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Technical efficiency of paddy farming in West Java: a combination of synthetic and organic fertilisers versus conventional farming

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Abstract

In developing countries, agriculture's burden is not just ensuring enough food for the people but also securing net income for the farmers to alleviate poverty and to conserve the environment at the same time. Consumption shift towards staples, particularly during economic crisis or pandemic, requires a policy that could make food growers respond to the demand appropriately. Initially, from soil science, an argument asserts that mixing organic and synthetic fertilisers can increase yield/productivity and be safe for the environment. Previous studies showed that, on average organic farming produced lower yield compared to conventional farming using synthetic fertilisers. The objective of this study was to investigate if the farming method using mixed fertilisers could outperform the conventional method. This study used the 2014 household survey data of paddy farmers in West Java, part of a more extensive survey on main agricultural sub-sectors conducted by Statistics Indonesia every ten years. Applying the Stochastic Frontier Analysis and the Generalised Linear Model, this study found that the combination of organic and synthetic fertilisers could yield an efficiency level as high as 9 % over the conventional method. The Logit model results also showed that improving efficiency reduced the likelihood of farmer households being in a state of poverty. Therefore, the government should encourage farmers to apply the mixed fertiliser method rather than using only synthetic fertilisers.

Keywords: mixed fertiliser, smallholder farmers, stochastic frontier analysis, poverty, Indonesia

1 Introduction

The green revolution has effectively enhanced global food production and greatly helped countries that experienced famine or were on the brink of famine in the late 1960s and early 1970s (Frankema, 2014; Hazell, 2020). Some estimates say that crop yields increased by three to four-fold (Borlaug, 2000; Shiferaw *et al.*, 2013). In Indonesia, late President Suharto declared that the country had experienced food self-sufficiency for the first time in 1984 (Supriyanto, 2019). The so-called conventional farming system started during the green revolution. Basically, this system relies heavily on the use of chemical fertilisers, pesticides, new seed varieties, and crop specialisation (Trewavas, 2002; Andres & Bhullar, 2016). Most governments subsidise synthetic fertilisers, making them more affordable and readily available for farmers. Past success in improving the yield of crops around the globe, coupled with the availability of cheap fertilisers, induced farmers to use more and more synthetic fertilisers on their land. There are two main environmental concerns regarding the usage of synthetic fertilisers. Firstly, synthetic fertilisers destroy soil microorganisms causing poor soil structure, being easily washed out by rain, polluting rivers, lakes, and other water sources used by humans. Secondly, the prolonged use of artificial fertilisers reduces soil biodiversity, causing soil food webs less diverse (Tsiafouli *et al.*, 2015).

Organic farming has been advocated as a solution to the above problems. In its ideal form, organic farming involves techniques that yield good crops without harming nature. These techniques include composting crop waste and manures, crop rotation and use of resistant crops, natural pesticides, predators that eat pests, good cultivation practice, and good animal husbandry. In most countries, the consumers (mostly the upper-middle class) reward this supposedly healthier product and the laborious effort put into it with a relatively high price premium. From the information we got from a rice off-taker in West Java and our observa-

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tion on supermarket prices for rice and vegetables, the price premium ranges from 25 to 30 %[1].

Various studies compare the yields or efficiency of organic farming to conventional farming in different food commodities. If we take just a few of them, it will be hard to conclude which method is better. For example: studies by Madau (2005), Wheeler & Crisp (2009), and Charyulu & Biwas (2010), find that conventional farming is better (in terms of yield or efficiency). However, studies by Tzouvelekas *et al.* (2002), Demiryurek & Ceyhan (2008), Beranova (2017), and Kumar *et al.* (2018) find the opposite results, whereas Argiles & Brown (2010) and Riar *et al.* (2020) conclude that there is no significant difference. Seufert *et al.* (2012) took a more balanced view by conducting a meta-analysis to compare organic farming's relative performance to conventional farming globally. They conclude that organic farming yields are generally lower than conventional ones. The differentials depend on the system and site conditions, and these could range from 5 % to 34 %. When the soils are favourable, the difference amounts to only 5 %. When organic farming practices are best applied, the difference is 13 %, but the difference can be as high as 34 % when organic and conventional systems are most comparable.

From a rough calculation, if a favourable land area could organically produce only 5 % less, but the price is 25 %-30 % higher, there would be enough profit margin to motivate farmers to go organic. However, in Indonesia, for example, the Indonesian Organic Certification office reports that there were only 0.14 % of farms and plantations organically certified in 2017. This figure is very low, considering that around 46 % of farming land in West Java still have high soil nutrients (Ministry of Agriculture, 2007)[2].

Amid the conventional versus organic controversy, there is an assertion about the benefits of mixing organic and synthetic fertilisers in farming. Briefly, the arguments say that organic fertilisers release nitrogen slowly that cannot keep up with the crops' demand as they grow, which further causes reduced grain production and lower protein content. The addition of synthetic fertilisers during plants' peak demand will optimize crop yield without worries that the chemical will leach due to high rainfall and cause environmental problems (Roy *et al.*, 2006; Chen *et al.*, 2007; Sullivan, 2014; McGuire, 2016).

Most studies on farming efficiency contrast the conventional versus the organic farming methods, but studies that measure farming efficiency using both organic and synthetic fertilisers are hardly found. This might be because of the unavailability of data or because the method is considered to provide insufficient environmental protection.

West Java is one of the largest paddy-producer provinces in Indonesia; it ranks first, sometimes second. Most farms are tiny compared to those of developed nations, with more than 50 % sizing less than 0.25 ha, and only 0.9 % having more than 2 ha. Though small farm size does not always relate to poverty, the incidence of poverty is higher in rural areas than in urban areas both in Indonesia and West Java. Statistics Indonesia conducted a national paddy-farming household survey in 2014. The survey covered 8203 households for West Java alone, but only 8142 households cultivated their lands in that year. Among these households, 485 of them used organic fertilisers. However, very few of them met the main organic farming criteria in that no synthetic fertilisers and chemical pesticides were used. Most of these 485 farming households used organic fertiliser with various amounts of inorganic (synthetic) fertilisers. The scarcity of studies regarding the efficiency of farming using mixed fertilisers attracted this team of researchers to fill this gap. This research used this large data set to test whether the paddy farming method using mixed organic and synthetic fertilisers could be more efficient than conventional farming and whether efficiency affected the probability of the farmers finding themselves in a state of poverty. Such a study is also crucial for policymakers aiming to boost paddy production and alleviate poverty. If the mixed fertilisers method is more efficient than the conventional one, it can be the second-best choice of farming method in that it enhances the farmers' income and incentivize them to improve the land structure at the same time.

2 Materials and Methods

2.1 Data

Statistics Indonesia conducts the national farming household survey every ten years. The 2014 paddy farming household survey is the most current survey available. The survey covered various household expenses, including expenses for seeds, fertilisers, pesticides, labour, and the yield's market value for a one-year cultivation period. Besides that, the survey also included household demographics and food security conditions.

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[1] USDA Economic Research Service reports that the price premium for organic fresh produced such as Apples, carrots and potatoes is between 27 % to 29 % whereas for organic processed food like baby food, bread and soup, it is slightly higher (https://www.usda.gov/media/blog/2016/06/14/investigating-retail-price-premiums-organic-foods)

[2] Unfortunately, the figure for 2014 is not available. Another survey was conducted in 2020 to evaluate the 2007 locational-based soil nutrients research results. The survey found that in West Java the soils high in P nutrients increased to 67.3 % while those high in K reduced to 43.3 % (Ministry of Agriculture, 2020)

Among the 8142 households in the sample, 485 households used organic fertiliser; either making it themselves or purchasing from others. Since there is no standard price for organic fertiliser, the quantity could not be measured precisely based on their spending. In 2007, the Ministry of Agriculture issued a decree containing recommendations on N, P, and K fertilisers usage based on farm location. The recommendations specified each fertiliser's amount per hectare if used alone and if combined with 2 tons of organic fertilisers. However, there was no strong pressure in the decree to use organic fertiliser.

Among the 485 households that used organic fertiliser[3] only three households did not use synthetic fertilisers or chemical pesticides. The rest used a various amount of synthetic fertilisers that can be classified in Rupiah (IDR) per hectare as mentioned in table 1.

Table 1: *Spending on synthetic fertilisers per ha by farmers who used organic fertiliser in 2014*

	Number of farms	
Spending on synthetic fertilisers	*frequency*	*%*
Less than IDR 400,000 (0–100 kg ha^{-1})	18	3.7
IDR 400,000 – 1000,000 (100–250 kg ha^{-1})	157	32.4
IDR 1000,000 – 1,800,000 (250–450,kg ha^{-1})	266	54.8
More than IDR 1,800,000 (> 450,kg ha^{-1})	44	9.1
Total	485	100

2014 Paddy farming household survey

The subsidized fertiliser price was IDR 3000 kg^{-1}; the unsubsidized was between IDR 5000 to IDR 6000 in 2014. Since farmers cannot always obtain subsidized fertilisers, the quantity of fertilisers in brackets in Table 1 is an approximation based on IDR 4000 kg^{-1} price (around USD 0.30). The highest spending was IDR 2800,000, or approximately 700 kg ha^{-1} for one-year production or 350 kg per planting season. This amount was the closest to the recommended quantity in the 2007 Ministry of Agriculture decree of 400–450 kg ha^{-1}.

2.2 Methodology

There are three kinds of efficiency usually discussed in economic theory: allocative efficiency, productive efficiency and technical efficiency. Allocative efficiency is achieved when the market price reflects the marginal cost of production. Productive efficiency is obtained when a given quantity of output is produced with the lowest average cost; whereas technical efficiency occurs when from a given input (costs) a maximum output is achieved. Though all the three forms of efficiency imply the same meaning i.e., getting the most out of a certain sacrifice, technical efficiency is used more in econometric modelling.

This study also focused on technical efficiency which was measured using the stochastic frontier analysis (SFA). The major contributors for the development of the stochastic frontier model are Aigner *et al.* (1977), Schmidt & Lovell (1979) and Kumbakar & Lovell (2000). This parametric technique is derived from the production function which represents the maximum feasible production/output for a given level of input (costs). The simplest (but easier to interpret) production function is the Cobb-Douglas production function which is written as follows:

$$Lnq_i = X_i'\beta + v_i \tag{1}$$

Where: q = output, X = vector of input variables in natural logarithm including a constant,β = vector of coefficients, v = error term and $i = 1, 2, 3, \ldots..$ N

Since the actual output usually less than the optimal output as assumed by the production function, the model becomes:

$$Lnq_i = X_i'\beta + v_i - \mu_i \tag{2}$$

Where μ is a positive random variable that represent the existence of inefficiency. Technical Efficiency is defined as the ratio of the realized output to the stochastic frontier (optimum) output, which is written as follows:

$$TE_i = \frac{q_i}{exp\,(X_i\beta + v_i)} = \frac{exp\,(X_i\beta + v_i - \mu_i)}{exp\,(X_i\beta + v_i)} = exp\,(-\mu_i) \tag{3}$$

Assumptions about v_i and μ_i:

$v_i \sim \text{Niid}\left(0, \sigma_v^2\right)$

$\mu_i \sim \text{N}^+\text{iid}\left(0, \sigma_\mu^2\right)$, μ_i is distributed half-normal

The parameters of the model are estimated using the maximum likelihood function as follows:

$$LnL\left(q_i \mid \beta, \lambda, \sigma^2\right) = N.Ln\frac{\sqrt{2}}{\sqrt{\pi}} + N.Ln\sigma^{-1} + \sum_{i=1}^{N} Ln\left(1 - F\left(\varepsilon_i\lambda\sigma^{-1}\right)\right) - \frac{1}{2\sigma^2}\sum_{i=1}^{N}\varepsilon_i^2 \tag{4}$$

Where $\sigma^2 = \sigma_v^2 + \sigma_\mu^2, \lambda^2 = \sigma_\mu^2/\sigma_v^2$ and $\varepsilon = v + \mu$.

The Stochastic Frontier model above provided the predicted efficiency level of each paddy farming household in the sample. To investigate what factors determine the technical efficiency, we used a generalised linear model (GLM).

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[3] In practice, farmers do not usually weigh the amount of organic fertiliser used. A heap of organic stuff of the size 2.5 m x 1 m x 0.75 m for 0.1 ha land area is generally considered sufficient.

Proposed by McCullagh & Nelder (1989), the GLM takes the following form:

$Y_1 = \mu_i + \varepsilon_i \quad \text{where } \mu_i = X_i'\beta$

Here the mean component μ_i is allowed to depend on a linear predictor through a non-linear function and the distribution of the stochastic component ε_i may be any member of the linear exponential family.

A Generalized Linear Model consists of:

- A linear predictor or index $\eta_i = X_i\beta + O_i$ where O_i is an optional offset term.
- A distribution for Y_i belonging to the linear exponential family.
- An invertible link function $g(\mu_i) = \eta_i$ relating the mean μ_i and the linear predictor η_i.

The parameters of the model were estimated using the maximum likelihood method. The Ordinary Least Squares is actually part of Generalized Linear Model where Y is continuous, and normally distributed and the link function is identity. However, since the dependent variable (efficiency score) is nonnegative, it can also take a gamma or exponential distribution. The maximum Likelihood method used in GLM also has a desirable mathematical and optimality property; namely it is unbiased estimator and has a minimum variance as the sample size increases.

Table 2: *Definition of variables used in Stochastic Frontier Model, GLM and Logit Model*

Variable	*Definition*
Farmers group	= 1 if household head belongs to a farmer group: 0 otherwise
Age	Age of household head (years)
Tractor	= 1 if household head uses a tractor; 0 otherwise
LnLand size	Cultivated land size (in hectare)
LnSeed Costs	Spending on seeds (IDR)
LnFertilisers costs	Spending on fertilisers (IDR)
LnPesticide cost	s Spending on pesticide (IDR)
LnWage costs	Spending on labour costs (IDR)
LnEquipment rent	Spending on agricultural equipment rental (IDR)
LnTax and retribution	Spending on property tax and retribution (IDR)
LnDepreciation	Estimate of capital depreciation (IDR)
Gender	= 1 if male; 0 otherwise
Seed variety	
Hibrida	= 1 if Hibrida varieties are used; 0 otherwise
Inbrida	= 1 if Inbrida varieties are used = 1; 0 otherwise
Education	
Junior High School	= 1 if education of household head is Junior High School or less; 0 otherwise
High school	= 1 if education of household head is high school; 0 otherwise
Diploma	= 1 if education of household head is diploma; 0 otherwise
University	= 1 If education of household head is university; 0 otherwise
Level of synthetic fertilisers used	
0–100 kg no pesticides	=1 if farmer uses a combination of organic fertiliser with less than 100 kg synthetic fertilisers/ha/year and no pesticides; 0 otherwise
100–250 kg no pesticides	= 1 if farmer uses a combination of organic fertiliser with 100–250 kg synthetic fertilisers/ha/year and no pesticides; 0 otherwise
250–450 kg no pesticides	= 1 if farmer uses a combination of organic fertiliser with 250–450 kg synthetic fertilisers/ha/year and no pesticides; 0 otherwise
>450 kg no pesticides	= 1 if farmer uses a combination of organic fertiliser with more than 450 kg synthetic fertilisers/ha/year and no pesticides; 0 otherwise
0–100 kg with pesticides	=1 if farmer uses a combination of organic fertiliser with less than 100 kg synthetic fertilisers/ha/year and use pesticides; 0 otherwise
100–250 kg with pesticides	=1 if farmer uses a combination of organic fertiliser with 100–250 kg synthetic fertilisers/ha/year and use pesticides; 0 otherwise
250–450 kg no pesticides	=1 if farmer uses a combination of organic fertiliser with 250–450 kg synthetic fertilisers/ha/year and use pesticides; 0 otherwise
>450 kg no pesticides	= 1 if farmer uses a combination of organic fertiliser with more than 450 kg synthetic fertilisers/ha/year and use pesticides; 0 otherwise
Poverty status Poverty status	= 1 if farmer's household is in poverty state; 0 otherwise

The GLM model for the technical efficiency of the paddy farming in this research used the predicted technical efficiency level from the Stochastic Frontier model as the dependent variable and the following covariates: Age, membership of farmers group, usage of a tractor, cultivated land size, gender, seed varieties, education, and level of mixed fertilisers. The last mentioned variable (level of mixed fertilisers) was composed of dummy variables representing the quantity of synthetic fertilisers used: 0–100 kg; 100–250 kg, 250–450 kg and more than 450 kg with and without chemical pesticides. The definitions are given in Table 2. The benchmark variable was the dummy variable for non-organic fertiliser users (conventional farming).

To examine the effect of technical efficiency on the probability of a farming household falling into a state of poverty, we used the Logit model, which was specified as follows: Prob(poverty status) = f(technical efficiency, age, gender, education, and land area). In this model, a household was said to be in a poverty state if it did not have daily enough food to feed the family.

3 Results

Among the 8142 households in the sample, 485 used organic fertiliser with various amount of synthetic fertilisers and 7657 households used synthetic fertilisers only. Comparison between the mean value of some characteristics of the two groups are given in Appendix 1.

Briefly, the average age of the farmers was over 50, and more than 90 % of them also had a relatively low education level (Junior High School or less). Apparently, while the proportion of aging farmers was growing, young and more educated people were moving out of the farm, searching for better job opportunities in the cities.

The land size of the organic fertiliser users was smaller on average. However, the yield ha^{-1} in Rupiah was on average higher. Spending on inputs was lower for the organic fertiliser users except for spending on equipment rent and spending on labour. The spending on synthetic fertilisers was higher for the group that did not use organic fertilisers, but not by far. The means of the quantity of synthetic fertilisers used per hectare were also similar, which was around 300 kg $year^{-1}$. This amount was lower than the amount recommended by the Ministry of Agriculture. This low spending could be because of the farmers' financial constraints.

Only about 30 % of farmers joined a farmers group and only around 10 % of farmers were female. Though mechanization of the farming process has been around since a few decades, more than 30 % of farmers in West Java did not use a tractor. Hibrida is a better quality paddy variety; however, because the price was much higher than inbrida variety, most farmers in West Java used inbrida variety.

Table 3: *Stochastic Frontier model estimates*

Variable	Coefficient	Standard Error
Constant	0.54341***	0.06566
LnSeed costs	0.07052***	0.00802
LnFertilisers costs	0.08455***	0.00696
LnPesticide costs	-0.01049***	0.00134
LnWage costs	-0.01331	0.00954
LnEquipment rent	0.01103***	0.00178
LnTax and retribution	0.02911***	0.00256
LnDepreciation	0.00289***	0.00239
LnLand size	0.82599***	0.01169
σ	2.36398***	0.05104
λ	0.67892***	0.00068

***, **, * $\Longrightarrow$ Significant at 1 %, 5 %, 10 % level..

In the Stochastic Frontier model, the value of total production became the dependent variable, whereas the costs (spending) of seeds, fertilisers, pesticides, equipment rest, depreciation of capital, tax and retribution, and labour were used as covariates. In addition, land size was used as a control variable. All variables were in natural logarithm. Table 3 shows the Stochastic Frontier estimates of the coefficients.

The coefficients of seeds costs, fertilisers costs, and cultivated land area, equipment rent, and tax and retribution were statistically significant and had positive signs as expected, while pesticide costs and wage costs had the opposite signs. The negative and significant coefficient of pesticide costs might indicate pesticide resistance after long-term use[4]. The negative and insignificant coefficient of wage costs could be due to the difficulty of measuring the workers' exact wages, especially when a production sharing system was used. The depreciation of capital had a positive sign but statistically insignificant. Like the wage cost, the difficulty in measuring the depreciation level accurately could cause this insignificant result. Here, σ and λ were variance parameters that were both statistically significant.

The main objective of running the stochastic frontier model was to estimate the technical efficiency level of each observational unit in the sample. The results could then be compared among the groups of interest without controlling them with other variables representing the social characteristics of the cross-sectional units in the sample (Table 4) or regressed them on both variables of interest and the control

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[4] Government regulation no. 7 of 1973 regulates the circulation, storage, and use of pesticides in Indonesia. But, how in practice the pesticides are applied in the field is hard to control.

Table 4: *Means of efficiency score comparison based on the quantity of synthetic fertilisers used*

Level of synthetic fertilisers kg ha^{-1} year^{-1}	*Synthetic fertilisers users*	*Mixed fertilisers users (no pesticides)*	*Mixed fertilisers users (with pesticides)*
< 100	0.6307	0.6581	0.7240***
100–250	0.6311	0.5770	0.6333
250–450	0.6502	0.6827*	0.6513
> 450	0.6580	0.7460***	0.6810*

***, **, * $\Longrightarrow$ Significant at 1 %, 5 %, 10 % level.

variables (Table 5). Table 4 displays the technical efficiency score means for the groups that used mixed fertilisers (organic and synthetic fertilisers) and those that used synthetic fertilisers only. The asterisks indicate the significance level of the t-test showing whether the technical efficiency mean score of the mixed fertiliser users without or with pesticide was significantly higher than that of the synthetic fertiliser users.

As shown in Table 4, all groups that used mixed fertilisers, whether with or without pesticide, had higher means of efficiency score except for the group that used 100-250 kg ha^{-1} synthetic fertilisers without pesticide. Furthermore, the mean value of those that used synthetic fertilisers only increased as the amount of synthetic fertilisers increased. The mixed fertilisers users that had significantly higher mean efficiency scores compared to that of users of synthetic fertiliser only were the ones that used 250-450 kg ha^{-1} and more than 450 kg ha^{-1} of chemical fertilisers without pesticide, as well as those that used less than 100 kg ha^{-1} and above 450 kg ha^{-1} of chemical fertilisers ha^{-1} with pesticides.

Table 4 gives a raw comparison between the groups that used synthetic fertilisers alone and those that combine organic fertiliser with different levels of synthetic fertilisers. However, since other variables might also affect the efficiency level, a regression model is needed to get better estimates. The Generalised Linear Model (GLM) was employed to estimate the efficiency difference between the groups that combine organic fertiliser with various levels of synthetic fertilisers with those that used synthetic fertilisers only. Relevant variables were also included as control variables. Different distributions were tried, such as Normal, Gamma, and Exponential with identity and log link functions. The coefficients of variables differed slightly, but they all gave the same signs of coefficients and significance level. The Normal distribution with the identity link function was chosen and presented in Table 5 because it gave the lowest AIC (Akaike Information Criterion), representing the amount of information lost. Since the White test indicated the existence of heteroscedasticity in the model, the coefficient covariance matrix was computed using the Huber-White method, which is usually applied when heteroscedasticity is assumed to occur.

Table 5: *GLM estimates for technical efficiency*

Variable	*Coefficient*	*Standard error*
Farmers group	-0.015112***	0.003939
Age	-0.000096	0.000148
Tractor	0.065602***	0.004059
LnLand size	-0.008087***	0.002252
Gender	0.001620	0.005788
Seed variety		
Hibrida	0.043686***	0.015291
Inbrida	0.037180***	0.010505
Education		
High school	0.020146***	0.007862
Diploma	0.050334***	0.019028
University	0.006283	0.015544
Level of synthetic fertilisers used per ha		
0–100 kg no pesticides	0.048631	0.099287
100–250 kg no pesticides	-0.026719	0.032372
250–450 kg no pesticides	0.067830***	0.020462
>450 kg no pesticides	0.088979***	0.016905
0–100 kg with pesticides	0.091721***	0.035303
100–250 kg with pesticides	-0.006050	0.013528
250–450 kg with pesticides	0.009188	0.010238
>450 kg with pesticides	0.032696***	0.016580
Constant	0.602153***	0.023648
AIC	-0.892950	
LR Statistics	383.7915***	
N		8142

***, **, * $\Longrightarrow$ Significant at 1 %, 5 %, 10 % level.
Source: 2014 Paddy farming household survey

Membership of a farmers' group had a negative effect on efficiency. The organisation of farmers in the form of farmers groups was expected to facilitate the distribution of government's support and medium of communication between government and the farmers and among the farmers themselves. However, as seen from the result of this model and the low participation of farmers in this organisation, apparently, this mechanism did not go well. Cultivating land with tractors is, of course, faster and easier than using animals. It affected yields and farming efficiency as shown in positive and significant coefficient. Larger land size did not mean higher efficiency in production processes than the smaller ones. The negative and significant land size coefficient showed that the larger lands were managed less efficiently, than the smaller ones.

The results also showed no significant difference in efficiency between households headed by male or female farmers, and efficiency did not significantly improve as farmers get older. There were three kinds of seed varieties used by farmers: the improved varieties Hibrida and Inbrida, and local varieties. The Hibrida and Inbrida varieties are significantly superior compared to the local varieties; however, the Hibrida variety showed the highest efficiency. Farmers with High School certificates and Diploma (D-3) degrees were more efficient than those with only a Junior High School certificate or less. Those with higher education are generally more adaptive to technology and advancement that could impact their success. However, farming is more of hands-on learning and direct involvement in the farm that there is no guarantee that those with more theoretical university education can do better than those with lower education, as the result of the model showed.

The mixed-method users without pesticides that had positive and significant coefficients were the group that uses 250-450 kg per hectare per year and above 450 kg of synthetic fertilisers per hectare per year. The highest synthetic fertilisers spending in the last group was around 700 kg ha^{-1} year^{-1} or 350 kg ha^{-1} each planting season. This quantity was still lower than the recommended amount in the 2007 Ministry of Agriculture decree. The group of farmers that applied mixed fertilisers but still used chemical pesticides and had positive and significant coefficients were the ones that use less than 100 kg and more than 450 kg synthetic fertilisers/,ha/,year. These four groups were also significant when a t-test was applied without controlling for other variables. Three of the more efficient groups (compared to the non-organic fertiliser users) tended to use higher synthetic fertilisers. The groups that used less than 100 kg synthetic fertilisers with pesticides and more than 450 kg synthetic fertilisers without pesticides had the highest coefficients (around 0.09), meaning their efficiency level was 9 % higher than those that used synthetic fertilisers alone.

Besides measuring and examining the determinants of efficiency, this study also sought to establish whether efficiency and other relevant variables affected the farmers' probability of being in a state of poverty. The logit model results in Table 6 showed that the efficiency and land size coefficients were highly significant and had negative signs. These negative signs meant that the lower the efficiency level, the higher the probability of being in a state of poverty, and the smaller the land size, the higher the probability of falling into a state of poverty. Another significant variable was the junior high school dummy variable or less. The coefficient was 1.74, which meant farmers with only a Junior High School certificate or less were about 174 % more likely to be in a state of poverty than those with a High School certificate. Age and Gender were other variables included in the model, but they did not significantly affect the probability of being in a state of poverty.

Table 6: *Estimates for Logit model for household poverty status*

Variable	*Coefficient*	*Standard Error*
Age	0.002476	0.007807
Efficiency	-1.868564***	0.547772
Education		
University	1.482754	1.419935
Diploma	2.209755	1.425752
Junior High School or less	1.743263*	1.007026
Gender	-0.320592	0.274882
LnLand size	-0.326091***	0.116397
Constan t	-2.114152	1.436975
LR Statistics	28.09175***	
N	8142	

***, **, * $\Longrightarrow$ Significant at 1 %, 5 %, 10 % level.

4 Discussion

A heated debate arose when Searchinger *et al.* (2018) published their findings that organic peas farmed in Sweden produce 50 % higher emissions than peas grown conventionally. The debate still continues, generating pros and cons regarding organic and conventional farming. However, these two facts are unequivocal: that excessive use of chemical fertilisers is bad, and the application of organic fertiliser improves soil structure, affecting land productivity. The method of mixing organic and synthetic fertilisers basically intends to combine the good aspects of both sides. Organic fertiliser retains water better, while synthetic fertilisers can be absorbed by plants faster. Most researchers used field experiments to prove the superiority of the combined fertilisers method. Among these are Jate (2012) for oat, rye, and potato, Magdoff & Amadon (1980) for corn, Chand *et al.* (2006) for mint and mustard, and Bokhtiar & Sakurai (2005) for sugarcane. When there are enough studies in a certain field, a meta-analysis[5] can be performed like the one done by Liu *et al.* (2021) for vegetables. They found that the vegetable yields increased when N's substitution rate with an organic source was less than or equal to 70 % in China and furthermore, the combination of synthetic with organic fertilisers also reduced net Global Warming Potential (GWP) at the field level.

This research was neither a field experiment nor a meta-analysis study. It used a large set of household survey data which potentially provides better generalisation. Besides adding to the literature on the mixed fertilisers method, which is still scarce, testing this method's effectiveness is urgent in a time when a great majority of farmers use the conventional method. For small-holder farmers whose livelihood depends on their land, reduction of yield due to pest/plant diseases or conversion to another farming method with uncertain results could be quite threatening. Besides, the green revolution has made farming processes more practical. Farmers do not have to earmark some part of the harvest for seeds; they can buy good quality seeds in the market. They do not have to collect animal waste and chop leaves and branches to be composted and then shovel the heavy organic matter into the farm. They just go to the seller to buy dry synthetic fertilisers and spread them on the farm. The fact that most farmers still use the conventional method tells us that the cost of going organic is not just some 5 % to 34 % yield decline but also implies a higher labour cost and the inconvenience of carrying out the method. A higher yield is therefore needed to incentivise farmers to use organic fertiliser.

The means of efficiency score in Table 4 are consistently increasing as the quantity of synthetic fertilisers used increases, particularly for the farmers that use synthetic fertilisers alone. This is unfortunate and might lead people to think that the only way to increase the crop yield (and therefore the efficiency) is by adding more and more synthetic fertilisers and in the end, becoming fertiliser overdose. The farmers that combined organic and synthetic fertilisers also had a similar trend except for the group that used 100–250 kg of synthetic fertilisers without pesticide. The good thing is that the groups that use the mixed fertilisers all have a higher mean of technical efficiency score except for the last-mentioned anomaly. These raw results are also manifested in the GLM results in Table 5. Farmers who used organic fertiliser with a sufficient amount of synthetic fertilisers (given land size and other control variables) generally reached a higher level of technical efficiency than those that used synthetic fertilisers alone. How much chemical fertiliser is considered too high is somewhat relative if we compare the figure for different countries. According to FAO record[6], in 2014, China used 408.79 kg on average per hectare. The figure was 273.66 kg for Vietnam, 251.94 kg for Bangladesh, 236.61 kg for Japan, 150.96 kg for India, and 118.72 kg for Indonesia. The figure for the last group that used mixed fertilisers was between 225–350 kg (450–700 kg per year). It is high enough but still less than that of China. The Indonesian Department of Agriculture recommends the usage of organic fertiliser alongside chemical fertilisers. However, since it is only a recommendation, the farmers have no compelling reason to follow the guidance.

Higher efficiency means a higher crop yield. Although farmers do not obtain a price premium, they still receive a higher revenue even though they do not fully convert to organic farming. Putting organic fertiliser on their land will improve the soil structure by adding natural nutrients. The green revolution has brought convenience and easier methods of farming but degrades soil if overly done. A minor step done by these farmers that restore nature's balance should be appreciated. Organic fertiliser is not as easily available as synthetic fertilisers. Proponents of organic farming usually encourage farmers to make their own fertiliser using a mixture of materials readily available in their location, such as banana hump, calliandra or moringa leaves, coconut coir, rotten fruits and peels, cow dung, chicken manure, paddy straw, and so forth. That is the cheapest way, but as a farmer said, it needs experimentations to get the right balance of the materials. Other ways to get organic fertiliser are from local waste banks that also do the composting processes, local chicken farms that sell or give away chicken manure, and suppliers of worm casting made from cow dung. Worm casting is of good quality and not heavy but expensive. Some farmers that we know partly buy and partly make organic fertiliser themselves to save on costs.

The high efficiency score obtained by the group that used the least amount of synthetic fertilisers gives hope that to increase the crop yield, it is possible not to use chemical fertilisers as much as the other three groups. But, sadly, the farmers under this group also used chemical pesticides. Globally, around 30 % of food production is lost due to pests and diseases (FAO, 2017). For small farmers like those in West Java, such a loss significantly reduces their welfare. The stochastic frontier results in Table 3 also showed that the higher the amounts of chemical pesticides used, the lower the yield, which was most likely due to pesticides resistance.

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[5] A meta-analysis is a systematic review to synthesize available evidence addressing specific research question using specific search parameter followed by critical appraisal and logical synthesis (Mikolajewicz & Komarova, 2019)

[6] Can be found in http://www.fao.org/faostat/en/#data/RFN

This is quite a dilemma everywhere, especially in developing countries (FAO, 2015). Farmers need to balance between the effort to protect their crops and safety for both humans and nature. However, small farmers with mostly limited resources should not be left alone to struggle against pests and plant diseases. It is the agricultural department and agricultural researchers' responsibility to find ways to provide farmers with a toolbox of protection that is friendlier for humans and nature.

Many developing countries' foods are produced by small farm holders, and yet these farmers are mostly poorer than the rest of the population they feed. Therefore, the poverty reduction effort also means confronting small farmers' problems. These problems are varied, ranging from the constraint on land size, market access, financial access, and low education to productivity and efficiency of resources utilisation. Not all problems can be solved simultaneously, but if productivity and efficiency can be enhanced, family food security will be improved, and in the longer run, financial constraints can be relaxed, and the farmers become more confident to choose more profitable off-takers.

The World Bank (2008) highlighted the importance of improving agricultural productivity as a way out of poverty, particularly for developing countries. Studies by Kiresur *et al.* (2010) and Diao *et al.* (2009) also concluded that low agricultural productivity had become the leading cause of rural poverty. This study showed that higher efficiency could reduce the probability of farmers falling into poverty. The negative sign of the land size coefficient indicated that those who were likely to fall into this state were small farm holders. Land size can hardly be enlarged unless the government conducts land reform. Larger farm holders are less likely to be poor because they can produce more in total, not because they are more efficient than smaller farm holders. For small farm holders, the only way to obtain higher revenue is to improve land productivity by farming more efficiently. The GLM estimate for land size variable in Table 5 also showed a negative relationship with efficiency, meaning larger size lands were less efficient than the smaller ones. The inverse relationship between land size and productivity was also found in Oseni *et al.* (2014), Deolalikar (1981), and Rao & Chotigeat (1981).

Another variable that significantly affects the likelihood of falling into poverty was education, where farmers in the lowest education level were more likely to end up poor. Low education often becomes an impediment to progress in other fields as well. However, as shown in Appendix 1, people with low education were more common in rural areas. Direct observation of a proven method is more likely to make them willing to imitate rather than extensive training for these people.

5 Conclusions

Studies that support the usage of mixed fertilisers employed either field experiments or meta-analysis. Field experiments normally have more controlled interventions but are limited in sample size. This study used a large survey data set on paddy households that could provide better generalisation. Using this data set, we could track which farmers used organic fertiliser and how much synthetic fertilisers they used. The Stochastic Frontier model results used in the GLM could then detect which group of farmers with what level of synthetic fertilisers outperformed the group that used synthetic fertilisers alone. In that way, it provided a unique contribution to the discussion on the mixed fertilisers studies that, to our knowledge, has not been done before. Our results generally supported the proponents of mixed fertilisers usage from soil science. The efficiency difference between the mixed fertilisers users and synthetic fertilisers users could be as high as 9 %. However, the users of mixed fertilisers that had higher efficiency levels also used synthetic fertilisers at $> 250\,\mathrm{kg\,ha^{-1}\,year^{-1}}$ or more than $125\,\mathrm{kg\,ha^{-1}}$ per planting season, which is too high for some countries' standards. An exception occurred for the group that used the least amount of synthetic fertilisers (less than $100\,\mathrm{kg\,ha^{-1}\,year^{-1}}$), but with pesticides. The fact that this group could maintain a high yield signified the pesticide role to prevent crop damage due to pests. The usage of chemical pesticides is, of course unwanted, however, knowing that this group could have high efficiency opens a possibility that productivity can be enhanced with less synthetic fertilisers as long as friendly and effective pesticides can be found or there is an innovation in seed variety that better withstands pests.

This study also examined whether efficiency affected the probability of paddy households falling into a state of poverty. The results showed that enhancing efficiency could hinder farmers from falling into a state of poverty. Land size also had a negative effect on the probability of being in a state of poverty. Since land size cannot be expanded, the only way to improve the farmers' condition is by enhancing the efficiency, where based on our results, mixing fertilisers is advisable. These results are also crucial for policymakers who are concerned about achieving Social Development Goals, especially SDG 1 (to end poverty in all its forms) and SDG 2 (to end hunger, achieve food security and promote sustainable agriculture).

The strength of a large data set such as the one used in this study is its ability to provide better generalisations than the one based on individual field research. However, such a data set lacks detailed information normally available in field research (experiment), such as the type of soil, the regularity of irrigation, and the frequency and timing of giving fertilisers, among others. When there are enough field research results, meta-analysis research can be conducted by way of comparison.

Supplement

The supplement related to this article is available online on the same landing page at: https://doi:10.17170/kobra-202201195572 .

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Conflict of interest

The authors declare that there is no conflict of interest.

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