounding conventional land, which can substitute demand for commercial biopesticides. The implication is that organic partnership programs require Integrated Pest Management interventions and evidence of biopesticide effectiveness (Waqas et al., 2024). Socialization/training on the creation and implementation of organic systems can encourage substitution (independent biopesticide production) and reduce pesticide use, thereby reducing commercial demand. Monitoring can also strengthen the use of external inputs. Indonesian evidence shows that organic training increases the application of organic inputs, and organic policies and practices do reduce pesticide dependence. Implications for the product's position as a certified organic IPM component (Grimm & Luck, 2020).

In the discussion of the F (Simultaneous) test, it can be seen that if the sig value is <0.05, then the joint influence variables are significant, meaning H1 is accepted (Jumiati et al., 2023). The F-test shows a simultaneously significant model: $F(3,56)=128.415$; $p<0.001$. This means that Willingness to Pay, Operational Performance, and the Go Organic Program jointly explain variations in demand for Biopesticide Products. Practically, the combination of Willingness to Pay (driven by income, land ownership, and perceived quality) and the dynamics of the organic program (training/monitoring) are the main determinants of the level of implementation, Operational Performance is strengthened when synergized with value levers. The implication is to focus on increasing Willingness to Pay based on evidence of efficacy and integration of biopesticides in organic schemes (Nanta et al., 2025).

The determination test showed R = 0.934 and $R^2 = 0.873$, approximately 87.3% of the variation in demand for Biopesticide Products was jointly explained by WTP, operational performance, and the Go Organic Program; Adjusted $R^2 = 0.866$ confirmed high suitability after the number of variable penalties. Std. Error of the Estimate = 0.311 indicates that the average deviation of the prediction is relatively small compared to the scale of the data. The F Change value = 128.415 ($p < 0.001$) is consistent with ANOVA, so the increase in R^2 is statistically significant. Substantively, the high R^2 is in line with the literature on WTP (influenced by income, land area, and perceived quality) as the main driver of bio-input adoption, while biopesticide policy/ecosystem and supply chain structure moderate demand realization (Moshkin et al., 2023). Other variables also influence the level of demand for biopesticide products, such as Biopesticide Risk, Organic Program Support, and Ease of Product Supply, but the percentage is relatively small (Nanta et al., 2025).

Exponential Smoothing

The discussion on the exponential smoothing approach can be seen in the table and graphical images, the accuracy indicators for the single exponential smoothing model with $\alpha = 0.3$ show relatively good forecasting performance for volatile demand data: MAD = 3.19 indicates that on average the prediction is off by about ±3 units from actual demand (a measure of error in real units, making it easy for stock decisions), while MAPE = 13.6% means the average relative correlation is only about 13–14%, making it quite helpful for comparisons across periods and supporting more responsive α selection—in line with your script's narrative that increasing α reduces MAPE from α=0.1 to α=0.3. Meanwhile, MSE = 15.77 (mean squared error) imposes a larger penalty on large deviations, making it suitable for listening to model stability when demand calls occur (e.g., in months 7–9). Methodologically, the use of the MAPE–MAD–MSE combination for accuracy evaluation is widely recommended because each metric captures different aspects (scale, proportion, and sensitivity to large errors), and this practice is common in modern forecasting studies including in the context of measuring exponential smoothing vs. other models as well as the study of the reliability of forecasting performance metrics (Rimo et al., 2025).

provides the closest trace and produces a higher month-10 forecast (≈27.4 units), although SES still “lags” the trend. Managerially, the use of α can accumulate higher when there is demand (pest attack season, promotion, or increase in WTP), and decrease α when the market is stable (Kumar et al., 2024). Biopesticide demand is often driven by pest seasons, market access, and organic education programs, and typically needs to mimic trends and seasonality, due to the importance of agronomic context in broadcasting input demand. Willingness to Pay behavior anticipates the cessation of biopesticide sales (YUE et al., 2023).

A policy paradox is evident in the finding that the Go Organic Program had a negative and significant effect on the demand for commercial biopesticides ($\beta = -0.446$; $p < 0.001$), indicating a policy paradox or unintended policy impact. A program designed to encourage environmentally friendly agricultural practices actually has the potential to reduce demand for commercial biopesticide products by encouraging substitution to independent biopesticide production practices at the farmer level.

In other words, the program's success in increasing capacity and training in organic inputs can have a "crowding-out" effect on the commercial biopesticide market, achieving environmental objectives but weakening market demand signals. This is important to emphasize because it demonstrates that policy success is not solely measured by increased program activity, but also by the direction of changes in adoption behavior and the resulting incentive structure. The policy implication is the need to redesign the Go Organic program to be complementary, for example by integrating certified commercial biopesticides as a component of the IPM/organic standard, distinguishing support between independent production and use of certified products, and directing subsidies or assistance toward quality, registration, and quality control so that the program continues to strengthen environmental objectives without creating distortions that include the discontinuation of commercial products whose quality and legality are compromised.

CONCLUSION

This study concludes that Willingness to Pay (WTP) is the most dominant factor in influencing the demand for biopesticide products, while the Go Organic Program has a significant influence but tends to cause a substitution effect on the use of commercial biopesticide products, and operational performance plays a simultaneous role in strengthening demand realization. From the policy implementation side, the government and agricultural services need to adjust the design and implementation of the Go Organic Program to be complementary to the biopesticide market, including through accelerating the product registration process, strengthening quality control, integrating certified biopesticides into the IPM scheme and organic standards, and providing more targeted and performance-based subsidies. From a managerial perspective, biopesticide producers are required to enhance perceived value and evidence of product efficacy through demonstration plots, packaging economy, and field-based benefit communication. Distributors need to optimize inventory and distribution management by utilizing demand forecasting results. Extension services play a strategic role as a link between policy, markets, and farmers through education that positions biopesticides as an integral part of sustainable agricultural practices. However, this study has limitations, including the use of a cross-sectional design and a linear approach that do not fully capture the complex dynamics of demand and adoption behavior. Therefore, further research is recommended using nonlinear models, panel data, and conjoint analysis or discrete choice experiments to gain a deeper understanding of farmer preferences and their impact on biopesticide development policies and strategies.

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