

## DOES THE ADOPTION OF GREENHOUSES REDUCE THE USE OF PESTICIDES AND CHEMICAL FERTILISERS? EVIDENCE FROM INDONESIAN MELON FARMERS

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**Abstract:** This study aims to evaluate the impact of the adoption of greenhouse technology on pesticide and chemical fertiliser use among melon farmers in Blitar Regency, East Java, Indonesia. Using a Propensity Score Matching (PSM) method, this research article compared farmers, who adopted greenhouse technology with a control group of non-adopters, considering various socio-demographic characteristics. Our analysis reveals that while greenhouse adoption tends to reduce the use of pesticides and chemical fertilisers, these differences are not statistically significant. The study highlights the fact that the adoption of greenhouse technology has the potential to decrease the farmer's reliance on chemical inputs and promote more sustainable and environmentally friendly agricultural practices. The findings underscore the importance of greenhouse technology in enhancing agricultural productivity while mitigating the negative impacts of conventional farming on the environment. This research article contributes to understanding how technological advancements can support sustainable farming practices in Indonesia.

Keywords: Greenhouse, melon farmers, Propensity Score Matching (PSM).

### Introduction

The increasing use of pesticides in agricultural intensification has become one of the most serious challenges in the agricultural sector. Although pesticides help control pests and plant diseases, the negative impacts well its use cannot be overlooked. Excessive pesticide use can lead to environmental degradation such as contamination of water, air, and agricultural land. Moreover, uncontrolled pesticide use can have an adverse effect on biodiversity by killing non-target organisms, including beneficial insects that play a crucial role in agricultural ecosystems (Andersson & Isgren, 2021; Li *et al.*, 2022; Meftaul *et al.*, 2023). Solutions are urgently needed to address the issues associated with pesticide and chemical fertiliser use. One potential solution that may resolve the issues involves the adoption of greenhouse farming.

Adopting greenhouses will impact pesticide use in the agricultural sector by reducing farmers' dependence on chemical pesticides. Greenhouse technology has become an effective alternative for addressing pest and plant disease issues, particularly in enhancing crop productivity and protecting plants from unfavourable environmental conditions such as temperature fluctuations, humidity, and extreme weather (Mulyani *et al.*, 2021). A greenhouse is a structure that allows sunlight to penetrate and support plant growth while minimising direct pest and disease attacks (Toiba *et al.*, 2023). Greenhouses are often used in the cultivation of horticultural crops such as fruits, vegetables, and ornamental plants, which have significant economic value. In a controlled environment within the greenhouse, plants are better protected from pests and diseases.

The adoption of greenhouses is regarded as a solution to reduce farmers' dependence on chemical pesticides and improve fertiliser use efficiency (Van Lenteren, 2000). This is largely due to the use of biological control methods, which can lower the reliance on chemical pesticides. Greenhouses create a cleaner environment and meet consumer demands for pesticide-free agricultural products. This presents an opportunity for farmers to avoid excessive pesticide use, as commonly seen in open-field agriculture. Additionally, with a more controlled environment, farmers can adopt more targeted and sustainable pest control approaches such as the use of natural predators or organic methods, which help reduce the dependency on chemical pesticides.

Previous research has examined various factors that contribute to reduced pesticide use, including the adoption of Green Prevention technology as an environmentally friendly farming technique. Moreover, biological and physical control technologies, as well as Integrated Pest Management (IPM), have been shown to reduce the use of chemical pesticides without compromising crop yields (Shuqin & Fang, 2018). The adoption of these environmentally friendly agricultural technologies can enhance farmer profitability while also reducing the risks to human health and the environment (Eyhorn *et al.*, 2015). However, these technologies are still rarely found in Indonesia. Conversely, greenhouse technology has been widely adopted in Indonesia, although research focusing on greenhouse adoption remains scarce.

Another alternative that may be able to reduce pesticide use is through farmer outsourcing. According to Li *et al.* (2023), in a study conducted in Jiangsu Province, China, farmer outsourcing reduced pesticide use and was more environmentally friendly compared to mechanical spraying. Outsourcing or hiring skilled experts allows for a tailor-made pesticide application designed according to the specific needs of the crops. This contrasts with automated mechanical spraying, which is often

more focused on regular pesticide application but is less efficient due to the amount of pesticide waste. Nevertheless, outsourcing associated with higher operational costs, has generally explored the impact of greenhouse adoption in developed countries. For instance, Evangelista *et al.* (2020) investigated the influence of greenhouse adoption in developed countries such as Australia while Kurihara *et al.* (2014) analysed the risks associated with greenhouse adoption among farmers in Japan. However, these studies have not thoroughly examined the impact of greenhouse adoption on pesticide and chemical fertiliser use in different agricultural environments, particularly in developing countries like Indonesia. Thus, this study aims to analyse the effect of greenhouse adoption on pesticide and chemical fertiliser use among farmers in Indonesia.

Research on the impact of greenhouse adoption on pesticide and fertiliser use among melon farmers in Indonesia will provide more insight into the potential of this technology to address environmental issues, especially the reduction of pesticide and chemical fertiliser use. This study is expected to guide efforts to promote sustainable melon farming by minimising the negative effects of pesticide and fertiliser use on farm and field ecosystems while driving economic growth.

Finally, this study contributes to the literature by examining greenhouse adoption's impact on pesticide and chemical fertiliser use in developing countries, focusing on melon farmers in Indonesia. While prior research was largely centred on developed nations, this study addresses a critical gap by providing localised insights into sustainable agricultural practices in resource-constrained environments. It demonstrates how greenhouse technology reduces reliance on harmful chemical inputs, promoting environmentally friendly farming. The findings highlight the potential of greenhouses to mitigate environmental degradation, enhance farmer profitability, and guide policy development for sustainable agriculture.

## Materials and Methods

### Research Data

This study was conducted in the district of Blitar, East Java Province, Indonesia. The research location was deliberately selected using purposive sampling. Blitar was chosen as the study site because it is a major producer of melons and has adopted and made use of greenhouse technology, which is in line with the objectives of the research.

Additionally, Blitar is one of the regions where agriculture is a top priority and a crucial component of its development plans. The agricultural sector encompasses various areas, including food crops, horticulture, livestock, forestry, plantations, and fisheries, spread across an area that spans approximately 31,725 hectares. The agricultural sector is a significant contributor to Blitar's Gross Regional Domestic Product (GRDP), accounting for 47% of the total earnings (Shohibuddin *et al.*, 2021).

Additionally, the agricultural potential of this region is supported by melon cultivation, which is the highest-producing fruit commodity in Blitar, with a production yield of 11,207 quintals (BPS Blitar Regency, 2023). Furthermore, the favourable climatic conditions, characterised by warm temperatures, play a vital role in the success of melon farming in the area.

Blitar is located in the lowlands of East Java which experiences a tropical climate with two seasons, dry and rainy. The relatively high year-round temperatures, averaging between 24°C and 32°C, provide optimal conditions for melon growth. The ideal temperature range for melon cultivation typically falls between 25°C and 30°C (Kyriacou *et al.*, 2018). The extended warm and bright growing periods in Blitar offer ideal conditions for melon growth, facilitating photosynthesis and fruit development. With a combination of favourable climatic conditions and attentive farming practices, melons have become one of Blitar's leading commodities, contributing significantly to the local economy while supplying ample fruit to both local and national markets.

The sampling of non-greenhouse melon farming households was conducted using a census method. Meanwhile, the sampling of greenhouse melon farming households employed the simple random sampling method. Simple random sampling is a type of probability sampling aimed at reducing data bias by randomly selecting samples so that each member of the target population has an equal chance of being chosen (Emerson, 2015). Sampling from the same geographical area ensures that the sample has similar socio-demographic characteristics, which can influence research outcomes.

Therefore, to minimise bias, simple random sampling was used from the population of individuals meeting the criteria for inclusion in the study. The number of greenhouse melon farmers in this study was determined using the Slovin formula, with a population of 127 greenhouse melon farmers while the number of non-greenhouse farmers totalled 83.

Primary data was obtained directly through interviews using an interview guide aimed at gathering information on people, activities, perceptions, organisations, acknowledgements, and other factors (Suwendra, 2018). Data collection was conducted through structured interviews using a questionnaire administered to melon farmers in Blitar. The questionnaire was divided into three sections.

The first section addressed farmer characteristics, including age, family size, education level, land area, membership in farmer groups, land ownership status, extension service intensity, Internet access, participation in shared processing groups, and partnerships. The second section focused on greenhouse adoption, specifically whether the farmers had adopted greenhouse technology or not. The third section dealt with the level of pesticide and chemical fertiliser use.

**Data Analyst**

In this study, the analytical method used to assess the impact of pesticide use on greenhouse adoption is Propensity Score Matching (PSM). Propensity Score Matching (PSM) was introduced by Rosenbaum and Rubin (1983) as a method aimed at creating a comparison group with similar characteristics to the participants' group to reduce the bias in estimating the impact of an intervention using observational data. Bias can be reduced when the comparison group closely approximates the characteristics of the treatment group. Therefore, the comparison in this study is between farmers who have adopted greenhouse technology and those who have not. This is supported by a statement put forth by Wijayanto *et al.* (2022), which explains that the objective of the PSM method is to find the nearest comparison group to the non-participant respondents, matching them with participants in a particular intervention based on observable characteristics.

According to Rahman *et al.* (2022), data analysis using the Propensity Score Matching (PSM) method can be carried out through the following steps:

- (1) Calculating the Propensity Score by selecting a model and variables to be used. In this study, the model used is the logit regression, with the treatment variable being greenhouse adoption and the independent variables being the farmer characteristics. The farmer characteristics used in this study are socio-demographic variables, including age (X1), family size (X2), education level (X3), land area (X4), membership in farmer groups (X5), land ownership status (X6), extension service intensity (X7), Internet access (X8), participation in joint processing groups (X9), and partnerships (X10).
- (2) Determining the Matching Algorithm to pair covariates which are independent variables that influence the dependent variable and as such need to be controlled. There are four matching methods: Nearest Neighbour Matching, Radius Matching, Kernel

Matching, and Stratification Matching. In this study, the Nearest Neighbour Matching (NNM) method was used, where the closest propensity score in the control group is matched with the covariates of the treatment group.

- (3) Identifying Overlap and Common Support between the two groups and analysing their distribution. If significant differences such as extremely low or high comparison scores are found, some observations must be excluded. Afterwards, a balance test is conducted to determine the average PSM for the control group. This allows for the calculation of the Average Effect of Treatment for Treated (ATT), which is used to identify the outcome variable differences. The ATT can be calculated using the following equations (Rahman *et al.*, 2021):

$$ATT = E \{Y_{1i} - Y_{0i} | P_i = 1\} \tag{1}$$

$$ATT = E [E \{Y_{1i} - Y_{0i} | P_i = 1, p(X_i)\}] \tag{2}$$

$$ATT = E [E \{Y_{1i} | P_i = 1, p(X_i)\} - E \{Y_{0i} | P_i = 0, p(X_i)\} | P_i = 1] \tag{3}$$

where:

ATT = Average Effect of Treatment for Treated (ATT)

$Y_{1i}$  = Pesticide use by farmers who adopted greenhouse technology

$Y_{0i}$  = Pesticide use by farmers who did not adopt greenhouse technology

$p(X_i)$  = Propensity score of participation influenced by farmer characteristics

$P_i$  = Dummy variable (P = 1 if the farmer adopted greenhouse technology and P = 0 if they did not)

**Measurement of Key Variables**

This study employs two key variables: Greenhouse adoption and the use of pesticides and chemical fertilisers. Greenhouse adoption is the first key variable, measured by farmers'

statements regarding whether or not they have adopted greenhouse technology. The decision to adopt greenhouse technology is assumed to be influenced by farmer characteristics such as age, family size, education level, land area, membership in farmer groups, land ownership status, intensity of extension services, Internet access, participation in joint processing groups, and partnerships.

The use of pesticides and chemical fertilisers is the second outcome variable in this study. This variable serves as a benchmark for evaluating the effectiveness of greenhouse adoption in reducing dependence on chemical pesticides and fertilisers. Pesticide and chemical fertiliser use by melon farmers is measured through data on the quantities used throughout one planting season.

In analysing the relationship between greenhouse adoption and the use of pesticides and chemical fertilisers, Propensity Score Matching (PSM) was used to examine the influence of farmer characteristics on the

decision to adopt greenhouse technology and its impact on pesticide and chemical fertiliser use. The PSM technique was used to match farmers who had adopted greenhouse technology with those who had not, based on the aforementioned characteristics, allowing for more accurate comparisons to be made.

## Results and Discussion

### *Statistic Descriptive*

After collecting data related to the treatment, outcome, and independent variables, descriptive statistical analysis was conducted, as presented in Table 1.

The descriptive statistics in Table 1 provide an overview of the respondents in this study. First, the farmers' decision to adopt greenhouse technologies was presented as a dummy variable, where 127 melon farmers had adopted greenhouse technology while 83 farmers had not. Next, the outcome variables include the use of pesticides and chemical fertilisers.

Table 1: Statistic descriptive

Variables	Measurement	Mean	Std. Dev.	Min	Max
<b>Variable Treatment</b>					
Greenhouse adoption	Dummy	0.74	0.43	0	1
<b>Variable Outcomes</b>					
Pesticide used	Litre/ha (one crop session)	2.35	3.72	0	30
Chemical fertiliser used	Kg/ha (one crop session)	77.73	119.56	0	150
<b>Independent Variables</b>					
Age	Year	46.28	11.54	20	75
Family size	Person	3.40	0.96	1	6
Education	Year	10.61	4.87	0	54
Farm size	m <sup>2</sup>	1449.96	2179.47	52	13000
Group farmer	Dummy	0.81	0.39	0	1
Land ownership	Dummy	0.82	0.37	0	1
Intensity of counselling	Frequency	1.07	1.46	0	12
Internet access	Dummy	0.96	0.19	0	1
Joint processing	Dummy	0.16	0.37	0	1
Partnership	Dummy	0.23	0.42	0	1

Pesticide use in melon farming is measured in litres per hectare during one planting season, while chemical fertiliser use is measured in kilogramme per hectare per season. The results show that, on average, farmers use 2.35 Ls of pesticides per hectare per season while chemical fertiliser usage is 77.73 kg/ha.

The average age of the melon farmers in this study was between 46 and 28 years, with the youngest farmer being 20 years old and the oldest being 75 years. The average farmers' household size consisted of three members. On average, the melon farmers owned 1,449.96 m<sup>2</sup> of farmland, with the smallest farm measuring 52 m<sup>2</sup> and the largest measuring 13,000 m<sup>2</sup>. Additionally, 81% of the farmers are members of farmer groups and 82% are involved in social groups. The study also found that farmers received at least one agricultural extension service. In terms of Internet access, 96% of the farmers reported having access to the Internet for various purposes. However, only 16% of the farmers participate in joint processing groups and only 28% are involved in partnership agreements.

**Factors Affecting Greenhouse Adoption**

Table 2 illustrates the various factors that influence farmers' decisions to adopt greenhouse technology. The results show that age, education level, participation in farmer groups, and Internet access have a significant positive impact on the adoption of greenhouse technology. Conversely, land size and land ownership status had a demonstrably negative influence on the decision to use greenhouse technology.

The analysis revealed that the age variable has a positive coefficient of 0.033, indicating that older farmers are more likely to adopt greenhouses. A significant *p*-value of 0.019 at the 0.05 level reinforces the finding that age significantly influences the decision to adopt greenhouses. This can be interpreted as an indication that the broader experience and knowledge of older farmers make them more prepared to embrace technological changes. This finding is consistent with Sennuga *et al.* (2020), who also found a positive and significant relationship between farmers' age and the adoption of modern agricultural technology, highlighting the importance of age in the

Table 2: Factor affecting greenhouse adoption; Probit regression

Greenhouse Adoption	Coefficient	Std. Error	P >  z
Age	0.033	0.014	0.019**
Family size	0.119	0.151	0.43
Education	0.125	0.057	0.029**
Farm size	-0.001	0.001	0.021**
Group farmer	0.796	0.345	0.021**
Land ownership	-1.516	0.576	0.009***
Intensity of counselling	-0.049	0.124	0.691
Internet access	1.573	0.796	0.048**
Joint processing	0.454	0.418	0.277
Partnership	0.29	0.372	0.436
Log-likelihood	-54.648976		
LR chi2(10)	34.08		
Prob > chi2	0.0002		
Pseudo R2	0.2377		

Note: \*, \*\*, \*\*\* indicates significance levels at 10%, 5%, and 1%, respectively.

decision-making process regarding greenhouse adoption.

Education showed a positive coefficient of 0.125, meaning that farmers with higher levels of education are more likely to adopt greenhouses. The  $p = 0.021$ , which is lower than the 0.05 significance level, confirms that education has a significant impact on greenhouse adoption. Higher education levels increase farmers' understanding and acceptance of modern agricultural innovations. This finding is in line with existing literature, including Sennuga *et al.* (2020), which emphasises the critical role of education in promoting the adoption of modern agricultural technologies.

Land size had a negative coefficient of -0.009, indicating that farmers with larger land holdings are less likely to adopt greenhouses. This may be due to the tendency of large-scale farmers to reduce their dependence on greenhouse technology. A significant  $p = 0.021$  confirms that land size significantly influences the decision to build and use greenhouses. Farmers with larger land areas may already have established production systems or rely on effective traditional practices, making them less inclined to adopt new technologies. This is consistent with Mao *et al.* (2021), who found that in large-scale production, time preference plays a lesser role in technology adoption, suggesting that larger-scale production can be a barrier to greenhouse adoption.

Membership in farmer groups had a positive coefficient of 0.796, indicating that farmers who are part of farmer groups are more likely to adopt and use greenhouse technology. A  $p = 0.021$ , which is below the 0.05 significance level, suggests that farmer group membership significantly influences greenhouse adoption. This finding is consistent with the literature showing that participation in farmer groups enhances farmers' access to information, resources, and technical support, thereby facilitating the adoption of agricultural innovations (Awotide *et al.*, 2016).

Farmers, land ownership status had a negative coefficient of -1.516, suggesting that farmers who own their land are less likely to adopt greenhouses. A  $p = 0.009$ , below the 0.05 significance level, confirms that land ownership status significantly influences greenhouse technology adoption decisions. Farmers without private land ownership such as those managing rented land, are more likely to adopt greenhouse technology, perhaps because adopting new technology on privately owned land is perceived as riskier. This finding aligns with Chavas and Nauges (2020), who found that risk-averse farmers are more likely to adopt new technologies, indicating that land ownership status can affect farmers' preferences and decisions regarding the adoption of greenhouse technology.

Lastly, the Internet access variable had a positive coefficient of 1.573, indicating that farmers with Internet access are more likely to adopt greenhouse technology. Statistical significance with a  $p = 0.048$ , below the 0.05 level, indicates that Internet access significantly influences the decision to adopt greenhouse technology. Internet access provides farmers with information and online resources about modern agricultural technology, increasing their awareness and interest in adopting these technologies. This finding is consistent with Drewry *et al.* (2019), who found that Internet access plays a crucial role in facilitating agricultural technology adoption.

### ***The Impact of Greenhouse Adoption on Pesticide and Chemical Fertiliser Use***

A Propensity Score Matching (PSM) analysis was carried out in order to evaluate the impact of greenhouse adoption on the utilisation of pesticides and chemical fertilisers among farmers. This method involves pairing farmers who have implemented greenhouse technology (treated group) with those who have not (control group) based on comparable sociodemographic characteristics. The detailed outcomes of this analysis, particularly with regard to pesticide use are presented in Table 3.

The results of this study directly address the research question by providing empirical evidence on the impact of greenhouse usage on the utilisation of pesticides and chemical fertilisers among farmers. Using Propensity Score Matching (PSM), this study demonstrated that the adoption of greenhouse technology leads to a significant reduction in the use of pesticides and chemical fertilisers.

Specifically, the Average Treatment Effect on the Treated (ATT) values revealed a reduction of approximately 1.16 L/ha in pesticide use and a reduction of 44.68 kg/ha in the use of chemical fertilisers by greenhouse adopters compared with non-adopters. These findings confirm the potential of greenhouse technology to promote more sustainable farming practices by minimising reliance on chemical inputs.

The negative ATT values observed in Table 3 imply that the adoption of greenhouse technology may contribute to a reduction in both pesticide and chemical fertiliser use. Several factors could account for this observed decrease. Firstly, the controlled environment provided by greenhouses allows for more effective management of plant growth conditions, thereby reducing the prevalence and impact of pests and diseases. This controlled setting diminishes the reliance on chemical interventions by facilitating the implementation of integrated pest management strategies and the use of biological control agents.

Secondly, greenhouse systems often incorporate advanced agricultural technologies and practices that enhance resource efficiency (Ahmed *et al.*, 2024). For instance, precision agriculture techniques can optimise the application of inputs, ensuring that plants receive

the necessary nutrients in appropriate quantities, thus minimising excess use and environmental runoff. Additionally, the adoption of sustainable farming practices within greenhouse settings contributes to an improvement in soil health and fertility as well as a reduction in the dependence on synthetic fertilisers over time.

These findings are consistent with those of earlier research papers such as the study conducted by Tando (2019), which demonstrated the greenhouse cultivation can effectively lower farmers' dependence on chemical pesticides and fertilisers. Such reductions not only contributed environmental sustainability by mitigating the negative impacts of agrochemicals on ecosystems but were also T viable and profitable greenhouse technology was able to achieve this by lowering input costs and potentially enhancing crop quality and yield (Gao *et al.*, 2024).

Furthermore, the decreased use of chemical inputs was in line with global agricultural sustainability goals and addressed concerns relating to food safety, environmental conservation, and public health. The transition towards more sustainable agricultural systems via the adoption of greenhouse technologies exemplifies how technological advancements can support ecological balance while maintaining agricultural productivity.

While the statistical insignificance of the results warrants cautious interpretation, the observed trends underscore the potential of greenhouse technology to advance sustainable agriculture by reducing reliance on chemical inputs. Future research with larger sample sizes and longitudinal designs could provide more definitive evidence of these effects and

Table 3: The impact of greenhouse adoption on pesticide and chemical fertiliser use

Variable	Sample	Treated	Controls	Difference	T-stat.
Pesticide used	Treated	2.16	2.92	-1.76	-1,001
	ATT	2.16	3.13	-1.97	-2.57
Chemical fertiliser used	Treated	44.68	175.84	-131.16	-6.09
	ATT	44.68	102.98	-58.29	-2.15

further elucidate the mechanisms through which greenhouse adoption influences input usage and overall farm sustainability.

### Conclusions

The conclusion connects the findings to a larger context, such as the wider conversation about an issue and the journal's theme. It suggests the implications of your findings or the importance of the topic. Asking questions or suggesting ideas for further research and revisiting your main idea or research question with new insight. This study aims to evaluate the impact of greenhouse technology adoption on the use of pesticides and chemical fertilisers among melon farmers in Blitar Regency. The Propensity Score Matching (PSM) method was employed to compare farmers who have adopted greenhouse technology with a control group that has not, considering their sociodemographic characteristics.

The results indicate that the adoption of greenhouse technology is influenced by various sociodemographic factors, including age, education level, participation in farmer groups, and access to the Internet. PSM analysis reveals that while greenhouse adoption tends to reduce the use of pesticides and chemical fertilisers among adopting farmers, the differences were not statistically significant. These findings suggest that the adoption of greenhouse technology has the potential to reduce dependence on chemical inputs and support more environmentally friendly and sustainable farming practices.

This research confirms that greenhouse technology adoption plays an important role in reducing pesticide and chemical fertiliser use in melon cultivation in Indonesia. The reduction in chemical usage not only contributes to environmental protection and public health but can also enhance the quality of agricultural products and support farm sustainability. Therefore, greenhouse technology adoption is expected to become a key strategy in improving agricultural productivity sustainably while minimising negative environmental impacts.

The primary limitation of this study is its reliance on cross-sectional data which restricts the ability to draw causal inferences or observe the dynamic effects of greenhouse adoption over time. It does not capture temporal changes or the long-term impacts of greenhouse adoption on pesticide and fertiliser use. Future research employing longitudinal data would provide a more comprehensive understanding of these dynamics and allow for the analysis of trends, sustainability outcomes, and potential feedback mechanisms.

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### Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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