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THE ROLES OF SMART FERTIGATION IN CHILI FARMING

Netti Tinaprilla*)1, Yanti Nuraeni Muflikh*), Rahmat Yanuar*), Kurnia Intan Permata*)

*)Department of Agribusiness, Faculty of Economics and Management, IPB University
Jl. Kamper Wing 4 Level 5, Dramaga Campus, Bogor 16680, Indonesia

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Abstract: Smart farming technology has been developed with Agriculture 4.0 to improve productivity and yield quality and solve challenges such as climate change, labor shortage due to regeneration difficulties, and resource efficiency. The objectives of this study were to analyze (1) the characteristics of farmers and chili production using smart fertigation and (2) the cost structure, revenue, profit, and efficiency. The study used primary data from interviews with 83 farmers in Central and East Java. Analytical methods included descriptive statistics, Cobb-Douglas production functions, and R/C. The results showed that smart fertigation farmers, who represented 2% of the total, had higher education (17 years), longer training (124 days), and significant participation in farmer groups (100%). The role of smart fertigation in chili production is to increase productivity (from 8.35 t/ha to 20.67 t/ha), reduce fertilizer use (from 26.730 t/ha to 8.540 t/ha) and reduce labor requirements from 748.17 HOK/ha to 609.33 HOK/ha. Despite the higher farm costs/ha with smart fertigation, the higher total revenue (due to increased productivity and selling price) results in higher profit and efficiency (R/C).

Keywords: smart fertigation, chili farming, adoption decisions, cost savings

Abstrak: *Teknologi smart farming telah berkembang sejalan dengan pertanian 4.0 dalam meningkatkan produktivitas dan kualitas komoditi pertanian, untuk menjawab tantangan perubahan iklim, langkanya tenaga kerja karena sulitnya regenerasi petani, serta tantangan efisiensi sumberdaya. Tujuan penelitian ini untuk menganalisis (1) karakteristik petani dan usahatani cabai dengan smart fertigasi, dan (2) struktur biaya, penerimaan, keuntungan, dan efisiensi. Penelitian ini menggunakan data primer berdasarkan wawancara kepada 83 petani cabai di Jawa Tengah dan Jawa Timur. Metode yang digunakan adalah descriptive statistics, Cobb-Douglas production functions, dan R/C. Hasil penelitian menunjukkan bahwa petani dengan smart fertigasi yang diwakili oleh 2% populasi memiliki pendidikan lebih tinggi (17 tahun), memperoleh banyak pelatihan (124 hari) dan berpartisipasi dalam kelompok tani (100%). Peran smart fertigasi dalam usahatani cabai dapat meningkatkan produktivitas (dari 8.35 ton/ha menjadi 20.67 ton/ha), menghemat pupuk (dari 26.73 ton/ha menjadi 8.54 ton/ha), dan menghemat tenaga kerja (dari 748.17 HOK/ha menjadi 609.33 HOK/ha). Walaupun biaya total per hektar lebih tinggi, usahatani cabai dengan smart fertigasi menghasilkan total revenue lebih tinggi pula (dikarenakan peningkatan produktivitas dan harga jual) sehingga menghasilkan keuntungan dan efisiensi (R/C) yang lebih tinggi.*

Kata kunci: *smart fertigasi, usahatani cabai, keputusan adopsi, penghematan*

[1] Corresponding author:
Email: netti_tinaprilla@apps.ipb.ac.id

INTRODUCTION

Smart agricultural technology (smart farming) has grown rapidly to improve the productivity, quality, and efficiency of resources (time, labor, and means of production, such as water, fertilizers, and pesticides). Smart farming is a solution to address the challenges of climate change and the scarcity of agricultural labor. Rapid population growth impacts increasing food demand, difficulty regenerating farmers, and limited land that requires the use of smart technology (Arkeman, 2021). The forms of smart farming include sensor technology, timers, smart greenhouses, the Internet of Things (IoT), and big data analytics. Smart farming technology is being intensively developed in the framework of Agriculture 4.0 to increase farmers' incomes and contribute to agricultural sustainability (Knierim et al. 2019). Implementing smart systems in agriculture can help farmers maximize their agricultural output (Rustan et al. 2021). This method can reduce the cost of agriculture and the land required to create smart farming (Shrivastava et al. 2021). Smart farming technology can save human resources, effort, time, and costs because cultivation activities can be monitored and controlled remotely. However, the initial costs are quite high. As a result, it is better suited for use on large open agricultural land (Ula et al. 2021), aligning with economies of scale.

Few studies discuss the economic impact of smart farming in open fields on farmers' profits, contributing to its limited adoption. Previous research has focused on the experimental application of smart farming. Therefore, research on the role of smart farming from an economic perspective is needed. Research on the role of smart fertigation is conducted to increase farmers' adoption of smart farming in Indonesia.

PKHT-IPB developed NUTFIFERADS, a smart fertigation product for open fields in drylands. This smart fertigation product has been trialed in West Java, Central Java, East Java, and West Sumatra. The commodities tested were horticulture in Central Java and East Java, including chilies.

Chili commodities are food products whose demand tends to increase. In 2022, total chili consumption will reach 4,388 kg/cap/year (MOA, 2022). According to BPS (2022), the chili production centers in Indonesia are East Java (25.26%), West Java (16.78%), and Central Java (14.20%). Chili production in Indonesia consists of 51.13% cayenne peppers and 48.87% large chilies.

Chili production increased from 1961 to 2023 (Figure 1) due to increased productivity rather than increased land area. During that period, there was an increase in efficiency or technological change. In chili commodities, technological changes tend to be applied more in the production centers of Central Java and East Java. Therefore, research on smart fertigation technology in Indonesia can be represented by two provinces: Central Java and East Java.

A range of studies have explored the impact of smart fertigation on chili farming. However, most of them were conducted in other countries and focused more on agronomy. Prabha (2018) and Suhaimi (2016) highlight the potential of IoT-based systems and fertigation technology in improving yield and reducing costs. Mali (2019) and Makkar (2020) further emphasize enhancing yield, nutrient uptake, and water productivity. Reddy (2016) and Hakkim (2014) provide practical evidence of the benefits of fertigation, with the former reporting higher yields and the latter showing the effectiveness of site-specific drip fertigation. This research uniquely focuses on smart fertigation technology in Indonesia, specifically in Central Java and East Java. Unlike the existing literature, which often examines general trends, this study delves into the application of smart fertigation technology in regions known for their prominence in chili production. By examining the efficiency and technological change within these provinces, the research provides nuanced insights into the factors influencing the dynamics of chili production in Indonesia. This specific regional focus adds valuable contextualisation to the broader discourse on agricultural technology adoption and its impact on productivity, providing insights particularly relevant to the Indonesian case.

The research aims to analyze the impact of Smart Farming fertigation on production and productivity and conduct a detailed cost structure and revenue analysis of chili farming. Through these objectives, the research provides valuable insights into the dynamics of fertigation adoption, its impact on chili farming outcomes, and the overall economic viability of different farming strategies.

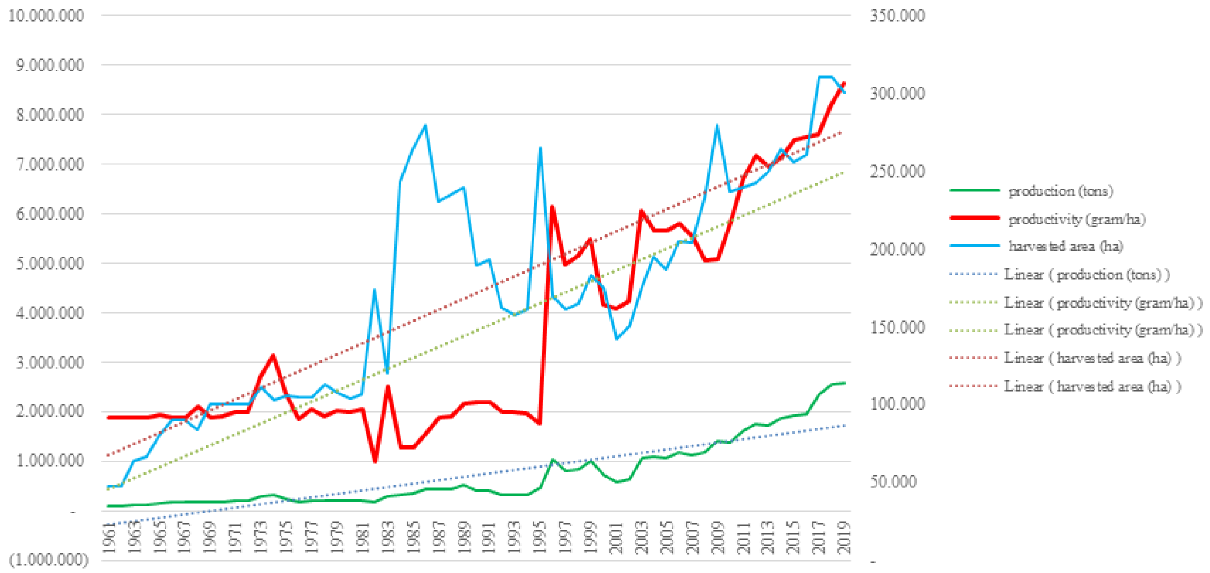

Figure 1. Chili production, productivity, and harvest area in Indonesia (1961-2018) (FAOSTAT, 2020)

METHODS

The research was conducted in Tegal Regency, Central Java, and Kediri Regency, East Java, and was deliberately chosen as a chili production center utilizing smart fertigation technology. Data were collected from August to November 2023 through direct interviews employing questionnaires. The respondents, totaling 83 farmers, were divided into two groups based on fertigation technology use: two smart fertigation chili farmers, 28 non-smart fertigation farmers, and 53 conventional chili farmers. The census method surveyed chili farmers using fertigation technology, while conventional technology users were purposively selected.

Research employed a range of analytical methods to address distinct objectives (Table 1). The impact of smart farming fertigation on production and productivity was assessed using the Cobb-Douglas production function. A tabulated approach clarified input costs for a detailed cost structure and revenue analysis. Profit calculation and the Revenue-to-Cost (R/C) ratio were utilized to gauge advantages and efficiency.

Analysis of characteristics of farmers and farms

The characteristics of farmers and chili enterprises in Central and East Java were analyzed using a tabulated descriptive analysis (descriptive statistics) to compare the demographic characteristics of farmers and farms by applying fertigation. Farming characteristics were investigated to assess changes resulting from fertigation technology.

Analysis of the effect of smart farming fertigation on production and productivity

This study analyzes chili farming production and productivity using the Cobb-Douglas production function. The choice of this function is based on its ability to derive a linear cost function, widely used in agricultural research. The Cobb-Douglas function can be transformed into a multiple linear equation in logarithmic form and describes returns to scale, indicating farmers' production capabilities. The equation for the Cobb-Douglas production function in this study is as follows:

1. Production Function

$$\ln Y = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 D_1 + \beta_6 D_2 + \beta_7 D_3 + e$$

Description: Y (chili production in one growing season (kg)); β_0 (Intercept or Constanta); β_{1-7} (coefficient of the model as the expected value); e (disturbance term or Error term); X_1 (land (ha)); X_2 (herbicides (Lt)); X_3 (seedling (plants)); X_4 (labor for tillage (HOK)); D_1(technology (1: fertigation 0: conventional)); D_2(access to loan (1: Yes 0: No)); D_3 (land expansion (1: Yes 0: No)).

Table 1. Linking research objectives and research methods

Research objectives	Research Methods
Analyze the effect of smart farming fertigation on production and productivity	Cobb-Douglas Production Function: Utilize a widely-used tool for agricultural research. Transform into a multiple linear equation in logarithmic form. Describe returns to scale (increasing, constant, or decreasing).
Conduct cost structure and revenue analysis of chili farming	Tabulated Cost Structure Analysis: Use a tabulating approach to show average production costs per input type. Group costs, including cash and non-cash costs. Determine the percentage of input costs to total costs.
Analyze the advantages and efficiency of chili farming	Profit Calculation and R/C Ratio Analysis: Calculate farm profits by subtracting receipts from total costs. Use the R/C ratio to assess financial profitability and efficiency. R/C > 1 indicates profitability, R/C < 1 indicates unprofitability, and R/C = 1 indicates cost equal to receipts.

2. Productivity Functions

$$\ln Y = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 D_1 + \beta_6 D_2 + \beta_7 D_3 + \beta_8 D_4 + \beta_9 D_5 + e$$

Description: Y (productivity chili in 1 growing season (kg/ ha)); β_0 (Intercept atau Constanta); $\beta_{1\text{-}9}$ (coefficient of the model as the expected value); e (disturbance term atau Error term); X_1 (herbicides (Lt/ha)); X_2 (ZPT* (Kg/ha)(ZPT is an abbreviation of Growth Regulatory Substances)); X_3 (seedlings (plants/ha)); X_4 (labor for processing land (HOK/ha)); D_1 (technology (1: fertigation 0: conventional)); D_2 (access to loan (credit) (1: Yes 0: No)); D_3 (land expansion (1: Yes 0: No)); D_4 (cooperative membership (1: member 0: non-member)); D_5 (chili as mainstay (1: Yes 0: No)).

The hypothesis or the expected value of the coefficients $\beta_{1\text{-}n}$ is > 0, which means that the estimated results of the Cobb-Douglas production function give a positive value for the alleged parameters. A positive coefficient of the conjectural parameter implies that a 1 percent increase in input X_i leads to a percent increase in chili pepper β_i production. In addition to multiple linear regression analysis, the classical assumption violation test includes a normality test, a multicollinearity test, and a heteroskedasticity test.

The chili production model is evaluated using an F-test to determine whether the independent variables in the model can jointly affect the dependent variable simultaneously. The Model is significant if the significance value is lower than the actual level. Meanwhile, the evaluation of the chili production model partially uses a t-test to determine whether the independent variables partially affect the dependent variable. Variable β_i significant if the sig value is less than the actual level. In addition to the evaluation, the coefficient of determination test (R^2) was used to determine the extent to which the proportion of diversity of the independent variables together affected the dependent variables. The maximum value R^2 is 1, and the minimum value is 0. The greater the value of R^2, the more accurate the conjectural model obtained to predict the dependent variable.

Cost structure and revenue analysis of chili farming

Cost structure analysis is performed using a tabulating approach in the form of a table to clarify the amount of input used based on the scale of business (Soekartawi, 1995). A tabulated analysis was used to show the average cost of production per type of input used. A cost structure analysis was performed by grouping the costs, including cash and non-cash and total costs. Cost structure analysis can be used to determine the percentage of production input costs to the total costs. The cash and non-cash costs can be determined by multiplying the number of inputs used by the price of these inputs.

Farm receipts represent the total product sales. Mathematically, the chili farming acceptance formula is as follows:

$$TR = PY \times Y$$

Description: TR (total chili farming revenue (Rp)); PY (chili price (Rp/Kg)); Y (number of chili peppers (Kg)).

Analysis of the advantages and efficiency of chili farming

Farm profits can be calculated by subtracting the receipts from the total cost. Profit is a benchmark for successful farming. Meanwhile, the R/C ratio is calculated because a large income does not always indicate a high efficiency. The R/C ratio describes the gross income received by farmers after spending as much as one unit. In this study, the R/C ratio used is the R/C over the total cost. If the R/C ratio is > 1, the cost incurred is less than the revenue, indicating that chili farming is financially profitable and efficient. If the R/C ratio of the costs is < 1, the farm is not profitable financially because the total costs incurred are greater than the receipts. If the R/C ratio is one, the cost equals the receipt.

Smart fertigation solves food demand, land, and human resource problems. Although it requires a large investment, the benefits are also very high. The challenge is more about open fields than greenhouse issues. Production factors influence production, while total revenue is influenced by production and selling price. Production factors result in cost structure, then cost structure and total revenue are variables to determine profit and efficiency. Finally, recommendations and policy implications are explained by profit and efficiency (Figure 2).

RESULTS

Characteristics of Respondents

Categorized into Smart, Fertigation+, and Non-Fertigation groups, key demographics showed that 94% of the farmers were male with an average age of 43 years. The Smart group had the highest average level of education at 17 years. The length of training varied, with the Smart group spending 124 days, while the average family size was three people. Participation in the farming group was high at 82%, with Smart at 100%, Fertigation+ at 67%, and Non-Fertigation at 91%. Farming experience averaged ten years. PPL visits per month varied, with the Smart group visiting seven times. Mobile phone ownership was widespread (86%), and chili farming was the mainstay of a significant proportion, particularly in the non-fertigation group (74%). Monoculture cultivation was highest in the Smart group (100%). Access to modern retail markets varied, with 50% in the Smart group. Loan capital averaged Rp50,773,585, with the Smart group having the highest at Rp750,000,000. Off-farm income per month was highest in the Smart group at Rp6,500,000. Total fertigation investment varied, with the Smart group having the highest average at Rp10,445,000.

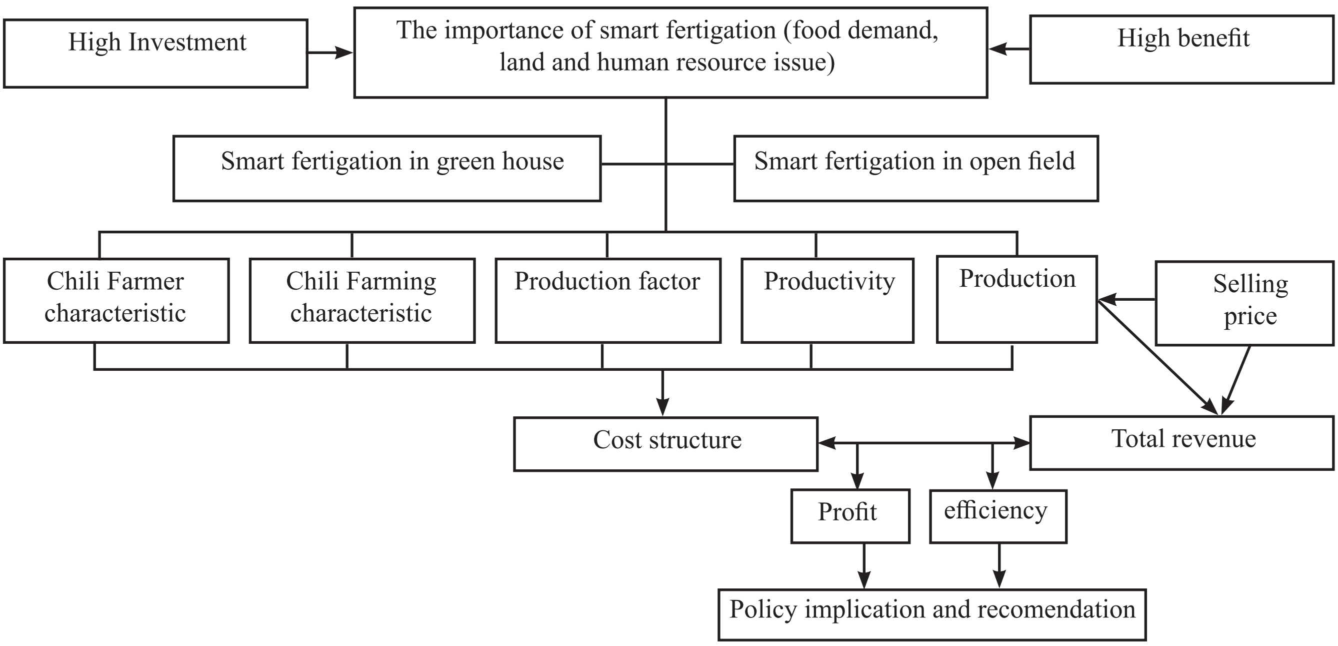

Figure 2. Research framework

The dominance of farmers in their productive age is consistent with Seran et al. (2020), who found reduced physical strength in older farmers. Age significantly impacts thinking, physical ability, and decision-making (Harahap et al. 2018). Younger farmers, driven by curiosity, are more likely to adopt fertigation technology, as observed by Adawiyah et al. (2017), who found that younger farmers have a more positive technology adoption rate than their older counterparts.

Fertigation farmers with higher education and extensive training have greater farming experience, facilitating faster technology adoption. Experience enhances understanding and enables better farming decisions (Bachri et al. 2019). Societal elements and exposure beyond formal education motivate technology adoption (Nurcahyo et al. 2019). Fertigation farmers, often group members, benefit from frequent PPL visits and mobile phone access to knowledge. Monoculture and increased access to markets and credit differentiate fertigation farmers, leading to higher off-farm incomes. The technology optimizes the time and supports significant investments (Bachri et al. 2019).

Characteristics of chili farming with Smart fertigation

In this study, chili cultivation relied predominantly on fertigation and non-fertigation methods, with only a few farmers adopting smart fertigation, fertigation+, and conventional fertigation practices. Smart fertigation, an advanced agricultural technique that integrates smart technologies and precision irrigation, showed superior performance in chili cultivation. Smart fertigation optimizes water and fertilizer application based on real-time data and crop needs, resulting in higher production volumes and productivity compared to other methods. Fertigation+, likely to include further innovations, represents an enhanced form of fertigation beyond conventional practices. Meanwhile, conventional fertigation remains a widely used to deliver water-soluble fertilizer to crops during irrigation. The analysis in Table 2 highlights the significant productivity gains achieved by smart fertigation, underscoring its potential to revolutionize chili production by maximizing yields and resource efficiency.

Table 2 presents comparative characteristics of chili farming based on technology adoption. The table indicates increased productivity due to fertigation technology, aligning with Bezerra et al. (2017) and Sinha et al. (2017), who highlight its role in enhancing crop productivity and fruit quality by managing nutrients and water. According to Darmaputra et al. (2019), the application of fertigation increases the production of grade A fruit or the weight of fruit production (Darmaputra et al. 2019).

Fertigation boosts productivity and reduces input usage, particularly fertilizer, as demonstrated by Sandals and Kapoor (2015), who found it can cut fertilizer use by 25–40%. Table 3 indicates that fertigation technology boosts the utilization of liquid fertilizers facilitated by a system that simultaneously combines water and nutrients. Appropriate provision of water and nutrients impacts plants' generative and vegetative growth, as seen from the increase in plant height, fruit per plot, and yield per hectare, which increases linearly (Umar and Prabowo, 2011). Fertigation plays an important role in improving quality. This increase has also affected the use of fewer pesticides.

Table 2. Characteristics of chili farming based on fertigation technology

Components	Total	Smart	Fertigation	Fertigation+	Non-fertigation
Production volume (Kg)	5,716.75	6,750.00	11,838.71	11,499.47	2,443.51
Land size (ha)	0.38	0.26	0.55	0.53	0.29
Productivity (Kg/ha)	12,995.18	38,000.00	20,007.99	21,207.46	8,346.72
Seeds (tree/ha)	23,966.25	17,966.67	21,282.72	21,061.65	25,610.36
Total of fertilizers used (Kg/ha)	22,648.51	6,040.00	16,108.89	15,437.63	26,730.13
Chemical fertilizer (Kg/ha)	834.97	706.67	509.57	522.71	1,011.72
Organic fertilizer (Kg/ha)	21,813.53	5,333.33	15,599.32	14,914.92	25,718.41
Total of pesticide use (Lt/ha)	33.62	18.77	33.72	32.73	34.13
Total of labor use (HOK/ha)	731.87	658.67	726.17	721.67	737.65

Table 4 shows the average pesticide use per hectare per season across different components for smart fertigation, fertigation+, and no fertigation practices. Comparing these categories, it is clear that smart fertigation farmers use less pesticide than conventional farmers, indicating a positive impact on crop quality and health. Adopting fertigation technology results in reduced pesticide and fertilizer use and implies significant labor savings. In particular, the labor savings are mainly related to maintenance tasks such as fertilization, spraying, and irrigation.

These findings underscore the efficiency and resource-saving benefits of implementing smart fertigation practices in agriculture (Rosma et al. 2021; Kabirigi et al. 2017; Bezerra et al. 2017). IoT-based fertigation automates nutrient and water provision based on plant needs, reducing labor and costs (Rosma et al. 2021). Table 5 shows smart fertigation requires fewer labor hours than conventional farming, resulting in significant time and cost savings (Kabirigi et al. 2017). This aligns with Rachmawati's statement (2021) that fertigation, particularly smart fertigation, can boost production by 20%, reduce water usage by 30%, cut human labor needs by 50%, and decrease fertilizer and pesticide usage by 10%.

Effect of fertigation technology on chili production

Based on the previous discussion on the role of fertigation in increasing production, it needs to be tested statistically. To determine the effect of fertigation on the increase in production, we analyzed the Cobb-Douglass production function. An analysis was conducted to determine the factors that affect the increase in production. The results of the analysis are presented in Table 6.

Table 3. Average use of chili farming fertilizer per hectare per season

Components	Total	Smart	Fertigation	Fertigation+	Non-fertigation
Organic fertilizer (Kg/ha)	21,688.03	4,000.00	15,527.89	14,759.37	25,609.91
Dolomite (Kg/ha)	125.51	1,333.33	71.43	155.56	108.50
ZPT - liquid (Lt/ha)	1.93	-	1.54	1.44	2.21
ZPT - solid (Kg/ha)	1.79	-	1.37	1.28	2.08
Urea (Kg/ha)	125.28	133.33	32.38	39.11	174.06
TSP (Kg/ha)	189.84	200.00	125.00	130.00	223.72
KCL (Kg/ha)	98.32	66.67	73.30	72.86	112.73
NPK (Kg/ha)	338.88	66.67	249.77	237.56	396.22
Other solid fertilizers (Kg/ha)	49.32	-	7.08	6.61	73.50
Other liquid fertilizers (Lt/ha)	33.12	266.67	21.43	37.78	30.48

Table 4. Average pesticide uses per hectare per season

Components	Total	Smart	Fertigation	Fertigation+	Non-fertigation
Furadan (Kg/ha)	3.48	-	1.22	1.14	4.80
Adhesive (Lt/ha)	5.67	6.67	4.44	4.59	6.29
Traps (Lt/ha)	0.30	-	0.89	0.83	-
Herbicide (Lt/ha)	0.63	-	-	-	0.98
Solid fungicide (Kg/ha)	11.76	10.00	14.65	14.34	10.30
Liquid fungicide (Lt/ha)	1.19	-	0.64	0.59	1.53
Solid insecticide (Kg/ha)	0.95	-	0.22	0.21	1.38
Liquid insecticide (Lt/ha)	7.85	1.00	9.88	9.29	7.04

Table 5. Average use of chili farming labor per season per hectare (HOK)

Farming activities	Combined farming activities	Smart	Fertigation	Fertigation+	Non fertigation
Labor for seeding	28.44	41.33	18.91	20.41	32.98
Labor for land	149.64	143.33	204.87	200.77	120.70
Labor for stake installation	17.70	30.67	16.87	17.79	17.65
Labor for planting	30.56	39.33	25.83	26.73	32.73
Labor for binding to stake	21.17	24.00	18.65	19.01	22.39
Labor for maintenance	145.43	50.67	112.33	108.22	166.49
Labor for harvesting	309.44	313.33	303.69	304.34	312.34
Labor for post-harvest	29.49	16.00	25.01	24.41	32.37
TOTAL of labor use	731.87	658.67	726.17	721.67	737.65

Table 6 shows the results of the simultaneous regression model test, partial test of the seven suspected variables, and classical assumption test. The suitability test model showed a Prob (F-statistic) value of 0.000. Therefore, the estimator variables simultaneously affect chili production. Meanwhile, the R-squared is 0.838, which shows that the regression model can explain 83.8% of the variation in production variables, and variables outside the model explain the other 16.2%. The test shows no collinearity problem in the model, as seen from the VIF value of less than 10**.** The test variables were as follows: Land area variables significantly positively affect the increase in chili production at alpha 5%. The addition of a land area of 1 percent will increase production by 89.4%. Herbicides had a significant positive effect on chili production by 10%. The addition of 1% herbicide increased production by 3.6%. Variable technology has a significant positive effect on increasing production at alpha 5%, meaning farmers using fertigation have 76.4% greater production. Variable access to loans has a significant positive effect on increasing production at 5% alpha, meaning farmers with access to loans have an agreement production of 28% compared to farmers without access to loans. Land expansion has a significant positive effect on increasing production at Alpha 10%, meaning that farmers who experience land expansion have 23.8% greater production than farmers who do not experience land expansion.

The Effect of Smart Fertigation on Chili Production

In addition to testing the effect of fertigation on production, statistical tests were conducted on the productivity variables. The test used the Cobb–Douglas productivity function. Productivity testing is an alternative to overcome collinearity problems; however, it is considered a more balanced comparison.

Table 7 shows the results of the simultaneous regression model tests, partial tests of the nine estimated variables, and the classical assumption tests. The model fit test showed a prob (F-statistic) value of 0.000, indicating that the estimated variables simultaneously affect chili productivity. Meanwhile, the R-squared value is 0.557, which indicates that the regression model can explain 55.7% of the variation in productivity variables, and variables outside the model explain the other 44.3%. The test results show no collinearity problem in the model, as seen from the VIF value of less than 10. The VIF value in the productivity model was smaller than that in the production model, particularly for the seed and land variables. This is because productivity is clustered within the same unit, making it more balanced. The test variables are as follows:

Variable herbicides significantly increase pepper productivity at 10% alpha, with a 1% herbicide addition resulting in a 3.5% increase. Fixed ZPT variables positively affect chili productivity at 20% alpha, with a 1% addition leading to a 2.8% increase in productivity. Technology, especially fertigation, significantly increases productivity at 5% alpha, with fertigation users having 80.3% higher productivity than non-f fertigation farmers. Land expansion has a significant positive effect on productivity, with an alpha of 15%, leading to a 21% increase in productivity. Cooperative membership positively impacts productivity at 10% alpha, with members having 27.2% higher productivity than non-members. Access to credit significantly affects productivity at 5% alpha, with access to credit associated with 28.6% higher productivity.

Table 6. Factors that influenced chili production (Cobb-Douglass production function)

Model	B	Std. Error	Sig.	Correlations			Collinearity	
				Zero-order	Partial	Part	Tolerance	VIF
(Constant)	8.372	1.650	0.000					
X1 (Ln of land)	0.894	0.182	0.000	0.819	0.493	0.23	0.126	7.93
X2 (Ln of herbicides)	0.036	0.019	0.061	-0.007	0.215	0.09	0.798	1.25
X3 (Ln of seed)	0.063	0.165	0.702	0.712	0.044	0.02	0.132	7.56
X4 (Ln of labor use)	0.013	0.013	0.298	0.110	0.120	0.05	0.844	1.19
D1 (D technology)	0.764	0.109	0.000	0.509	0.630	0.33	0.752	1.33
D2 (D loan access)	0.280	0.113	0.016	0.351	0.275	0.12	0.805	1.24
D3 (D land expansion)	0.238	0.133	0.077	0.364	0.203	0.08	0.844	1.19
R-squared								0.838
Prob (F-statistic)								0.000

Table 7. Factors affecting chili productivity (Cobb-Douglass productivity function

Model	B	Std. Error	Sig.	Correlations			Collinearity	
				Zero-order	Partial	Part	Tolerance	VIF
(Constant)	7.983	1.608	0.000					
X1 (Ln of herbicides)	0.035	0.019	0.067	-0.135	0.213	0.145	0.730	1.371
X2 (Ln of solid ZPT)	0.028	0.020	0.168	0.071	0.161	0.108	0.952	1.050
X3 (Ln of seeds)	0.114	0.163	0.484	-0.142	0.082	0.055	0.736	1.359
X4 (Ln of labor use)	0.010	0.012	0.397	0.139	0.099	0.066	0.845	1.184
D1 (D technology	0.803	0.106	0.000	0.655	0.662	0.587	0.741	1.350
D2 (D land expansion)	0.210	0.129	0.107	0.216	0.188	0.127	0.849	1.178
D3 (D cooperative membership)	0.272	0.143	0.061	0.114	0.217	0.148	0.887	1.127
D4 (D chili as mainstay)	0.025	0.111	0.826	-0.026	0.026	0.017	0.938	1.066
D5 (D loan access)	0.286	0.109	0.010	0.343	0.294	0.205	0.827	1.210
R-squared								0.557
Prob (F-statistic)								0.000

The analysis reveals key relationships affecting chili production and productivity. More extensive land holdings correlate with higher production, highlighting the importance of land area. Herbicide use positively affects both production and productivity, highlighting the importance of effective weed control. Fertigation consistently outperforms traditional irrigation in increasing production and productivity. Financial factors, including access to credit, are associated with increased production and productivity. Cooperative membership and land expansion also have a positive impact on outcomes. As members of cooperatives, farmers are expected to have access to finance, markets, and technology (Barham and Chitemi, 2009; Fisher and Qaim, 2012). These findings highlight the importance of modern agricultural practices, efficient land management, and financial resources in optimizing chili production. The results provide valuable guidance for policymakers, extension services, and farmers seeking to achieve sustainable and efficient chili production.

Revenue and Cost Structure Analysis

Fertilization resulted in a significant increase in production and productivity based on statistical tests. However, economically, an increase in production must align with an increase in revenue. Total revenue is obtained by multiplying the selling price farmers receive by the production amount produced. The average price per kg received by the farmers was IDR 21,584. The average price per kg received by smart fertigation, fertigation, fertigation+, and conventional farmers was IDR 26,500, IDR 16,571, IDR 17,233, and IDR 24,046, respectively. The price received by smart fertigation farmers has a greater value, which indicates that the quality of chili produced is good. The average revenue received by farmers was IDR258,768,451. The average income smart fertigation, fertigation, fertigation+, and conventional farmers received was IDR1,107,333,333, IDR318,600,765, IDR371,182,937, and IDR195,137,610, respectively.

When adopting innovations, farmers consider their impact rationally. Fertigation showed increased acceptance but needed to be seen as dampened in terms of costs. Therefore, the implementation of innovations has an impact on cost structures. The cost structure of chili farming based on fertigation adoption is presented in Table 8.

Based on the cost structure shown in Table 8, the largest percentage of labor costs is incurred. The total labor cost of smart fertigation farmers is lower than that of conventional fertigation farmers. Controlling a single system can reduce labor costs by 45% (Bezerra et al. 2017). The total cost incurred by fertigation farmers is greater than that of conventional farmers. However, the difference was insignificant, and the percentage of labor costs to the total cost for conventional farmers was greater than that for fertigation farmers. Compared to fertigation and fertigation farmers, the second largest cost for conventional farmers is fertilizer costs, with the second largest percentage of depreciation costs. This shows that fertigation can save fertilizer costs but increases depreciation costs because of the large initial investment. Smart fertigation resulted in water and nutrient (fertilizer) savings of 6,500 ml/plant or 7.64%, equivalent to IDR183.00/plant (Prastowo et al. 2023).

The use of fertigation technology also has an impact on increasing internet costs. This is indicated by the fact that the Internet costs of farmers using fertigation technology are much higher than those of other farmers. The Internet is a system used in fertigation to control the delivery of water and nutrients remotely. Smart agriculture applies information and technology to improve economic returns from crop production and optimize agricultural inputs and processes (Nukala et al. 2016; Idoje et al. 2021).

Analysis of the benefits and efficiency of chili farming

An analysis of the profits and efficiency of chili farming was conducted based on the revenues and costs of chili farming. This analysis showed the economic benefits to farmers regarding the impact of technology adoption. The results of the analysis are presented in Table 9.

Table 9 shows that smart fertigation and fertigation showed higher acceptance than conventional farmers. In addition, technology adoption increases the total cost of use. However, the increase in revenue is still much higher than the increase in costs. Hence, the benefits received by smart fertigation and fertigation farmers are higher than those of conventional farmers. According to Muladi et al. (2021), with IoT, revenue results can provide an additional income of IDR225 thousand for a square meter area. In addition to profit, fertigation farmers showed a higher efficiency value, as seen in the higher R/C value than conventional farmers. In terms of production efficiency before and after smart farming, there is an increase in technical efficiency, pure technical efficiency, and scale efficiency (Choi et al. 2018).

Table 8. Cost structure of chili farming per hectare per season

Costs	Smart	%	Fertigation	%	Fertigation+	%	Non-fertigation	%
Land rent	6,750,000	6.48	8,775,191	9.27	8,640,179	9.07	8,668,918	10.04
Seed cost	7,241,667	6.95	4,564,049	4.82	4,742,557	4.98	4,152,801	4.81
Fertiliser cost	12,666,667	12.16	12,963,128	13.70	12,943,364	13.58	17,678,405	20.46
Pesticide cost	2,003,333	1.92	6,489,350	6.86	6,190,283	6.50	4,809,795	5.57
Labor cost	37,733,333	36.21	43,079,447	45.51	42,723,040	44.83	39,653,047	45.90
Depreciation cost	33,379,278	32.03	11,946,379	12.62	13,375,239	14.04	6,768,374	7.84
Taxation	166,667	0.16	86,458	0.09	91,806	0.10	276,941	0.32
Internet cost	1,200,000	1.15	539,133	0.57	583,190	0.61	72,403	0.08
Other utility cost	3,066,667	2.94	6,212,780	6.56	6,003,039	6.30	4,303,423	4.98
TC	104,207,611		94,655,916		95,292,696		86,384,106	

Table 9. Advantages and efficiency of chili farming per hectare per season

Components	Total	Smart	Fertigation	Fertigation+	Non-fertigation
TR	258,768,451	1,107,333,333	318,600,765	371,182,937	195,137,610
TC	89,604,078	104,207,611	94,655,916	95,292,696	86,384,106
Profit	169,164,372	1,003,125,722	223,944,849	275,890,241	108,753,503
R/C	3.671	10.377	4.780	5.153	2.833

Managerial Implications

Smart fertigation technology in Indonesia has attracted a few chili farmers to open fields. From the 83 respondents, most were farmers who did not use fertigation (53 farmers) and farmers who used fertigation (28 farmers). Finding chili farmers in open fields who perform smart fertigation is difficult, so there are only two (one farmer in Tegal and Kediri). The lack of interest was attributed to the large initial investment, limited expertise, and belief that the results would be similar. Although the results of this study prove that smart fertigation technology plays an important role in open field chili farming that can increase sales, profits, and savings, farmers still need to be educated to convince them through socialization and demonstration plots. With successful examples and farmers seeing them firsthand, they will naturally be interested and try it. Farmers who need to be educated must match the characteristics of millennial farmers, namely, being educated and experienced in chili farming and focusing on their business with high motivation. The increasing difficulty of finding farm laborers, uncertain climatic conditions, and the scarcity of fertilizers, seeds, and pesticides that impact high production costs will encourage farmers to adopt smart fertigation technology immediately. For this reason, capital support, land management policies, farmer selling price policies, and production facility policies, especially fertilizers, are needed.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Smart fertigation technology has demonstrated significant advantages in chili farming. Farmers utilizing this technology, predominantly young individuals with relevant education and experience, exhibit heightened motivation and focus on their agricultural enterprises. Their adoption of smart fertigation correlates with increased production values and productivity while reducing inputs such as fertilizers, pesticides, and labor. Statistical analyses confirm the substantial impact of fertigation on production and productivity. Moreover, factors such as land area expansion, herbicide use, access to capital, and cooperative support further amplify these benefits. Smart fertigation enhances productivity and minimizes labor costs, particularly maintenance expenses related to fertilization, watering, and pest control. Furthermore, it reduces pesticide usage, leading to higher depreciation and total costs. Notably, the quality of chili is improved, resulting in higher selling prices and increased revenues compared to non-fertigation methods. Ultimately, the profitability of fertigation farming surpasses that of non-fertigation practices, affirming the efficiency and efficacy of smart fertigation in chili cultivation.

Recommendations

Despite positive study results on sales, profits, and savings in open-field chili production, extensive education through socialization and demonstration plots is needed. To promote the immediate adoption of smart fertigation, addressing challenges such as scarce farm labor, uncertain climatic conditions, and scarcity of key inputs is critical. Recommendations include targeted outreach and training for young farmers, especially millennials, in regions with high adoption potential, such as East Java. Access to credit, farmer collaboration, and government incentives for specific input conditions can facilitate adoption. Strengthening extension services and involving *Penyuluh Pertanian Lapangan* (PPL) in farmer support through regular visits, workshops, and training is essential to raise awareness. Encouraging collective action like cooperative support and collaboration can facilitate knowledge sharing. Advocacy for government incentives linked to input conditions that promote smart fertigation is critical. Emphasizing the resource management benefits, reducing input costs, and promoting the economic benefits of smart fertigation can further encourage adoption. Support for quality improvement through workshops on best practices and quality control measures is recommended to increase the impact of smart fertigation on chili production.

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