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SINTA 2

Optimization of Production Input Use in Curly Chili Farming in the Pepe Watershed Area, Boyolali Regency

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ABSTRACT

Boyolali Regency, especially the Cepogo District, has significant potential for curly chili farming, supported by favorable topographical conditions and the presence of the Pepe Watershed Area. However, the productivity of curly chili in this region remains lower than the provincial average in Central Java. This study aimed to analyze the effects of production inputs and to evaluate the optimization of input use in curly chili farming in the Pepe Watershed Area, Boyolali Regency. The study employed a quantitative, survey-based approach with 68 curly chili farmers as respondents. Data were analyzed using the Cobb-Douglas production function, and input optimization was assessed using the ratio of marginal value product to input prices. The findings demonstrated that land area, seed use, and labor exerted had a positive and significant influence on curly chili farming, whereas manure, Phosphorus fertilizer, and pesticides exhibited no significant impact. The optimization research indicated that land area and seed utilization had not attained optimal levels and require enhancement. The application of manure, Phosphorus fertilizer, and pesticides was excessive and requires reduction. These findings offer valuable insights for enhancing input management efficiency and promoting the sustainability of curly chili farming in watershed regions.

Keywords: curly chili; farming efficiency; inputs production; optimization

INTRODUCTION

Horticultural commodities significantly contribute to agricultural growth by increasing farmers' income, creating employment opportunities, and maintaining food price stability. Curly chili plays a crucial role among horticulture products due to its importance as a staple ingredient in domestic consumption and its substantial economic value. National curly chili production has demonstrated a consistent upward trend, increasing from 1, 264,190 tons in 2020 to 1,554,498 tons in 2023, reflecting growing demand in the domestic market (BPS Indonesia, 2024). Domestic consumption has similarly grown at an average rate of 0.62% over the past five years, reaching 4.614 kg per capita per year in 2023, recovering from a temporary decline during the pandemic in 2020 (Pusdatin Kementan, 2024). Despite this growth in production and consumption, price volatility remains a persistent structural challenge. Producer prices have ranged between IDR 20,000 and 30,000 per kilogram in recent years, while consumer prices consistently exceeded producer prices by IDR 9,000 to 15,000 per kilogram, and occasionally spiked to IDR 77,000–87,000 per kilogram during supply shortfalls (Pusdatin Kementan, 2024). Hidayati et al. (2022) stated that fluctuations in chili prices directly affect regional food inflation volatility, underscoring the need to enhance production to maintain market stability. Van den Broeck and Maertens

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(2016) argue that enhancing the performance of the horticultural sector, particularly through improved production management and farming efficiency, is crucial for bolstering food security and improving the welfare of producer households in developing nations.

Given its strategic significance and considerable economic value, curly chili farming continues to face challenges due to low yields. Low productivity is generally attributed to limitations in natural resources and to the inefficient use of production factors, including both input volumes and their combinations. Misallocation of resources, such as land, seeds, fertilizers, labor, and pesticides, can increase production costs without a corresponding increase in output. Nurmalita et al. (2025) stated that the majority of chili farmers in Indonesia have not achieved optimal technical efficiency, indicating considerable potential for production improvement through enhanced input management and allocation without excessively increasing the use of production factors. Krasachat and Yaisawarng (2021) demonstrate that inefficiencies in the use of vital inputs in chili farming reduce output potential and increase production costs, underscoring the need to optimize input combinations to enhance productivity and economic efficiency in chili agriculture.

Boyolali Regency, specifically the Cepogo District, is recognized as a prominent center for cultivating curly chili, supported by its advantageous agroecological conditions and location within the Pepe Watershed. Data from the Boyolali Regency Agriculture Department indicate a significant expansion in curly chili farming in the district, with harvested area increasing more than twofold from 717.5 hectares in 2022 to 1,648.7 hectares in 2023, accompanied by a rise in total production from 49,969.34 quintals to 115,714.1 quintals (Dinas Pertanian Kabupaten Boyolali, 2023). However, despite this expansion, land productivity remained relatively stagnant at approximately 69.64 to 70.19 quintals per hectare, which remains lower than the provincial average of Central Java (BPS Provinsi Jawa Tengah, 2023). This persistent productivity gap highlights ongoing challenges in the management and allocation of production inputs, underscoring the need for a systematic investigation into the factors constraining yield performance in the area.

In practice, the majority of curly chili farmers in the Pepe Watershed continue to rely on experiential knowledge and conventional methods to determine the use of production inputs. Such approaches frequently lack a basis in economic efficiency, potentially leading to either excessive input usage or inadequate application at optimal levels. This situation highlights a gap between the potential of available resources and the actual output achieved, underscoring the need for a systematic investigation to evaluate the relationship between production parameters and agricultural yield.

Production function analysis provides a pragmatic analytical framework for identifying critical inputs that substantially influence agricultural output while concurrently assessing their utilization efficiency. This method facilitates the assessment of each input's contribution to production and determines if its utilization has attained an optimal level. Furthermore, input optimization analysis enables the evaluation of economic efficiency by comparing the marginal value product with input prices, thereby determining whether an input should be increased, maintained, or reduced (Yanuarti et al., 2019; Krasachat and Yaisawarng, 2021).

This study aimed to investigate the influence of production parameters on curly chili yield in Cepogo District, Boyolali Regency. Furthermore, this study aims to assess the optimization of essential agricultural inputs, including land area,

seeds, fertilizers, labor, and pesticides, to determine their economic efficiency. The findings are expected to provide informed management advice to farmers and to establish a basis for policymakers and agricultural extension agents to enhance productivity and ensure the sustainability of curly chili production in the Pepe Watershed.

RESEARCH METHOD

This study employed a quantitative research design, utilizing a survey-based methodology, which is frequently adopted in agricultural economics to examine input-output correlations and economic efficiency at the farm level. Quantitative methods facilitate the assessment of causal linkages between production inputs and output performance by using numerical data and econometric models, yielding objective and replicable result (Gujarati & Porter, 2009; Creswell & Creswell, 2023). The study area was selected through purposive sampling, based on criteria that align with the research aims, including its status as a prominent center for curly chili production and its favorable agroecological characteristics conducive to horticultural production. Purposive site selection is appropriate when the research site exhibits specific traits pertinent to the phenomenon under study, particularly in farm-level efficiency and production research (Etikan et al., 2016). Despite increases in harvested area and total production over time, curly chili productivity in this region remains below the provincial average in Central Java, suggesting potential inefficiencies in the management and allocation of production inputs.

The research population comprised curly chili farmers in the Pepe Watershed Area of Cepogo District. Since the exact size of the farming population was not known, the sample size was determined using the Cochran formula for unknown populations (Cochran, 1991) with a 95% confidence level and a maximum margin of error of 5%, yielding a minimum required sample of 68 farmers. A non-probability sampling method, specifically convenience sampling, was employed to select respondents based on their accessibility and willingness to participate during the production season (Etikan, 2016; Creswell & Creswell, 2023). The criteria for respondent selection were curly chili owner-farmers actively cultivating in the Cepogo District who were willing to participate in the study. Both primary and secondary data were utilized in this study. Primary data were collected through direct interviews using structured questionnaires to obtain information on production output, land area, seed usage, fertilizer application, labor utilization, pesticide use, and input prices, which is a standard data collection approach in agricultural production and efficiency studies (Coelli, Prasada Rao, and Battese, 2012; Greene, 2020). Secondary data were obtained from relevant institutions, including the Central Bureau of Statistics and the Department of Agriculture of Boyolali Regency, as well as related scientific literature, to support empirical analysis and contextual interpretation.

This study employed the Cobb–Douglas production function to examine the impact of production inputs on curly chili output, a widely used model in agricultural economics for assessing input–output relationships and quantifying production elasticity. This functional form facilitates the direct estimation of output elasticities from the regression coefficients, providing a clear economic explanation of the contribution of each production input (Gujarati and Porter, 2009). The production function was transformed into a logarithmic linear model to facilitate parameter estimation and interpretation, and to reduce potential heteroscedasticity commonly found in cross-sectional farm-level data (Coelli et

al., 2012; Greene, 2020). The model is specified as follows:

$$\ln Y = \ln a + \beta_1 \ln X_1 + \beta 2 \ln X_2 + \beta 3 \ln X_3 + \beta 4 \ln X_4 + \beta 5 \ln X_5 + \beta 6 \ln X_6 + \varepsilon$$

Where:

Y = Production of curly chili (Kg)
X_1 = Land area (Rp/Ha)
X_2 = Seed usage (Kg)
X_3 = Manure (Kg)
X_4 = Phosphorus fertilizer (Kg)
X_5 = Pesticide use (L)
X_6 = Labor (HOK)
a = Intercept
b1 – b6 = Production elasticity coefficients
ε = error term

To evaluate the economic efficiency of input use, this study applied an input optimization analysis based on the ratio between the Marginal Value Product (MVP) and the input price (Px). The marginal value product of each input was calculated as follows:

$$MVP_{Xi} = \beta_i \times \frac{Y}{X_i} \times P_y$$

Where:

MVP_{Xi} = Marginal value product of input X_i
β_i = Estimated production elasticity of input X_i
Y = Average output
X_i = Average input usage
P_y = Output price

Economic efficiency is achieved when the ratio between the marginal value product and the input price equals one:

$$\frac{MVP_{Xi}}{P_{Xi}} = 1$$

The criteria for evaluating input efficiency are defined as follows:

$\frac{MVP_{Xi}}{P_{Xi}} > 1$: input use is below the optimal level and should be increased
$\frac{MVP_{Xi}}{P_{Xi}} = 1$: input use is economically optimal
$\frac{MVP_{Xi}}{P_{Xi}} < 1$: input use is excessive and should be reduced

This input optimization analysis is grounded in the production economics framework proposed by Dibertin (2012) and Coelli et al. (2012), in which the condition MVP/Px = 1 represents the economically optimal input allocation. The analysis, therefore, constitutes an optimization approach, as it identifies the direction and magnitude of input adjustments required to achieve allocative efficiency.

RESULT AND DISCUSSION

Characteristics of respondents

The characteristics of respondents provide a crucial basis for analyzing production behavior and input use in curly chili farming. The respondents in this study were 68 chili farmers from the Pepe Watershed Area in Cepogo District. Table 1 shows that the majority of curly chili farmers fall within the 50–60 age group (37%), followed by the 39–49 age group (30%), with 83% of respondents classified within the productive working age range. Farmers in this age range generally possess both the physical capacity and experiential knowledge to manage labor-intensive farming operations (Colnago and Dogliotti, 2020; World Health Organization, 2015). However, the predominance of older farmers also reflects a broader structural trend in Indonesian smallholder agriculture, where younger generations increasingly shift toward non-farm employment, leaving agricultural activities to older household members (Susilowati, 2016). This aging profile implies that while input decision-making tends to be experience-driven and stable, receptiveness to new input management practices may be limited, potentially constraining allocative efficiency in curly chili farming.

Table 1.
Characteristics of Respondents

Characteristic	Category	n	%
Age (years)	28–38	11	16
	39–49	20	30
	50–60	25	37
	61–71	11	16
	72–82	1	1
Gender	Male	58	85
	Female	10	15
Education	Elementary School (SD)	35	52
	Junior High School (SMP)	15	22
	Senior High School (SMA/SMK)	17	25
	Higher Education (PT)	1	1
Farming Experience (years)	<5	1	2
	5–10	9	13
	>10	58	85

Source: Primary data (analyzed), 2024

Table 1 indicates that curly chili farming in the Pepe Watershed Area is predominantly male (85%), reflecting the physically demanding nature of chili cultivation, which encompasses land preparation, crop maintenance, and harvesting. Male dominance in smallholder horticultural systems has been widely documented, as women account for approximately 43% of agricultural labor in developing countries but remain underrepresented in physically intensive field operations (Doss, 2018). The limited participation of female farmers (15%) nonetheless suggests a complementary role in farm operations, particularly in post-harvest activities such as sorting and marketing, which are critical for produce quality and household income (Njuki et al., 2022).

Regarding educational attainment, 74% of respondents completed no more than junior high school, reflecting limited access to formal education in rural upland farming communities. Low educational attainment is associated with restricted access to technical information and suboptimal decision-making regarding input management, which can negatively affect production efficiency (Asfaw et al., 2012). This suggests that input use decisions in curly chili farming are largely guided by habit and experience rather than evidence-based agronomic recommendations, which may partly explain the allocative inefficiencies identified in this study.

The majority of respondents (85%) possessed more than ten years of farming experience, with an average of approximately 20 years. Extensive experience enables farmers to develop a deeper understanding of local agroecological conditions, seasonal variability, and risk management, which enhances production decision-making (Ainembabazi and Mugisha, 2014; Taramuel-Taramuel et al., 2023). However, long-term reliance on experiential knowledge without exposure to updated agronomic information may reinforce habitual input use patterns, potentially contributing to the allocative inefficiencies observed in fertilizer and pesticide application in this study.

Determinants of Curly Chili Production in the Pepe Watershed Area

The factors affecting curly chili production in the Pepe Watershed Area

were analyzed using the Cobb–Douglas production function, with the estimation results presented in Table 2. Based on the estimation results, the production function is expressed as follows:

$$\text{Ln } \hat{Y} = 1.400 + 0.107 \ln X_1 + 0.359 \ln X_2 - 0.031 \ln X_3 + 0.145 \ln X_4 - 0.067 \ln X_5 + 0.462 \ln X_6$$

The model demonstrates strong explanatory power, with an R^2 of 0.710, indicating that approximately 71% of the variation in curly chili output is explained by the six production inputs. The Adjusted R^2 of 0.681 confirms the model's robustness after accounting for the number of predictors, and the F-test result is statistically significant ($p = 0.000$), confirming the collective relevance of all production inputs and validating the appropriateness of the Cobb–Douglas model for this farm-level analysis (Gujarati and Porter, 2009; Coelli et al., 2012).

Land area exhibits a positive and statistically significant effect on curly chili production ($\beta = 0.107$, $p = 0.003$), leading to the rejection of H_0 at the 99% confidence level. This finding indicates that farm size is a crucial factor influencing output, particularly in smallholder farming systems, where land availability directly impacts planting capacity and production scale. Prior research has consistently shown that land area has a substantial influence on horticulture production and agricultural revenue, particularly for labor-intensive crops such as chili (Nuraini et al., 2023; Saragih et al., 2024). Limited landholdings, therefore, constitute a structural constraint that necessitates efficient input management to enhance productivity.

Seed use exhibits a positive and statistically significant effect on curly chili production ($\beta = 0.359$, $p = 0.017$), leading to the rejection of H_0 at the 95% confidence level. This finding underscores the importance of proper seed allocation to achieving optimal yield performance, as appropriate seed quantity and quality are essential for maximizing plant population density and consistent crop development. Empirical research suggests that seed input is a crucial determinant of chili productivity and technical efficiency, particularly in smallholder systems, where planting decisions significantly impact production outcomes (Nuraini et al., 2023; Nurmalita et al., 2025).

Labor input exhibits a positive and statistically significant effect on curly chili production ($\beta = 0.462$, $p = 0.013$), leading to the rejection of H_0 at the 95% confidence level. This finding reflects the labor-intensive nature of horticultural farming. Farm operations such as land preparation, transplanting, fertilization, pest control, and harvesting require sufficient and timely labor input to ensure proper crop management. Notably, labor shows the highest elasticity coefficient among all significant inputs ($\beta = 0.462$), suggesting that a 1% increase in labor input would yield approximately a 0.462% increase in production, making it the most influential input in determining output performance in this study. Empirical research on smallholder horticultural systems has consistently shown that labor availability and labor utilization efficiency are crucial determinants of production performance and yield outcomes, particularly for high-value crops that require intensive management practices (Coelli et al., 2012; Maertens and Verhofstadt, 2013). This study emphasizes the importance of effective labor distribution and management in improving production outcomes and overall agricultural productivity.

In contrast, the application of manure, Phosphorus fertilizer, and pesticides did not have a statistically significant effect on curly chili yield. The insignificance of these inputs suggests potential inefficiencies in their use, including overuse, improper timing, or disproportionate pairing with other inputs. Prior research indicates that excessive fertilizer and pesticide use often results in

lower returns, higher production costs, and potential environmental hazards without corresponding yield gains (Krasachat and Yaisawarng, 2021; Sharafi et al., 2025). These findings indicate that increasing chemical input intensity alone is insufficient to enhance productivity unless accompanied by improved input management practices.

Table 2.
The Result of Cobb-Douglas Regression Analysis

Variable	Regression Coefficient	Standard Error	Sig.
Constant	1,400	1,061	0.192
Land area (X1)	0.107	0.035	0.003***
Seed (X2)	0.359	0.146	0.017**
Manure (X3)	-0.031	0.093	0.742^{ns}
Phosphorus fertilizer (X4)	0.145	0.123	0.244^{ns}
Pesticide (X5)	-0.067	0.118	0.575^{ns}
Labor (X6)	0.462	0,180	0.013**
R^2	0.710		
Adjusted R^2	0.681		
F-sig	0.000		

Source: Primary data (analyzed), 2024

Where:
***) : Significant at 99%
**) : Significant at 95%
*) : Significant at 90%
ns : Not Significant

The estimated Cobb–Douglas production function indicates that curly chili output in the Pepe Watershed Area is primarily influenced by land availability, seed management, and labor utilization. From an economic standpoint, these findings underscore the need to improve input allocation efficiency rather than simply increasing input levels. Improving farmers' comprehension of optimal input combinations and advocating for efficient resource utilization are crucial strategies for enhancing productivity and profitability in smallholder curly chili farming, especially in environmentally sensitive watershed regions (Coelli et al., 2012; Yanuarti et al., 2019).

Analysis of Production Input Optimization in Curly Chili Farming

The optimization of production inputs in curly chili farming was analyzed based on the concept of allocative (economic) efficiency, which is achieved when the marginal value product (MVP) of an input equals its corresponding input price. The results of the input optimization analysis, as presented in Table 3, indicate that the utilization of production inputs in the Pepe Watershed Area has not yet reached optimal economic conditions. These findings suggest inefficiencies in input allocation, which may lead to suboptimal production performance and reduced farm profitability. Comparable methodologies have been widely used in agricultural economics research to evaluate the economic rationality of farmers' input-use decisions in light of prevailing price conditions (Coelli et al., 2012; Dibertin, 2012).

Table 3.
Results of Production Input Optimization Analysis in Curly Chili Farming

Variable	b	Py	Y	Xi	Pxi	NPMXi	ki
Land area	0.107	22,290	248	0.11	1,634,600	8,468,794	5.18
Seed	0.359	22,290	248	2,469.80	222	769,5224	3.58
Manure	-0.031	22,290	248	1,590.00	10,000	-106,839	-0.01
Phosphorus	0.145	22,290	248	100.36	230,000	7,917.22	0.03
Pesticide	-0.067	22,290	248	0.18	85,000	-2,039.7	-24.00
Labor	0.462	22,290	248	51.06	50,000	49,582.28	1.02

Source: Primary data (analyzed), 2024

The optimization analysis reveals that land area and seed input are underutilized, with MVP-to-price ratios of 5.18 and 3.58, respectively, both substantially exceeding the optimal threshold of one. These values indicate that each additional unit of investment in land expansion and seed input would yield marginal returns far exceeding their respective costs, suggesting that current utilization levels remain well below the economically optimal level. The pronounced underutilization of land area (ki = 5.18) reflects a structural constraint common in smallholder agricultural systems in Indonesia, where land fragmentation and limited access to additional arable land prevent farmers from expanding their cultivated area even when economic returns would justify doing so (Binswanger-Mkhize et al., 2010). In the Pepe Watershed Area, this constraint is further compounded by the region's topography, which limits the availability of suitable agricultural land for horticultural production. Similarly, the suboptimal use of seed input (ki = 3.58) suggests that farmers are applying seed quantities below agronomically recommended levels, likely due to cost-minimization behavior and limited access to quality seed supplies. Increasing seed input to optimal levels would enhance plant population density and crop uniformity, directly improving yield potential (Abate et al., 2015; Nurmalita et al., 2025). From a policy perspective, these findings underscore the importance of facilitating farmers' access to land consolidation programs and to subsidized, high-quality seed supplies to improve allocative efficiency in curly chili farming within watershed-based agricultural systems.

In contrast, manure, Phosphorus fertilizer, and pesticide inputs are found to be overutilized, with MVP-to-price ratios of −0.01, 0.03, and −24.00, respectively, all of which fall substantially below the optimal threshold of one. These values indicate that the marginal returns from additional units of these inputs are far outweighed by their respective costs, confirming that current application levels exceed the economically justified quantities. The extreme negative ratio of pesticide use (ki = −24.00) is particularly notable, suggesting severe overapplication relative to its productive contribution. This pattern is consistent with risk-averse behavior commonly observed among smallholder farmers in developing countries, where excessive pesticide application is perceived as a precautionary strategy against crop failure despite its diminishing productive returns (Krasachat and Yaisawarng, 2021). In the Pepe Watershed Area, this behavior is likely reinforced by limited access to accurate information on recommended pesticide dosages and the absence of adequate extension services providing evidence-based pest management guidance. The overuse of Phosphorus fertilizer (ki = 0.03) similarly reflects a tendency among farmers to apply chemical inputs beyond agronomically optimal levels, driven by the belief that

higher input quantities will proportionally increase yields, a perception that is not supported by the empirical findings of this study. The near-zero and negative MVP values for manure and pesticides further suggest that these inputs have reached or exceeded their point of diminishing returns, where additional application not only fails to increase output but may actively impair soil health and crop performance (Pretty and Bharucha, 2014). Reducing the application of these three inputs to economically optimal levels would simultaneously lower production costs, improve profit margins, and reduce the environmental burden of chemical inputs on the Pepe Watershed ecosystem, a critical consideration given the ecological sensitivity of watershed-based agricultural systems.

Labor input demonstrates an MVP-to-price ratio of 1.02, which is remarkably close to the optimal threshold of one, indicating that farmers' labor allocation decisions are approaching economic efficiency under existing production conditions. This near-optimal ratio suggests that the marginal value of an additional unit of labor is approximately equal to its cost, reflecting relatively rational labor-management practices among curly chili farmers in the Pepe Watershed Area. This finding is particularly significant, given that labor has the highest elasticity coefficient among the significant inputs ($\beta = 0.462$), underscoring its central role in determining output. The near-optimal labor utilization observed in this study may be attributed to farmers' extensive practical experience, averaging approximately 20 years, which enables them to make relatively informed decisions regarding labor scheduling and deployment across critical farm operations such as transplanting, fertilization, and harvesting (Ainembabazi & Mugisha, 2014). However, as production scale expands, maintaining optimal labor allocation will require greater attention to labor scheduling efficiency and, where necessary, access to additional seasonal labor to sustain productivity gains (Coelli et al., 2012; Maertens and Verhofstadt, 2013).

Optimization research indicates that inefficiencies in curly chili farming in the Pepe Watershed Area are mostly due to uneven input allocation rather than inadequate total input utilization. Enhancing allocative efficiency by optimizing underutilized resources, such as land and seeds, while minimizing the overuse of fertilizers and pesticides, would improve productivity and profitability from an economic standpoint. The findings highlight the need to improve farmers' access to extension services, input management training, and evidence-based recommendations to foster efficient resource utilization and facilitate sustainable curly chili farming within watershed-based agricultural systems (Dibertin, 2012; Pretty and Bharucha, 2014).

CONCLUSION

This study demonstrates that the production of curly chili in the Pepe Watershed Area, Boyolali Regency, is significantly influenced by land area, seed utilization, and labor input, indicating that production efficacy is predominantly determined by scale-related variables and the effective management of essential production inputs. Conversely, the use of manure, Phosphorus fertilizer, and pesticides does not markedly enhance productivity, indicating inefficiencies in their present application. The input optimization analysis indicates that the allocation of production inputs has not yet attained optimal economic conditions, as land area and seed utilization are underutilized, while fertilizer and pesticide inputs are overutilized, and labor input is relatively close to the optimal level. The data suggest that inefficiencies in curly chili farming are predominantly caused by

disproportionate input allocation rather than inadequate overall resource utilization. Consequently, enhancing allocative efficiency by optimizing the use of underutilized inputs, minimizing excessive input application, and bolstering farmers' access to extension services and evidence-based guidance on input management is crucial for improving the productivity, profitability, and sustainability of curly chili farming within watershed-based agricultural systems.

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