Quantity and monetary value of agrochemical pollution from intensive farming in Indonesia

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Abstract

Purpose – The purpose of this paper is to measure the environmental performance of intensive farming and estimate agrochemical waste in physical and monetary terms. The intensive farming provides adverse impacts including health and environmental quality associated with the use of agrochemicals.
Design/methodology/approach – This study uses a theory of environmental efficiency that measures how efficient the farm uses agrochemical inputs. The efficiency was estimated using a set of farm-level data of intensive farming that use agrochemicals. Data were compiled from a survey of randomly selected 240 farmers who operated intensive farming in three regions of Java in 2014.
Findings – The results show that the performance of intensive farming was low. This condition caused agrochemical waste leading to the externality. Taking the external costs into account resulted in the improvement in efficiency of agrochemicals. The actual level of agrochemicals was about a hundred times higher than the most efficient level.
Research limitations/implications – This study is beyond the exogenous external costs. There is a need for a further comprehensive study to include more exogenous external costs associated with agrochemicals to have the potential value of such costs and the most socially efficient use of agrochemicals. The long-term effects of external cost to the environment and socio-economic livelihood of the farmers and other communities are considerable. Advocating for alternatives to decrease the use of detrimental agro-inputs, in the long run, will provide sound quality of the environment. Socially, both producers and consumers get the environmental and health benefits.
Practical implications – To reduce the agrochemical waste that caused environmental problems, a policy should be formulated to make farming more efficient, particularly for agrochemical use. It can be done by introducing agronomic technologies and enhancing farmers' knowledge on environmentally friendly agriculture.
Originality/value – Environmental efficiency is able to estimate the quantity of agrochemical waste. The waste is a kind of non-point source pollution whose source and quantity are very difficult to identify and measure. As there are many definitions and measurement of environmental performance, this concept of environmental efficiency can be one of the alternatives.

Keywords Monetary value, Agrochemical waste, Costs of externality, Environmental efficiency, Vegetable farming
Paper type Research paper

1. Introduction

Recently, climate change, resulted from greenhouse gas emissions, became a concern in the agricultural sector. Usage of agrochemicals is identified as one of the sources of greenhouse gasses (Flynn and Smith, 2010). As agriculture approximately uses

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40-50 percent of the Earth's surface, it contributes 10-12 percent of global emission of greenhouse gases (Smith *et al.*, 2007). For rice production, emissions related to agrochemicals are the highest contributor, compared to machinery, fuels, and animal labor (Maraseni *et al.*, 2009). In the vegetable industry, the contribution of agrochemical use to the emission of greenhouse gasses is 17 percent from soil emissions due to nitrogenous fertilizer use and 10 percent is from other agrochemicals (Maraseni *et al.*, 2010). The use of fertilizers was the primary contributor to the pollution intensities in conventional production. Because a lot of fertilizer is required for high-yield production with an increased grain protein content, chemical fertilizer production and field emissions from fertilizer application are the environmental hot spots for conventional production (Charles *et al.*, 2006; Biswas *et al.*, 2008; Tuomisto *et al.*, 2012). Pesticide residues provide an adverse impact on human health. The number of cases of sickness caused by pesticides in developing countries is higher than that in developed countries. Pesticide residues also affect environmental quality. Farmers serve as the main unit of agricultural production; their life and their daily production are closely related to the natural environment (Bhandari, 2014).

Detailed information on the socially efficient use of agrochemicals in agricultural practices, particularly vegetable production in Indonesia is still limited. There is a need of a study to provide a better understanding of the analysis of agrochemical use in intensive chili production in Java, Indonesia. This study aims to evaluate the use of agrochemicals and examine the environmental performance related to the use of agrochemicals in intensive chili farming at the farm level. The measures of performance cover environmental, allocative, and social efficiencies. The estimation of agrochemicals is derived from environmental efficiency. External costs resulting from the inefficiency of agrochemical use are estimated endogenously, and social efficiency is obtained by internalizing the external costs into the production costs.

The following sections are as follows: a literature review that provides a brief narration of environmental problems associated with the use of agrichemicals in intensive farming systems and elucidates the relevant studies of environmental impacts associated with agrochemicals; a theoretical framework that explains a concept of environmental efficiency; a research method that justifies the procedure of study. Results and discussion explore the findings. The last section concludes the important outcomes and provides a formulation of recommendation.

2. Literature review

The Green Revolution, introduced in the early 1960s, is the starting time of agricultural scientific euphoria. Since the late 1980s, optimism has been tempered due largely to a persistent problem of environmental and social concerns about intensive agriculture methods (Nijkamp and Vindigni, 2000). As reported by the United Nations (1997), there is a greater recognition of the problem of long terms of depletion of natural resources, environmental pollution, and land degradations.

A signal indicates that agriculture leads to non-point source pollution and this leads to high external costs[1]. Houndekon and de Groote (1998) report that the external costs of controlling migratory locust pests during 1992-1996 in Niger were around US$416,607, which was the value of livestock poisoned by insecticides. In Thailand, Jungbluth (1996) reports that the external costs of agrochemical use in 1992 reached about US$43 million, which came from the market value of chemical-contaminated vegetables and fruits. While in the Philippines, regarding health cost, each farmer spent approximately an extra US$24 for recovering health associated with a kg of pesticide application (Rola and Pingali, 1993). In China, the use of pesticides was a persistent problem affecting the quality and safety of agricultural products (Wu and Hou, 2012). Farmers suffered from pesticides intoxication after spraying. Farmers who sprayed more pesticides were more likely to have more signs and symptoms of pesticides poisoning (Qiao *et al.*, 2012).

Some studies also report that not only developing countries suffer from agricultural pollution and climate change problems, agrochemical pollution and climate change resulting in external costs also occur in many developed countries. In Germany, some external costs were associated with the unintended, undesirable side effects of agrochemical application. Every year, at least US$164 million should be spent to deal with water contamination, residues in foods, plants destroyed by herbicides, and loss in honey production. The ratio of such external costs to pesticide expenses was 23 percent. Compared to the benefit of pesticides, there was a net welfare loss of US$587 million, which was equivalent to 5 percent of the net domestic agricultural product (Fleischer, 1999). Pincus *et al.* (1999) note that the net welfare loss associated with the agrochemical use also happened in the USA. Pretty *et al.* (2000) estimate the monetary value of the negative externalities coming from modern farming practices that used agrochemicals in the UK. They conclude that:

> Modern farming clearly results in substantial external costs per hectare and per kilogram of non-renewable input. These per hectare costs are substantially greater than those estimated in other studies, probably reflecting the more comprehensive nature of the framework and range of impacts measured. Nonetheless, we believe them to be a conservative estimate of the true costs (p. 118).

In Indonesia, environmental degradation related to intensive agricultural practices had been recognized well during the Green Revolution (Barbier, 1989). Land degradation is associated with agrochemical use which has damaging effects on the environment (Bond, 1996). High use of agrochemicals was triggered by agrochemical-augmenting technological change during the Green Revolution (Mariyono, 2009a, 2015).

In rice agriculture, studies on external costs associated with the agrochemical use have been done in The Philippines (Rola and Pingali, 1993), Vietnam (Dung and Dung, 1997), and China (Huang *et al.*, 1997). The external costs analyzed in the studies are based on health costs associated with pesticide uses. But, the studies do not internalize the external costs, such that the socially efficient level of pesticides has not been determined. The internalization of external costs associated with the pesticide use in Indonesian rice production has been conducted, and the socially efficient level of pesticide use has been determined (Mariyono, 2009b; Mariyono *et al.*, 2010).

Note that majority of external costs associated with the use of agrochemicals are obtained exogenously from other sectors, which could be either over- or under-estimates. The use of agrochemicals may not necessarily lead to severe pollution if the system of agriculture is able to efficiently use the agrochemicals. Besides, the level of agrochemical usage in rice production – as a base of previous studies – is lower than that in the intensive vegetable production. Thus, in the practice of intensive vegetable-based agriculture, environmental degradation associated with the use of agrochemicals seems to be more serious. In this study, chili farming is selected since it is an important component of Indonesian agriculture (Mariyono, 2017). Regarding crop acreage, chili is the first rank of important vegetables in Asia and the third globally (Ali, 2006). Chili was cultivated on more than 190,000 ha in Indonesia with the production of about one million ton, which was about 3 percent of the annual global supply of chili (Mariyono and Sumarno, 2015).

Since the publication of *Silent Spring* by Rachel Carson in 1963, issues of environmental problems related to intensive agriculture have been raised. Many publications raising concerns over the sustainability of intensive agriculture have continued to increase since the late 1970s, (e.g. Barbier, 1989; Conway and Barbier, 1990). The demand for a clean and healthy environment is greater today than it has ever been because of the growing property rights of people to a better environment. The expression of the greater demand for this is seen in several ways. The existence of organizations that lobby for environmental regulations and policies is one of the expressions. Environmental performance is now receiving increasing attention as an approach to agriculture that attempts to reconcile environmental, sustainability, and production goals by emphasizing the application of ecological concepts and principles to the design and management of agricultural systems. It can be seen as a part of a broader approach to sustainable farming practices focusing on ecological intensification alongside technological intensification (Lampkin *et al.*, 2015).

A net social benefit is the best target by internalizing the value of environmental impacts. Providing the right incentives should help maximize the total return to society of the net benefits of agricultural production. Nevertheless, many environmental problems and ecosystem services are difficult to monitor and quantify. For nitrogen and pesticide runoff, it may be costly to assess the environmental performance of individual farms. Proxies for environmental performance may be as close as policy can get. The World Business Council for Sustainable Development (2000) introduces a concept of eco-efficiency as one of the measurements of environmental performance. It refers to the ability of firms, industries, regions, or economies to produce more goods and services with fewer impacts on the environment and requiring less consumption of natural resources, thus bringing together economic and ecological issues.

Eco-efficiency starts at a firm level with recommendations to reduce material requirements, the energy intensity of commodities and services, and toxic dispersion and to maximize the sustainable use of renewable resources. However, as human societies aspire to satisfy the increasing levels of consumption and the simultaneous attainment of reasonable environmental quality, the eco-efficiency concept should be extended to an economy-wide, macro level, beyond the business sector and production patterns. In this part of the world, it is, therefore, reasonable to pursue improvements in eco-efficiency rather than sole yield increases (Huppes and Ishikawa, 2005). For example, in Japan, Masuda (2016a, b) examines the eco-efficiency of agricultural production with an adequate application of nitrogen fertilizer. The eco-efficiency of the modeled farm was calculated by a combination of the results of linear programming and life cycle assessment. This method enables us to measure an eco-efficiency score with respect to each environmental impact category. A finding of Kulak *et al.* (2013) suggests that eco-efficiency of agricultural production can be improved by increasing yields in a sustainable matter. Life cycle assessment provides a useful framework to identify the environmentally optimum levels of inputs and trade-offs between various intensification scenarios. Many studies have confirmed the effectiveness of a combined application of life cycle assessment and data envelopment analysis in aggregate eco-efficiency assessment of agricultural production. Although eco-efficiency based on data envelopment analysis measurement is useful for comprehensive eco-efficiency assessment, it requires a large sample size (Masuda, 2016b).

Another measurement of environmental performance is a concept of environmental efficiency. It measures how efficient the farm uses agrochemical inputs that have detrimental effects on human health and the environment. Sorvari *et al.* (2011) report that environmental performance is interpreted to be a synonym for environmental efficiency, as per the European and national eco-design regulations. However, there is a need to clarify the concept of environmental efficiency to facilitate the interpretation of companies' reporting. Reinhard *et al.* (2002) adopt an econometric technique to find the efficiency estimates. By using a single output and a stochastic production frontier, the environmental performance of individual farms is determined. Graham (2004) examines the concept of environmental efficiency and how it can be used to evaluate the performance of Australian dairy farming, using nitrogen surplus, arising from excessive applications of fertilizer, as a detrimental input. The farming promotes an image of the clean and green production process, and if this image is to be maintained, there is a need to ensure activities are environmentally friendly. Gang and Felmingham (2004) study the environmental efficiency to estimate salt emission in Australian irrigation. In the study, a stochastic production function frontier is specified to estimate the input-oriented technical efficiency of major Australian irrigation schemes. The study finds a potential reduction of the environmentally detrimental salt emissions resulting from the improvement of environmental inefficiency.

The studies that use either eco-efficiency or environmental efficiency only determine the environmental performance of the agricultural production. There is no information about the amounts of environmental impact caused by both eco-inefficiency and environmental inefficiency, in terms of physical pollution and the negative value of pollution. Understanding the environmental impact in terms of physical and monetary magnitudes is important because it can be used by policy makers to formulate appropriate policies and regulations. This present study examines the environmental performance of intensive farming using the concept of environmental efficiency proposed by Reinhard *et al.* (2002), and proceeds with an estimation of agrochemical pollution in terms of physical and monetary terms. This approach is considered the novelty of this study.

3. Theoretical framework

3.1 Environmental efficiency

In modern agricultural practices, including vegetable production, chemical inputs are commonly used. The inputs are considered environmentally detrimental. The use of chemicals leads to non-point source pollution, i.e. a form of pollution whose source and quantity are difficult to identify (Grafton *et al.*, 2004). The pollution happens because the chemicals are not perfectly used by the production system, and to some extents are discharged into the environment. Based on the fact above, it is relevant to use a concept of environmental efficiency to analyze agricultural practices that use damaging inputs. Starting from a concept of stochastic production frontier, the environmental efficiency is defined as:

> *Definition 1.* Environmental efficiency is defined as the ratio of minimum attainable environmentally detrimental input use to the actual usage given the actual level of output and other inputs at the existing technology (Reinhard *et al.*, 2002).

A technically efficient farm is a necessary condition for environmental efficiency, meaning that if a farm is technically efficient, the farm will consequentially be environmentally efficient. Figure 1 describes the definition of environmental efficiency.

At Point B, suppose Y^{pot} is a potential production level which is produced through a frontier production technology $f(X, Z)$ with the level of $X^{\min}$ and $Z^{\min}$, where X is an environmentally detrimental input and Z is a usual input. Because of being a technically inefficient producer, the same level of Y is produced with the actual level of X^{act} and Z^{act}, at point A. In this case, the rate of technical efficiency – φ – is the ratio of Y^{act} to Y^{pot} or OB/OA.

Improvement in technical efficiency is represented by a shift in actual production from A to B, such that both inputs can be reduced in the same proportion to produce the potential output. This is a kind of Hicks-neutral shift in actual production toward frontier production. By definition, environmental efficiency is represented by the ratio of $O\overline{X}/OX^{\mathrm{act}}$. It implies that to be environmentally efficient, producers should reduce input X from X^{act} to $\overline{X}$ to produce the potential output. This means that there is a shift in actual production from point A to point C. This is particularly true if the shift in actual production is not Hicks-neutral. In fact, the definition is based on a Hicks-neutral shift. Thus the definition of environmental efficiency above violates the concept of a stochastic

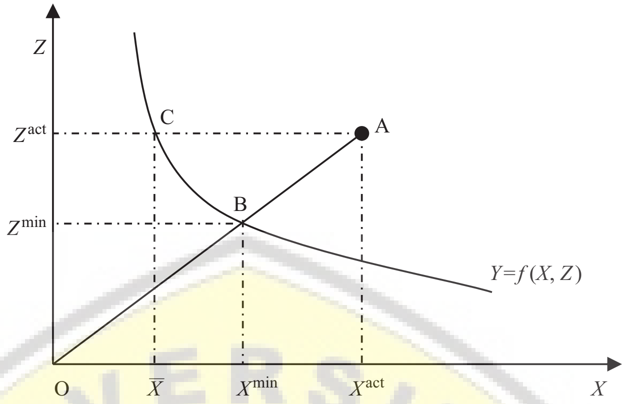

Figure 1.
Input-oriented environmental efficiency

production frontier with which the definition starts. The definition of environmental efficiency needs to be revised as follows:

Definition 2. Environmental efficiency is the ratio of minimum feasible environmentally detrimental input to the actual use, given the actual level of output and efficient level of other inputs.

By definition, the minimum level of detrimental inputs is determined endogenously, that is, the lowest level of such input relative to other farmers in the sample. In Figure 1, the environmental efficiency is represented by the ratio of OX^{min}/OX^{act}. Thus, to be environmentally efficient, producers should reduce input X from X^{act} to X^{min} to produce the potential output. In the output-oriented approach, environmental efficiency can be depicted in Figure 2.

At point B, potential output can be produced with actual inputs $(X, Z)^{act}$. Because of technical inefficiency, the actual output at point A can be efficiently produced with minimum feasible inputs $(X, Z)^{min}$. As defined above, the rate of technical efficiency – φ – is the ratio of Y^{act} to Y^{pot} (Graham, 2004), and environmental efficiency – ψ – is the ratio of X^{min} to X^{act}.

The relationship between technical efficiency and environmental efficiency can be explored in a mathematical approach. In an input-oriented approach, the actual level of

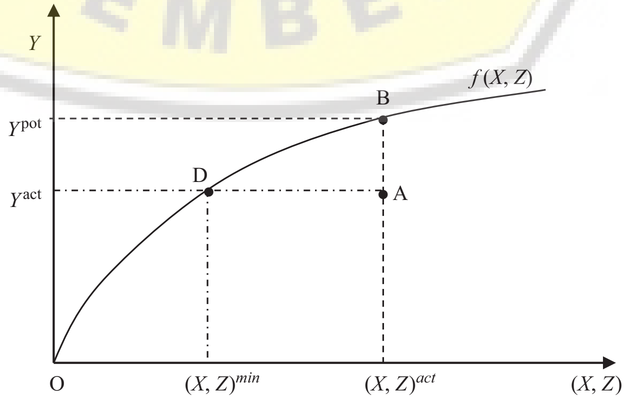

Figure 2.
Output-oriented environmental efficiency

output can be represented by:

$$Y^{\mathrm{act}} = f(\psi X, \psi Z) \tag{1}$$

In an output-oriented approach, the actual level of output can be represented by:

$$Y^{\mathrm{act}} = \varphi Y^{\mathrm{pot}} \tag{2}$$

Let the core deterministic frontier production function taking a functional Cobb-Douglas form technology be[2]:

$$Y^{\mathrm{pot}} = AX^{\alpha} Z^{\beta} \tag{3}$$

Substituting (1) into (2) with the functional form of (3) gives:

$$\varphi AX^{\alpha} Z^{\beta} = A(\psi X)^{\alpha} (\psi Z)^{\beta} \tag{4}$$

and solving for ψ results in:

$$\psi = \varphi^{\frac{1}{\alpha+\beta}} \tag{5}$$

Equation (5) shows that environmental efficiency can be indirectly estimated in two steps. First, estimate technical efficiency and technology parameters using the production frontier. Second, measure environmental efficiency derived using the estimated technical efficiency and the output elasticity with respect to inputs. It can be seen that there are two conditions that make environmental efficiency the same as technical efficiency. The first is when the firm is operated at full technical efficiency ($\varphi = 1$) and the second when production exhibits constant returns to scale, that is ($\alpha + \beta = 1$).

Output elasticity is expected to vary among producers, and it could be the case that producers with high technical efficiency have more output elasticity and vice versa. Consequently, producers with high technical efficiency are likely to have a similar measure of environmental efficiency to producers with low technical efficiency. It is, therefore, more informative to estimate environmental efficiency using more flexible production technology to capture variation in output elasticity with respect to each input.

3.2 Agrochemical waste and environmental costs

Intensive agricultural practices have been known as one of the sources of pollution, particularly non-point source pollution resulting from chemical waste. One of the main reasons for agricultural non-point pollution is inefficient utilization and redundancy inputs of fossil resources in the process of agricultural production (Zhang *et al.*, 2014). From the estimated environmental efficiency – ψ – the amount of non-point source pollution can be calculated as:

$$W = (1-\psi)X \tag{6}$$

where W is the amount of agricultural waste, and X is the actual use of environmentally detrimental inputs.

In a period in which the society has property rights to a clean environment, the existence of agricultural waste reduces amenity, and the society normatively should have compensation from disutility due to “consuming” a contaminated environment. The amount of compensation is dependent on the level of agrochemical waste discharged into the environment. Therefore, the environmental impact of agrochemical waste needs to be valued in monetary terms. The value is then called an environmental cost.

Monetary valuation of that pollution is difficult because it is a non-marketed good, and there is no general method because every case needs a specific approach as a consequence of different states of nature. To some extents, due to lack of information, there is a little agreement on the economic costs of externalities in agriculture. Some authors suggest that the current system of economic calculations grossly underestimates the current and future values of natural capital (Costanza *et al.*, 1997). Such valuations of ecosystems are still debatable because of methodological and measurement problems, and because of their role in affecting public opinions and policy decisions (Hanley *et al.*, 1999; Carson, 2000). However, this does not immediately mean that valuation of externalities should be ignored since this can exaggerate a negative correlation between economic and environmental sustainability of farms (Antonini and Argilés-Bosch, 2017).

Some approaches have been proposed and examined in the literature to value the environmental cost associated with certain pollution. One of the strategies suitable for this study is called "effect on production" (Garrod and Willis, 1999) which suggests that the existence of additional pollution will affect production such that the level of output will be different from the production with the existing pollution. The difference of the monetary value of output represents the environmental cost. Since using the environmentally detrimental inputs provides benefits to producers in terms of increased output for a given level of inputs (Paul *et al.*, 2002), it is reasonable to make an inverse statement of the effect on production as follows: environmental cost is the monetary value of output that must be given up in order to maintain minimum pollution.

Figure 3 shows the valuation of endogenous environmental cost using the effect on production approach. This is caused by inefficiency loss. Given the estimated production function, the endogenous environmental cost associated with the amount of environmentally detrimental input discharged into the environment can be approached as:

$$EC = P\left\{f\left(X^{\text{act}}, Z\right) - f\left(X^{\text{min}}, Z\right)\right\} \tag{7}$$

where P is the prevailing price of output.

By using such approach, the endogenous external cost resulting from efficiency loss can be derived by inverting the production function, ranging from X^{act} to X^{min}, while keeping Z constant. Such reduction will not jeopardize the production while improving efficiency. But there will be a potential reduction if the production already in the frontier.

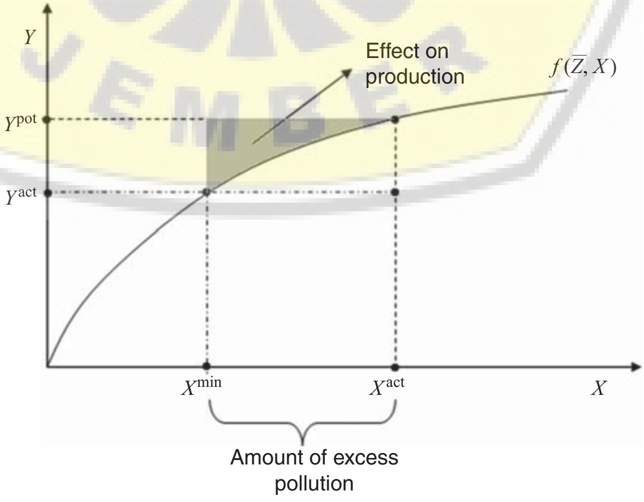

Figure 3.
Valuation of externality using "effect on production" approach

3.3 Efficient level of resource use

In the framework of static equilibrium analysis, the study of resource use efficiency has been a popular field of research for agricultural economists. Efficient level of resource use relates to profit maximization. In a production process that results in externalities, there are two efficiency levels: private and social levels. The diagrammatical explanation of private and social efficiencies can be described in Figure 4.

Private efficiency occurs when the producers do not take the externality into account. The privately efficient use of agrochemicals – X^{aef} – is reached when the marginal benefit of agrochemicals – MB_X – is equal to its marginal private cost, *MPC*. The second is social efficiency in which the producers take the externality into account. The socially efficient use of agrochemicals – X^{sef} – is reached when MB_X is equal to marginal social cost, *MSC*. In the case of negative externalities, social efficiency will be obtained when the producers reach maximum profit at which the external costs have been internalized into production costs.

4. Research method

4.1 Empirical model

This study employs the Cobb-Douglas production technology to be practical in estimation. Agrochemicals include the aggregate of inorganic fertilizers, insecticides, and fungicides. The model is specified as:

$$Y = AL^{\alpha}X^{\beta}G^{\delta} \tag{8}$$

where *Y* is output, *A* is labor, *X* is agrochemicals, and *G* is other materials[3]. The marginal benefit of agrochemicals is specified as:

$$MB_X = \frac{\partial Y}{\partial X} \times P = \beta AL^{\alpha}B^{\beta-1} \times G^{\delta} \tag{9}$$

where *P* is the prevailing price of *Y*. The individual output elasticity with respect to agrochemicals is then evaluated at the actual level of each input. Environmental efficiency is then calculated using the formula:

$$\psi = \varphi^{1/(\alpha+\beta+\delta)} \tag{10}$$

where $\varphi = \exp\{-u_i\}$ is estimated technical efficiency[4]. The estimation of environmental efficiency using this formula is expected to overcome the problem when a producer uses zero level of an environmentally detrimental input.

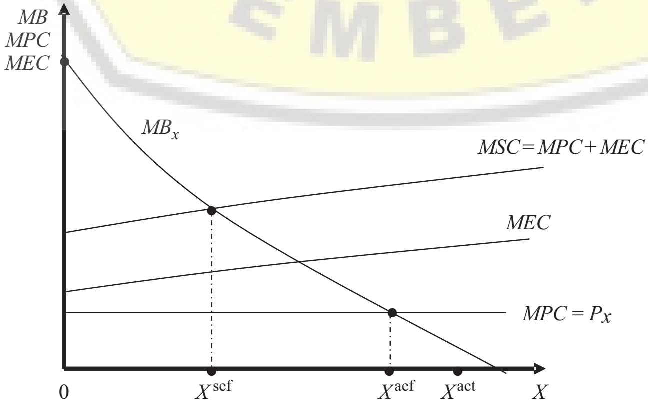

Figure 4.
Actual and optimum levels of agrochemical use

Based on Figure 4, the levels of X^{aef} and X^{sef} are called as allocative and social efficiencies of agrochemical use, respectively. These levels are determined by setting the marginal benefit of agrochemicals, MB_X, equal to the average price and internalizing the endogenous external cost of agrochemicals. Comparing to the actual level of agrochemicals will identify whether the use of agrochemicals was under-utilized or over-used.

4.2 Data source and collection

Chili and shallot were selected in this study since these crops use agrochemicals intensively (Mariyono, 2017, 2018a). This study defined western regions that include West and Central Java provinces; Eastern regions that include Central and East Java provinces and central regions that include Central Java and Yogyakarta provinces. The locations were the production center of chili and shallot in Indonesia. Due to a limitation of resources, 80 growers in each region were selected randomly as a sample survey. For a micro-economic study, the total respondents of 240 farmers have fulfilled the minimum requirement of statistical analysis. The selection of sub-districts and villages were based on the acreage of chili. Data were collected through a household survey carried out using personal interviews using a structured questionnaire.

Data of farming management were collected. These include the characteristics of farm and the use of farm inputs. Particular attention was paid to the use of agrichemicals consisting of inorganic fertilizers and synthetic pesticides. Such inputs were considered to be detrimental to human health and the environment. Other data of material and labor inputs were also collected. These data were collected for estimating the frontier production function as specified in Equation (8). In the process of estimation of the frontier production function, the inorganic fertilizers and synthetic pesticides were aggregated as agrochemicals to make it simple in the estimation of agrochemical waste and its monetary value.

Analyses were conducted in two steps: descriptive and econometric analyses. The descriptive analysis provided a brief description of agrochemical characteristics. The econometric analysis estimated a production function as specified in Equation (8). Further analyses were conducted to compute the marginal benefit of agrochemicals as specified in Equation (9), environmental efficiency as specified in Equation (10), output elasticity with respect to each input (α, β, δ), agrochemical waste as specified in Equation (6), endogenous external costs as specified in Equation (7), and socially efficient level of agrochemicals use where the amount of agrochemicals will provide marginal benefit of agrochemicals (Equation (9)) equal to the cost (or price) of agrochemicals.

4.3 Hypothesis

This study established a set of hypotheses which are as follows:

H1. The performance of intensive farming is low, which is indicated by a low level of environmental efficiency. As for the low environmental efficiency, non-point source pollution exists, and this leads to environmental costs associated with the pollution.

H2. There is an overuse of agrochemicals in the intensive farming leading to a low net benefit of the agrochemicals.

5. Results and discussion

5.1 Descriptive findings

Let us first discuss the share of input use as shown in Figure 5. Agrochemicals accounted for about 40 percent, and pesticides accounted for 22 percent. Pesticides consisted of three types: insecticides, fungicides, and other non-toxic compounds including stickers, dispersants, and surfactants.

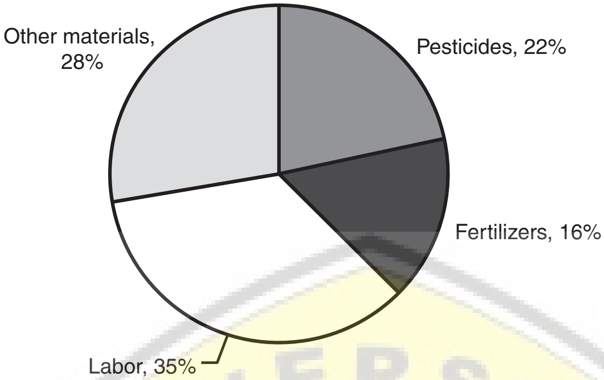

Figure 5.
Share in input use

Figure 6 shows that insecticides dominated the pesticides. Insecticides are the most toxic agrochemicals that have a side effect on non-targets such as fish and other aquatic life. The level of pesticide use can be represented by the frequency of spray per growing season. Figure 7 shows that the frequency of sprays was, on average, 24 times/growing season. The variety of crop affects the level of pesticides use because of different characteristics.

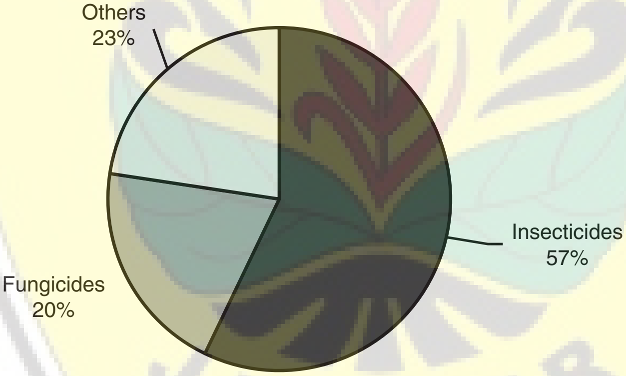

Figure 6.
Composition of pesticides

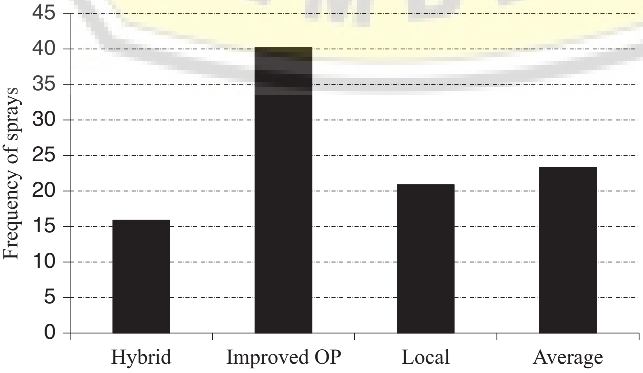

Figure 7.
Frequency of sprays, by variety of crop

Hybrid varieties were the lowest in terms of frequency of sprays, meaning that the hybrids were considered more tolerant of resistance to pests and diseases than non-hybrids.

Regarding the quantity, the level of pesticide use was 12 kg/ha. The Western site where no farmers grew hybrids showed the highest level of pesticide use. This finding is consistent with the above fact that non-hybrids needed more sprays than the hybrids (see Figure 8).

The level use of fertilizers in chili farming is shown in Table I. The total use of inorganic fertilizers was about 90 kg/ha. This substance consisted of urea, phosphate, sodium chloride, ammonium sulfate, complex solid fertilizers, and complex liquid fertilizers.

In general, West and East regions used fertilizers at a higher level than the Central region. This could be the effect of the type of cultivars cultivated in both regions where farmers preferred to grow a non-hybrid chili. The high level of pesticide use along with fertilizers leads to environmental problems and human health if the agrochemicals are not fully absorbed by the production system. There is also a potential of greenhouse gas emission leading to climate change. The amount of agrochemical waste is dependent on the environmental efficiency.

For the agrochemical use, a recent survey indicates that the level of synthetic pesticides used on chili in Central Java ranged from 10 to 20 kg formulation per hectare per crop cycle of four months. Farmers who cultivated local varieties of chili applied double the amount of pesticides, and applied more frequently, than those who cultivated hybrids or improved varieties. Likewise, the level of inorganic fertilizer use on chili, on average, was 850 kg per hectare in the three surveyed sites (Mariyono *et al.*, 2018). Compare to rice, the level of inorganic

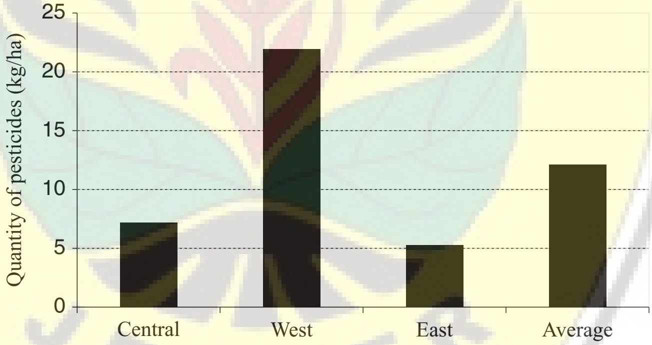

Figure 8.
Quantity of pesticides, by sites

	Central		West		East		Average	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Organic material	78.3^{C}	168.7	20.4	85.6	120.0^{W}	187.0	70.5	156.0
Urea	27.5	77.7	33.1^{E}	23.4	13.9	7.34	25.2	46.6
SP36	27.0^{E}	21.5	25.3^{E}	19.7	1.74	4.21	18.3	20.5
KCl	22.1^{WE}	19.5	16.5^{E}	14.1	3.51	3.77	14.1	15.9
NPK	14.4	25.9	12.7	15.7	13.4	11.6	13.5	18.5
ZA	24.8^{WE}	23.8	14.5^{E}	19.4	3.9	7.8	14.4	20.0
Foliar fertilizers	12.5^{WE}	43.0	0.15	1.39	0.41	2.98	4.14	24.8
Other fertilizers	0.4	1.15	5.07^{CE}	10.5	0.81	2.35	2.25	6.84

Notes: Significant difference of means across sites is indicated by superscript C, W, and E, which stand for Central, West and East. A mean comparison is tested using *t*-test at 90% of confidence interval

Table I.
Quantity of fertilizer use (kg/ha)

fertilizer use in intensive chili farming in Central Java was double that in rice farming, and the level synthetic pesticide in chili was around ten times higher than that in rice (Mariyono and Bhattarai, 2011).

5.2 Econometric findings

The technical efficiency of production needs to be estimated first to measure the environmental efficiency. Table II shows the estimated frontier production function and information of efficiencies[5].

In terms of Cobb-Douglas power function, the estimated production function can be written as:

$$Y = 13.28 \times L^{0.329} \times X^{0.11} \times G^{0.009} \qquad (11)$$

and the marginal benefit of X can be written as:

$$MB_X = 13.38 \times L^{0.329} \times 0.11X^{-0.8} \times G^{0.009} \times P \qquad (12)$$

where P is the price of output.

The production was decreasing returns to scale, in which the sum of elasticity was 0.45, which is less than 1. The technical efficiency was less than 1, meaning that the production process is not efficient. This means that the environmental efficiency is lower than the technical efficiency. The average technical efficiency was 62 percent. This is considered low. Based on the estimated technical efficiency and the sum of elasticity and using Equation (9), the environmental efficiency was estimated to be 34 percent. This means that agrochemicals used in the production system were just only 34 percent, and the remaining of 66 percent was discharged as agrochemical waste into the environment[6].

The total use of agrochemicals (synthetic pesticides and inorganic fertilizers) was about 102 kg/ha. Given the level of environmental efficiency and using Equation (6), the amount of agrochemical waste in magnitude was about 67.32 kg/ha in terms of unused synthetic pesticides and inorganic fertilizers. This amount has been polluting soils, rivers, lakes, and other water resources. The non-target organism such as beneficial insects and fishes could be affected by the waste. Further, this agrochemical waste also leads to the emission of greenhouse gasses. These adverse impacts are considered as an endogenous externality coming from the inefficient production system. If the production system were in full technical efficiency, there would be zero externality since all agrochemicals, along with other inputs, would be fully utilized by the intensive farming system.

With the current level of output, the use of agrochemicals would be just only 34.68 kg if the production system was fully technically efficient, by means that all agrochemicals were totally absorbed by the farming system. In fact, this was not the case. Given the efficiency level, the value of agrochemicals discharged into the environment results in inefficiency loss,

Factor	Elasticity	SE	z	Efficiency
TFP	13.281	0.1923	69.06	
Labor (L)	0.329	0.0607	5.43*	
Agrochemicals (X)	0.110	0.0335	3.27*	
Material (G)	0.009	0.0115	0.76^{ns}	
Sum of elasticity (θ)	0.448			
Technical efficiency (φ)				0.62
Environmental efficiency (ψ)				0.34

Notes: Dependent variable is the yield of output. *Significant at 1 percent

Table II. Estimated production function and efficiencies and this can be considered external costs. Using Equation (7), the value of inefficiency loss associated with 67.32 kg of agrochemicals was about Rp545,261,000 or Rp5,346,000/kg (approx. US$410/kg)[7].

The benefit of agrochemicals can be seen in the estimated production function provided in Table II. Agrochemicals still significantly played an important role in the production. This means that total elimination of agrochemical use would not be economically efficient. Setting the marginal benefit (Equation (12)) equal to the marginal private cost and marginal social cost (private + external costs) will have the allocative and social efficiency of agrochemical use. Given the average prevailing price of produce and agrochemicals of Rp5,000 and Rp50,000/kg respectively, the efficient level of agrochemicals was 1.33 kg/ha[8]. This is much lower than the actual use, meaning that the use of agrochemicals was very excessive and no longer efficient. Internalizing the external cost results in the socially efficient use of agrochemicals, which accounted for only 0.007 kg/ha. The reduction of agrochemicals up to this level is expected to provide a significant contribution to the improvement of environmental quality and mitigation of climate change through the reduction in emission of greenhouse gasses from the intensive farming system.

By using the concept of environmental efficiency, the amount of agrochemicals discharged into the environment was high. In monetary terms, the value of endogenous external costs was substantial. This is the novelty of these findings. When the external costs were taken into account, the use of agrochemicals was excessive. The best outcome when the external cost is taken into account. Note that this is the maximum recommended dose of agrochemicals because if other external costs associated with use agrochemicals are taken into account, the dose will be lower. Other exogenous external costs could be from human health costs, non-target life, land degradation, and environmental pollution associated with agrochemicals.

If the use of agrochemicals can be minimized, the long terms of benefits will be gained by farmers and other societies. The benefits include healthy foods resulting from a low residue of agrochemicals and good quality of the environments in terms of low contaminants in the soil, water, and air. In contrast, if the use of agrochemicals is excessive, farmers and other communities will suffer from the detrimental impacts. The long-term impacts of agrochemicals on environment and health are serious. The wildlife gets more threatened by the negative effects of using these chemicals. The toxicities and impact of agrochemicals causing the death of animals can be easily identified and influenced. The impacts of agrochemicals on the environment are hampering nature and also human life with their negative chemical reactions. Health effects of pesticides may be acute or delayed in those who are exposed. The effects include cancer (Bassil *et al.*, 2007), neurological problems, birth defects, fetal death (Sanborn *et al.*, 2007) and neurodevelopmental disorder (Jurewicz and Hanke, 2008).

Based on the findings, the level of agrochemicals should be reduced equal to the allocative and social levels. Reducing the level of agrochemicals will lead to a higher net benefit of agrochemicals, and, eventually, improve the environmental performance of the intensive farming. An agro-ecological approach can contribute to sustainable by maintaining natural capital in the form of soil and water resources as a result of reduced use, careful management (e.g. reduced or zero tillage) and reduced or restricted use of potentially polluting inputs (Lampkin *et al.*, 2015).

The performance can be improved in a sustainable manner. The use of ecologically friendly technology can mitigate the environmental impacts of inorganic fertilizers. For example, the complete substitution of nitrogenous fertilizers by air scrubber water can almost double the economic benefits, while the energy use and greenhouse gas emissions are 2.5 times reduced (Vaneeckhaute *et al.*, 2014). A study concludes that zero tillage in rice-wheat systems has the potential to be agronomically productive, economically viable with benefits also for the environment in terms of soil health and greenhouse gasses emissions (Sapkota *et al.*, 2017). Organic farming is also one of the alternatives. A study suggests that organic farming practice slows the decline in key enzymes of nitrogen metabolism in organic nitrogen-efficient type rice, thus maintaining a relatively high capacity for nitrogen uptake and utilization and increasing yield during the late growth period. Cultivating selected cultivars varieties of rice with the synergistically high efficiency of nitrogenous fertilizer and high grain yield under organic farming is able to increase the efficiency (Huang *et al.*, 2016).

However, strategies such as breeding, increasing diversity, no-tillage or intercropping will not be effective under all conditions. Life cycle assessment provides a useful framework to identify environmentally optimum levels of inputs and trade-offs between various intensification scenarios (Kulak *et al.*, 2013). One important thing is the proactivity of producers toward environmental performance. There is an indication of positive correlation of environmental proactivity with economic and environmental performance. Although environmental proactivity improves business performance, it has a greater impact on reducing environmental impacts and improving eco-efficiency (Barba-Sánchez and Atienza-Sahuquillo, 2016).

In comprehensive manners, an integration of compatible types of technology can be the best strategy. Integrated crop management (ICM) and integrated pest management have reduced the use of agrochemicals. In vegetable farming, ICM can simultaneously reduce the use of agrochemicals (Mariyono *et al.*, 2013; Mariyono, 2018b) and increase the productivity of farming (Luther *et al.*, 2018). Special for fertilizer management in intensive farming, Pandey and Diwan (2018) suggest that organic fertilizers are a substitute for inorganic ones. With the lower use of agrochemicals, including synthetic pesticides and inorganic fertilizers, while keeping the production unchanged, the agricultural practices will be environmentally friendly and approach to sustainable production.

6. Conclusion and policy implication

The usage of agrochemicals in intensive farming was high. Agrochemicals, which contain inorganic fertilizers and synthetic pesticides, have been applied in the high valued vegetable farming to reach and guarantee the potential production. Sometimes, farmers apply agrochemicals without taking economic aspects into account. The condition is amplified by the poor performance of production system related to the efficiency of agrochemicals. Based on the analysis, intensive farming has not been technically efficient. The level of technical and environmental efficiency was about 62 and 34 percent, respectively. This means that 66 percent of agrochemicals was discharged into the environment, and eventually provided adverse impacts. This agrochemical waste led to external costs.

Farmers applied excessively agrochemicals. The external costs associated with inefficiency were substantially high. The social efficiency of agrochemicals use was very low when the external costs were taken into account, and the optimum level of agrochemicals was very low. The optimum level is the maximum acceptable for farmers to use to get the maximum social benefit. If other exogenous external costs associated with the use of agrochemicals are taken into account, the optimum level will be much lower than the optimum one.

An important step is to reduce agrochemical waste by improving the efficiency level of farming. As efficiency increases, the environmental efficiency will consequentially increase, along with the reduction of agrochemical waste and its external costs. The improvement of efficiency can be conducted by enhancing the farmers' knowledge and introducing improved agronomic technologies for intensive farming.

Using technical efficiency and environmental efficiency can precisely calculate the magnitude of agrochemical waste. This is because the concepts have been used and verified by other researchers to estimate non-point source pollution in agricultural sectors in Australia and European countries. The monetary value of agrochemical waste is estimated using the value of products that should be jeopardized to keep the zero agrochemical waste. This is considered a new approach, which also applies to other commodities or sectors. This model of analysis is considered the novelty of this paper.

6.1 Caveats

For transparency reasons, limitations are acknowledged when interpreting the results. In this study, the limitation is the reliance of agrochemicals as detrimental inputs, and the environmental costs associated with agrochemicals are represented by yield forgone. There are numerous methods to assess and indicators to describe the environmental efficiency or some of its components. The approaches and principles of these methods and indicators vary due to the differences in business applications and desired outcome, i.e. for what purpose the results from the environmental efficiency assessment are used. The use of variable methods (and indicators) makes the comparison of the results from separate assessments difficult. When choosing the environmental efficiency methods, it is important to be aware of their principles, suitability for assessment of a particular case, and any limitations and pitfalls they have. This study is beyond the exogenous external costs. There is a need for a further comprehensive study to include more exogenous external costs associated with agrochemicals to have the potential value of such costs and the most socially efficient use of agrochemicals.

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Notes

1. Non-point source pollution is a form of pollution whose source and quantity are very difficult to identify (Grafton *et al.*, 2004).
2. Sexton *et al.* (2007) point out that estimating the contribution of pesticides using the Cobb-Douglas model leads to the underestimating of pesticides. But in this study, chemicals consist of fertilizers and pesticides; using this model is still considered applicable. The exact probability distribution function of pesticides is still unknown. Ajayi (2000) estimates models with four probability distribution functions. The result indicates that "the model does not exhibit a conclusive statistical superiority over the other specification models" (Ajayi, 2000, p. 151).
3. Using STATA and data set collected from the survey, the production frontier was estimated using a command: "frontier $\ln Y$ $\ln L$ $\ln X$ $\ln G$, where Y is production, L is labor, X is chemicals, G is material, ln is logarithmic operation. In the estimation of production frontier, α, β, δ were automatically estimated as the coefficients of $\ln L$, $\ln X$, and $\ln G$, respectively.
4. Technical efficiency was estimated after the estimation of production frontier, using a command: "predict TE, te." The technical efficiency was then used for calculation environmental efficiency using Equation (10).
5. Again, by using STATA and data set collected from the survey, the production frontier was estimated using a command: "frontier $\ln Y$ $\ln L$ $\ln X$ $\ln G$, where Y is production, L is labor, X is

chemicals consisting of pesticides and fertilizers, G is material, ln is logarithmic operation. In the estimation of production frontier, α, β, δ were automatically estimated as the coefficients of ln$L$, ln$X$, and ln$G$, respectively. Technical efficiency was estimated after estimation of production frontier, using a command: "predict *TE*, te." The technical efficiency was then used for calculation environmental efficiency using Equation (10).

6. In intensive soybean farming, the level of environmental efficiency even was lower than in this study (Mariyono, 2012).
7. The endogenous external costs are calculated using $EC = P\{f(X)^{\text{act}}, Z) - f(X)^{\text{min}}, Z)\}$, where $P = 5{,}000$, $X^{\text{act}} = 102$, and $X^{\text{min}} = 34.68$; Z consisting of average material and labor to be used in estimated production function (Equation (11)).
8. This is an approximation of composite price of agrochemicals, coming from the combination of pesticides and fertilizers. The composite price is obtained by calculating total costs of agrochemicals divided by total amount of agrochemicals. Equalizing the marginal benefit of agrochemicals (Equation (12)) to the price resulted in the efficient use of agrochemicals.

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Further reading

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