Reallocation the use of chemical fertilizers and pesticides to increase vegetable farmers income and prevent land degradation in Indonesia

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Research Article

Reallocation the use of chemical fertilizers and pesticides to increase vegetable farmers income and prevent land degradation in Indonesia

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Abstract

The study, which aims to analyze the use of chemical fertilizers and pesticides using the Cobb Douglas production function approach and their reallocation to increase the income of vegetable farmers and prevent land degradation, was conducted in Sumberejo Village, Batu City, Indonesia. Data were collected from 138 pakcoy, celery and red chili farmers through interviews using a questionnaire. The relationship between input and output was analyzed by regression with the Cobb Douglas production function approach. Data validity and reliability, as well as classical assumption tests were performed to ensure the accuracy of the regression model. Furthermore, the F test and t test were applied to analyze the production response to chemical fertilizers and pesticides. This study reveals that the regression equation that is modeled is appropriate where R2 = 0.827-0.933. Vegetable production by type gives a different response to the use of chemical fertilizers (TSP, Urea and NPK) and pesticides. It is still possible to increase these chemicals in pakcoy and celery farming, but they have no significant effect on increasing production. Farmers need to compare the opportunity cost between the cost of adding this input to income and the possibility of land degradation. This chemical has been applied excessively in red chili farming. This is a signal for farmers to re-allocate the use of inputs containing these chemicals, so that their land is not degraded in the long term. To confirm this, it is necessary to study the condition of vegetable fields in Sumberejo Village and the optimal use of chemical fertilizers and pesticides.

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Introduction

Land degradation is caused by various forces, including biophysical and socioeconomic factors (Lestariningsih *et al*. (2018), excessive pesticide application (Joko *et al*. (2017), where erosion is the main cause in tropical climates (Ambarwulan *et al*. (2014). Land degradation is one of the causes of the lack of success of agricultural activities in Indonesia due to a continuous decrease in land productivity, and ultimately reduces the income/welfare of farmers.Land degradation can occur, both in dry land and in wet land, so prevention and/ or rehabilitation of degraded land is very important so that agricultural areas can be used sustainably (Sitorus & Pravitasari, 2017). One of the farmers' efforts to prevent it is to be wise in using chemical fertilizers and pesticides according to plant needs.

Land conditions with more damage are experienced in vegetable farms, because the use of more pesticides causes lower organic content. Vegetables are widely cultivated by farmers in various countries in the world because these commodities contribute greatly to human health. Vegetable production provides a promising economic opportunity for reducing rural poverty and unemployment in developing countries and is a key component of farm diversification strategies (Schreinemachers, *et al*., 2018). In Indonesia, farmers grow various types of high-quality vegetables that have a potential to generate foreign exchange for the country. It has a positive contribution to the trade balance (Pudjiastuti & Kembauw, 2018).

In Indonesia, farmers grow various types of high-quality vegetables that have the potential to generate foreign exchange for the country. It has a positive contribution to the trade balance (Pudjiastuti & Kembauw, 2018).

Three types of Indonesian vegetables with great potential for expansion are pakcoy, celery and red chili. There is a gap in production, growth and production value of these three types of vegetables in Indonesia (see Figure 1), where red chilies contribute the most to farmer income and gross domestic product because apart from production, the price is also the highest.

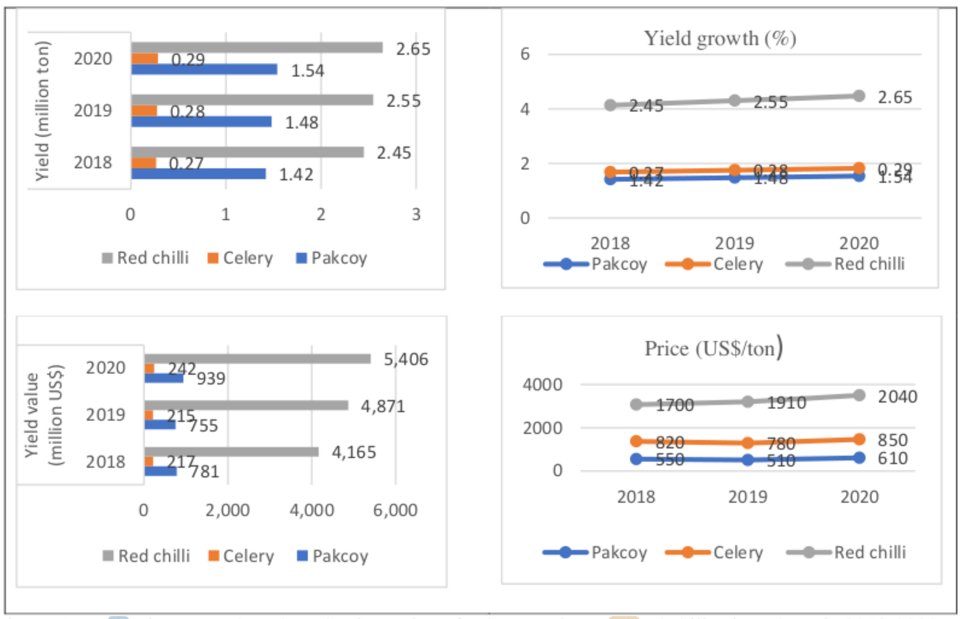

Figure 1. Production, growth and production value of pakcoy, celery and red chilies in Indonesia 2018-2020
Data source: Ministry of Agriculture of the Republic of Indonesia and Central Bureau of Statistics, processed

In the context of vegetable production, the Cobb-Douglas production function is commonly used to analyze the relationship between input and output. This function shows how production responds to chemical fertilizers and pesticides. Elasticity and production efficiency figures can be used to analyze production response to input use and identify inputs that are applied excessively (unbalanced).

There is no research that highlights the allocation of inputs in vegetable farming, especially pakcoy, celery and red chili, related to land degradation. However, the technical efficiency that shows the relationship between input and output of several agricultural commodities such as vegetables in Africa has been studied by Rajendran *et al*. (2015) and Rijal & Bhatta (2022), maize in Ghana (Adzawla & Alhassan, 2021) and in Malawi (Jolex, 2022, and Mgomezulu *et al*., 2022). These studies used the Cobb-Douglas production function and found technical inefficiencies in the cultivation of agricultural commodities. According to Khatri *et al*. (2011) and Shrestha *et al*. (2022), the efficiency of resource use differs between types of vegetables. Other researchers mention factors that significantly contribute to input use efficiency, namely plant productivity (Okello *et al*., 2019), farmers' educational background, farm size, water availability, the application of manure, and poor drainage systems (Karimov, 2014). This study aims to analyze the reallocation of the use of chemical fertilizers and pesticides in Indonesian vegetable farming to increase farmers' income and prevent land degradation by using the Cobb Douglas production function approach.

Materials and Methods

The research was conducted in Sumberejo Village which is a vegetable center in Batu City. Primary data was collected from pakcoy, celery and red chili farmers. Samples were selected by simple random sampling from 350 farmers cultivating vegetables in monoculture. Farmers are homogeneous because the vegetable cultivation area is less than 0.6 hectares. The number of samples is determined using the Slovin formula:

$$n = \frac{N}{1+N \cdot e^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where, n = number of samples; N = total population; and e = desired level of accuracy. The number of samples obtained through this formula were 45 pakcoy farmers, 45 celery farmers and 48 red chili farmers, so that the total respondents were 138 farmers.

Farmers were interviewed at home during their free time or on the land when they were working. The questionnaire as a research instrument was tested for validity and reliability. Data that has been collected, edited in the field, then tabulated, processed and analyzed. Reallocation of input use begins with estimating the relationship between input and output with the Cobb Douglas production function:

$$Y_i = b_{0i} X_{1i}^{b_{1i}} X_{2i}^{b_{2i}} X_{3i}^{b_{3i}} X_{4i}^{b_{4i}} X_{5i}^{b_{5i}} X_{6i}^{b_{6i}} X_{7i}^{b_{7i}} X_{8i}^{b_{8i}} \quad i = 1,2,3 \ \ldots \quad (2)$$

where: Yi = yield of each type of vegetable (kg) where Y_1 = pakcoy yield, Y_2 = celery yield, Y_3 = red chili yield; b_{0i} = constant; b_{ji} = regression coefficient of each production factor (j=1,2, …, 8); X_{1i} = land area (ha); X_{2i} = seed (gr); X_{3i} = manure (kg); X_{4i} = TSP fertilizer (kg); X_{5i} = NPK fertilizer (kg); X_{6i} = urea fertilizer (kg); X_{7i} = labor (mandays); X_{8i} = pesticide (ml).

The model is first transformed into multiple linear functions in natural logarithmic:

$$\ln Y_i = \ln b_{0i} + b_{1i}\ln X_{1i} + b_{2i}\ln X_{2i} + b_{3i}\ln X_{3i} + b_{4i}\ln X_{4i} + b_{5i}\ln X_{5i} + b_{6i}\ln X_{6i} + b_{7i}\ln X_{7i} + b_{8i}\ln X_{8i} \quad \ldots\ldots \ (3)$$

The classical assumption test was conducted to show that the regression model is a good estimator. Cobb Douglas production function for each type of vegetable is obtained by retransforming the estimated multiple linear regression function. Technical efficiency is formulated as:

$$TE = \frac{\text{MPPxi}}{\text{APPxi}} = \frac{\Delta Y/\Delta X_i}{Y/X_i} = bji \qquad \ldots\ldots\ldots\ (4)$$

where: TE = technical efficiency; MPPxji = Marginal Physical Product for input ji; APPxji = Average Product for input ji.

Justification: If TE = 1, then production factor is technically efficient. If TE > 1, then production factor is not technically efficient. If TE < 1, then production factor is technically inefficient. It can be an indicator of efficiency in the short term.

RTS as an indicator of long-term efficiency is the sum of the regression coefficients of all factors of production. These parameters are classified into: 1) increasing return to scale, if $\sum_{i=1}^{j} bji > 1$, 2) constan return to scale, if $\sum_{i=1}^{j} bji = 1$, and 3) decreasing return to scale, if $\sum_{i=1}^{j} bji < 1$.

Results and Discussion

Characteristics of vegetable farmers

Farmers in Sumberejo Village generally cultivate various types of vegetables in wetlands. Types of vegetables that are widely cultivated include pakcoy, celery and red chilies. Farmers' characteristics of the three types of vegetables are presented in Figure 2.

Most (89-100%) of vegetable farmers are of productive age, and (87-94%) are male. However, the findings of Missiame *et al*. (2021), even though there is a technological gap between male and female farmers, it turns out that the farming they manage is still technically inefficient. The majority (90-98%) of farmers have a high school education and below, but with relatively long farming experience (> 10 years) and only cultivate vegetables on limited land (< 0.6 ha). Rahaman & Abdulai (2022) stated that farmer education affects farm input use and output. Meanwhile, according to Josephson & Ricker-gilbert (2020), the smallholder farmer faces considerable risk and uncertainty, the relationship between market failure and crop choice. In addition, 67-91% of vegetable farmers have large family members (> 3 people). Most of these three types of vegetables (93-94%) are cultivated on their own land, except for mustard greens, 64% of which are grown on leased land.

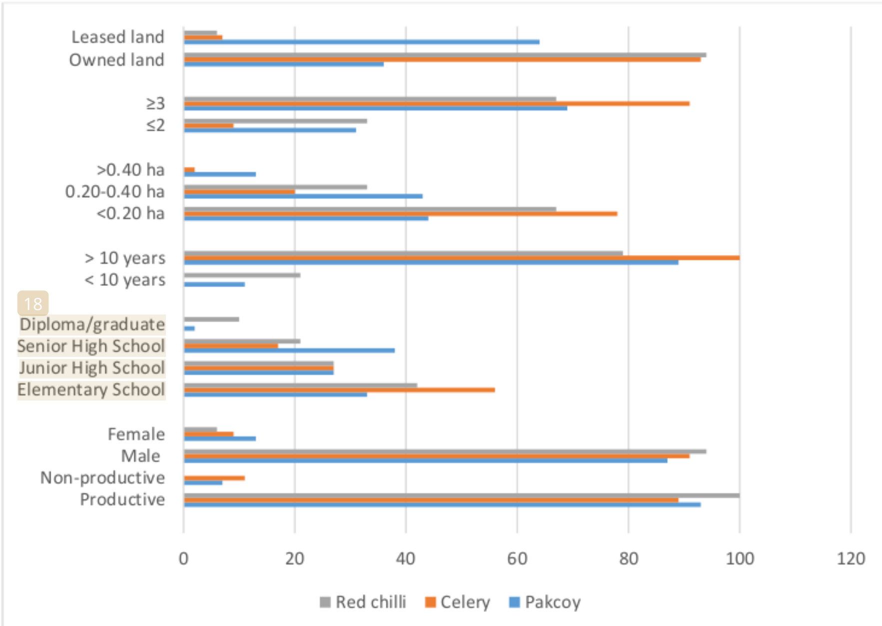

Figure 2. Characteristics of vegetable farmers

Cobb Douglas production function estimation for vegetables

Cobb Douglas production function estimation for vegetables

The production functions of the three vegetables (see Table 1) reveal about their input and output relationships. The estimation results fulfill the goodness of fit model because the coefficient of determination (R2) is close to 1 (0.827-0.933). That is, the production factors used by farmers are able to explain variations in vegetable production by 83-93%. Only land area affects the production of mustard greens and celery, while red chili production is affected by land area and seeds.

Vegetables in Sumberejo Village were indeed cultivated on a relatively small area of <0.6 ha; even for a maximum red chili plant area of only 0.4 ha. Red chili seeds were usually bought by farmers at farm shops because they hope to get a high income from the production of this commodity. The reason was that the price of red chilies was higher than other vegetables, even though the fluctuations were also greater. However, farmers plant red chilies in smaller areas to minimize the risk of loss when the price of red chilies falls.

Table 1. Production function of pakcoy, celery, and red chili

Variable	Pakcoy (Y_1)			Celery (Y_2)			Red chilli (Y_3)		
	regression coefficient	sig.	effi-ciency	regression coefficient	sig.	effi-ciency	regression coefficient	sig.	Effi-ciency
Constant	1.866			0.947			0.296		
Land area (X_{1i})	**1.014	0.000	e	**0.985	0.000	ne	**0.842	0.000	ne
Seed (X_{2i})	-0.195	0.495	ne	0.052	0.471	ne	**0.430	0.001	ne
Manure (X_{3i})	0.021	0.836	ne	0.046	0.413	ne	0.040	0.735	ne
TSP fertilizer (X_{4i})	0.048	0.768	ne	0.097	0.241	ne	-0.137	0.300	ne
NPK fertilizer (X_{5i})	0.184	0.359	ne	0.079	0.324	ne	-0.125	0.239	ne
Urea fertilizer (X_{6i})	0.111	0.526	ne	0.092	0.314	ne	0.021	0.790	ne
Labor (X_{7i})	-0.413	0.057	ne	0.055	0.617	ne	0.063	0.692	ne
Pesticide (X_{8i})	0.251	0.142	ne	0.040	0.521	ne	-0.131	0.270	ne
R^2	0.827			0.933			0.897		
Sig. F	0.000			0.000			0.000		

Description: ** = highly significant (sig.< 0.01); e = efficient, ne = inefficient.

Almost all factors of production are used inefficiently in vegetable farming, except for the area of land in pakcoy farming. Seeds and labor were inefficient production factors in pakcoy cultivation, as well as TSP fertilizers, NPK fertilizers and pesticides in red chili farming. Farmers have to reduce the amount of this input. Meanwhile, the amount of other inputs must be increased, especially land area and seeds. Red chili farming is very intensive in the use of chemicals (TSP fertilizers, NPK fertilizers and pesticides), because farmers want to increase their production..

Cobb Douglas production function for the three types of vegetables (Y_1 = pakcoy yield; Y_2 = celery yield; Y_3 = red chili yield) can be written mathematically as follows:

$$Y_1 = 1.866 X_{11}^{1.014} X_{21}^{-.195} X_{31}^{.021} X_{41}^{.048} X_{51}^{.184} X_{61}^{.111} X_{71}^{-.413} X_{81}^{.251} \quad (5)$$

$$Y_2 = 0.947 X_{12}^{.985} X_{22}^{.052} X_{32}^{.046} X_{42}^{.097} X_{52}^{.079} X_{62}^{.092} X_{72}^{.055} X_{82}^{.040} \quad (6)$$

$$Y_3 = 0.296 X_{13}^{.842} X_{23}^{.430} X_{33}^{.040} X_{43}^{-.137} X_{53}^{-.125} X_{63}^{.021} X_{73}^{.063} X_{83}^{-.131} \quad (7)$$

Sum of the production function exponents shows a return to scale (see Table 2). It can be a signal for vegetable farmers in managing their farming in the following season. In the long term, farmers can change their business scale by expanding the planting area and improving the combination of chemical fertilizers and pesticides that have a potential to degrade their land.

Table 2. Estimated return to scale of vegetables

Description	**Pakcoy**	**Celery**	**Red chili**
Return to scale figures	1.021	1.446	1.003
Justification	Increasing return to scale	Increasing return to scale	Increasing return to scale
Implication	If all inputs are increased by one time, output will increase by 1.021 times	If all inputs are increased by one time, output will increase by 1.446 times	If all inputs are increased by one time, output will increase by 1.003 times

Increasing return to scale (IRTS) means that vegetable farming has the potential to use more efficient production factors, the capacity to accumulate capital for land expansion and to be a source of profit and attractive to other farmers. The IRTS of these vegetables is similar to the results of studies on yam plants in Nigeria (Izekor & Alufohai, 2015), tomatoes (Subedi *et al*., 2020) and vegetables in Nepal (Rijal & Bhatta, 2022).

According to Jabbar (1977), within Cobb-Douglas production function, determination of optimum scale requires production elasticity of each factor input to be less than unity, i.e. all the factors are variable and marginal productivity of each factor is declining. It can happen only when at least one factor is fixed. Scale relationship may then be presented in the form of a two factor production function implying proportionality relationship between one factor as a fixed factor and all the other factors as an aggregate homogeneous variable. Increasing returns may prevail over a wide range of output if substantial unused capacity in production exists; decreasing returns will prevail when production capacity is reached and negative returns will ensue as size expands beyond production limit. An optimizing farmer would be expected to operate within the range of diminishing returns to scale.

By incorporating research from diverse contexts and geographical settings, this narrative strengthens its argumentative framework and demonstrates the consistency of findings across different regions (Schreinemachers et al.,, 2017). Further research and analysis are required to explore the underlying factors contributing to observed returns to scale and their implications for agricultural policy and practice.

Farmer income and land degradation

The fertile soil conditions due to volcanic eruptions make the agricultural land in Sumberejo Village very suitable for growing vegetables. However, the conversion of agricultural land has reduced the scale of farmers' businesses. Small farmers have limited capital, so the income earned from their farming is also small. Because most of the income is used for consumption, the income allowance for reinvestment in farming is also low. This is what makes it difficult to develop small-scale farming. So that their income does not decrease, the farmers of Sumberejo Village are trying to keep their vegetable production increasing through the intensive allocation of TSP, Urea, NPK fertilizers and pesticides.

Farmers assume that the chemicals applied to their fields will be able to produce vegetables in a minimum quantity equal to the production in the previous growing season. Generally, they grow vegetables in monoculture with an intensity of planting three times a year. This cropping pattern is possible because enough water is available, although water sources in this area are also starting to decrease. There is a tendency for farmers to continue to increase the use of chemical fertilizers and pesticides in vegetable cultivation, especially those that are highly commercial. It was revealed by the results of this study that chemical fertilizers and pesticides were applied excessively in red chili farming (see Table 1).

The production functions of different vegetables demonstrate variations in the efficiency of production factors. Some input factors show effectiveness in increasing output, while others exhibit inefficiencies. These inefficiencies can have implications for productivity and resource management (Mariyono, 2017; Izekor & Alufohai, 2015; Subedi *et al*., 2020).

Furthermore, small-scale vegetable farmers face challenges, primarily limited capital, hindering their development and sustainability (Bahta & Owusu-Sekyere, 2019). This indicates that the optimal scale of vegetable production may vary depending on the context and available resources. The results of returns to scale analysis in vegetable production align with and complement existing research findings. Zhang *et al*. (2020) conducted a study in China, focusing on vegetable producers and technological change. They found evidence supporting the presence of increasing returns to scale in vegetable farming, affirming the notion that economies of scale can be achieved through the proper allocation of resources and technology adoption.

Farmers' efforts to increase production and income if done continuously will cause their land to be degraded. Farmers need to highlight the following: 1) the use of chemical fertilizers and pesticides is still possible to be added in pakcoy and celery farming, but it does not have a significant effect. This indicates that there is no point in increasing the amount of this input because it will not increase production. Farmers must compare the opportunity cost of adding chemicals to the chance of degradation of their land in the future. 2) the application of chemicals in red chili farming is excessive. In addition to reducing farmers' income, the addition of chemical fertilizers and pesticides can also lead to faster land degradation than other vegetable commodities. It is necessary to study the condition of farmers' land in this region to confirm this.

Based on the results of this study and supported by a previous study by Jaya *et al*. (2014) and Maftu'ah *et al*. (2014), it can be identified several ways to prevent the degradation of vegetable land. These efforts include: 1) implementing conservation farming patterns such as agroforestry, intercropping, and integrated farming, 2) implementing eco-friendly organic farming patterns, and 3) increasing the role and participation of farmer institutions.

Conclusion

The use of chemical fertilizers and pesticides by vegetable farmers is not in accordance with the proper proportions, so they must be reallocated. Pakcoy and celery farmers can increase the amount of these chemical inputs to increase their income, although the increase is not significant. On the other hand, red chili farmers must reduce their application, because the amount is excessive. If this is allowed, besides reducing the production and income of farmers, it will also cause land degradation in the long term. The government needs to facilitate farmers to be willing to reduce the amount of chemical fertilizers and pesticides on their land, but a study must first be carried out on the current condition of farmers' land.

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