Direct and indirect impacts of integrated pest management on pesticide use: a case of rice agriculture in Java, Indonesia

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Abstract

BACKGROUND: Integrated pest management (IPM) technology has been disseminated since 1989 in Indonesia to cut down pesticide use, but the adoption and diffusion of the technology are still debated. This study aims to estimate the models of demand for pesticides and to analyse the impact of IPM technology on pesticide use. Aggregate cross-section time series data from 1990–1998 are used.

RESULTS: The results show that IPM technology reduces the use of pesticides by improving the process of rice production, such that pesticides are more efficiently used. In this case, the IPM technology is not a pest control technique.

CONCLUSION: There is an indication that IPM technology has been adopted by farmers. This is evidence that the IPM programme in Indonesia was successful in this area.

Keywords: pesticides; pest infestation; integrated pest management; demand for pesticides; rice agriculture

1 INTRODUCTION

The Indonesian government waived the subsidy for pesticides and at the same time introduced IPM technology through a National IPM Programme.[1] One of the expected outcomes of this policy was a reduction in pesticide use. Adverse effects of the high use of pesticides, particularly with regard to the environment and human health, were important factors behind this policy.[2,3] The high use of pesticides supported an intensive agricultural technology characterized by the use of high-yielding crop varieties. The government of Indonesia has spent around $US 725 million to subsidize agricultural inputs, and approximately 40% of this subsidy has been allocated for pesticides.[4,5] Starting from 1975, the subsidy increased substantially until 1985 and then gradually decreased, eventually becoming zero in 1989.[6]

There are two conflicting parties related to the success of the IPM programmes in reducing pesticide use. The first party, mostly IPM promoters, claims that the Indonesian IPM programme has been successful in reducing pesticide use through the adoption and diffusion of IPM technology.[7–14] The second party claims that the IPM programme in Indonesia has been unsuccessful in reducing pesticide use.[15,16] There is no evidence that the expected environmental and health benefits of the programme are significant, as there is no effect of the programme on pesticide use and there is no evidence of technology diffusion among farmers. The main criticism of the first party is a selection bias resulting from a lack of adequate econometric procedures in the previous IPM impact studies.

Until now it has been disputable which party represents the real impact. It seems that the two parties cannot be reconciled, because the fundamental debate comes from the different methodological approach and the different samples used to evaluate the programme. The first party mostly uses descriptive and simple statistical approaches of case studies to identify the impact of IPM programmes. The second party uses a quite complex econometric approach with a number of samples randomly drawn from farmers who have graduated from farmer field schools. This method is claimed to be able to cope with selection biases.

Neither the first nor the second party uses aggregate data representing the total number of graduated farmers. Therefore, both parties may still make errors in estimating the impact of IPM programmes. Making a strong claim about the superiority of IPM technology, it is assumed that, if the total number of farmers who apply IPM technology were to increase, the use of pesticides would be expected to decrease in the long run. Obviously, the application of IPM technology is not the only factor causing the decline in pesticide use in Indonesia. A continual increase in the price of pesticides, resulting from the elimination of the pesticide subsidy, may also contribute to such a reduction. Theoretically, analysing the effect of

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price and IPM technology on pesticide use can be approached by demand functions derived from a production theory.

The objectives of the present study were to estimate the demand for pesticides in rice farming and to analyse the impact of IPM technology on this demand at aggregate level. Using aggregate data was expected to cope with selection bias, because the aggregate data include both IPM-trained and non-IPM farmers. In addition, the aggregate data also cover the diffusion of the technology. The findings of this study are expected to provide more information for a better understanding of the economic impacts of the Indonesian IPM programme.

2 METHODS

2.1 Study site and data source

The study was conducted in Java, Indonesia, covering four districts: Bantul, Gunung Kidul, Kulon Progo and Sleman. IPM technology has been disseminated in these areas through a number of farmer field schools (FFSs) giving training in IPM. Secondary cross-section time series data were employed in this study. The data comprised four districts and covered the nine-year period 1989–1998 when the government was introducing IPM technology through the National IPM Programme. The data were compiled from a number of sources such as the Annual Report of Pest and Disease Monitoring and Forecasting, the Annual Report of the Provincial Agricultural Office and statistical data published by Provincial and District Statistical Offices. Types of data analysed were pesticide use in one year, rice-planted area, number of IPM farmer field schools, average price of rice, average price of pesticides and aggregate pest infestation. Pest infestation included rice stem borers *Scirpophaga* spp., *Chilo* spp. and *Sesamia inferens* (Walker); rice bugs *Leptocorisa* spp.; rice brown planthopper *Nilaparvata lugens* (Stål) and rice green leafhopper *Nephotettix* spp. These pests are considered important pests of rice in Indonesia.[17] A summary of the statistics for these variables is given in Table 1.

2.2 Pesticide demand functions

The idea underlying the analysis was based on the fact that the nature of the relationship between pesticides and pest infestation could be in two forms. One form is that pesticide demand will increase when pest infestation increases. This is mainly based on a pest control principle stating that pesticides will be used whenever pest infestation exists.[18] Another form could be that the pest infestation depends on the use of pesticides. This is also due to the fact that pest infestation declines when the application of pesticides increases.

Pesticide demand has unique characteristics compared with other common productive agricultural inputs such as land, labour, fertilizers, seeds, etc. Firstly, pesticides are a protective input that affects production indirectly. The direct impact of pesticides is to minimize crop loss due to pest infestation. Secondly, the effect of pesticides is uncertain because it depends on the nature of the pest infestation.[19] A significant effect will only be observed when pest infestation exists. In other words, the use of pesticides will be ineffective when pest infestation does not exist. Based on the above arguments, the pesticide demand function should be estimated in order to reach the potential production. Models need to be developed in order to find the most appropriate demand function for pesticides. Two models of impact of technology have been employed, namely direct and indirect impacts. The direct impact is based on a recursive model, whereas the indirect impact is based on a simultaneous model. By using recursive and simultaneous equation models, the impact of IPM technology on the demand for pesticide can be identified.

The recursive demand model is based on the assumption that IPM technology not only is able to control the pest but also affects the production process, and so pesticides are considered as an input factor. The IPM technology changes the marginal product of pesticides. In this case, the use of pesticides will be influenced by the level of pest infestation, the relative price of pesticide to that of rice and the planted area of rice. By using this assumption, it is expected that IPM technology will determine both the pest infestation and pesticide use. Then the following equations are formulated:

$$I = \phi_{10} + \phi_{11} \ln T + u_1 \quad (1)$$

$$X = \phi_{20} + \phi_{21} I + \phi_{22} \ln T + \phi_{23} P + \phi_{24} A + u_2 \quad (2)$$

where I is the pest infestation; X is the pesticide use; T is the number of IPM-trained farmers (and thus $\ln T$ represents growth in IPM technology); $P = P_X/P_Y$ is

Table 1. Summary statistics for variables

Variable	Mean	Std Dev.	Min	Max
Pest infestation (%)	5.38	2.89	0.37	11.57
Pesticide use (kg)	754.97	659.06	50.30	2484.00
Price of pesticides (Rp)[a]	6931.38	1696.60	5237.75	11 229.48
Price of rice (Rp)[a]	458.85	216.56	263.25	1147.00
IPM farmers' field school (unit)	161.72	111.42	21.00	358.00
Rice-sown area (thousand hectare)	24.46	15.75	5.41	50.55

[a] Rp = Indonesian Rupiah, 1 \$US ≈ Rp 9250.

the relative price of pesticide (P_X) to price of rice (P_Y); and A is the rice-sown area. Since the error terms u_1 and u_2 are assumed to be uncorrelated, in the recursive model the demand function (2) can be directly estimated.[20]

The simultaneous demand function is constructed by assuming that IPM technology does not influence the production process, so that the marginal product of pesticide is not changed. IPM technology is merely considered to be a controlling agent together with pesticides. In this case, the use of pesticides will be influenced by the level of pest infestation, the relative price of pesticide to that of rice and the planted area of rice. Pesticide use is dependent on pest infestation because of a new plant protection strategy where pesticides are no longer used regularly but will be used if there is pest infestation exceeding the economic threshold.[18] By using this assumption, it is expected that the pest infestation will be affected not only by the use of pesticides but also by the IPM technology. Based on the above idea, two structural equations are formulated as follows:

$$I = \alpha_0 + \alpha_1 X + \alpha_2 \ln T + u_1 \qquad (3)$$

$$X = \beta_0 + \beta_1 I + \beta_2 P + \beta_3 A + u_2 \qquad (4)$$

The structural equations are simultaneous, so they cannot be estimated directly. To cope with the problem, a two-stage least-squares (2SLS) estimation is used.[20] The first step is to estimate reduced-form equations obtained by solving for I and X from Eqn (3) and Eqn (4). The reduced-form equations are as follows:

$$\hat{I} = a_{10} + a_{11} \ln T + a_{12} P + a_{13} A \qquad (5)$$

$$\hat{X} = a_{20} + a_{21} \ln T + a_{22} P + a_{23} A \qquad (6)$$

Using the above equations, the estimated values of $\hat{I}$ and $\hat{X}$, which are independent of each other, can be obtained. The second step is to estimate the structural demand function by using the following equations:

$$I = \delta_0 + \delta_1 \hat{X} + \delta_2 \ln T + v_1 \qquad (7)$$

$$X = \gamma_0 + \gamma_1 \hat{I} + \gamma_2 P + \gamma_3 A + v_2 \qquad (8)$$

It is expected that $\delta_2 < 0$ and $\gamma_1 > 0$. The impact of IPM technology on pesticide use is expressed as

$$\frac{\partial X}{\partial \ln T} = \frac{\partial X}{\partial I} \cdot \frac{\partial I}{\partial \ln T} = \gamma_1 \cdot \delta_2 < 0 \qquad (9)$$

This indicates that IPM technology will indirectly reduce pesticide use by the following mechanisms. Firstly, the technology should be able to lower the level of pest infestation. Secondly, the reduction in pest infestation will lead to a fall in the use of pesticides. Note that the price of fertilizers is not included in the models. This relies on the assumption that fertilizers and pesticides are technically independent of each other, meaning that they are not substitutable and are not complementary inputs in the production process.

Both models are estimated using cross-sectional time-series feasible generalized least-squares (FGLS) regressions under the condition of which panels are heteroskedastic with cross-sectional correlation to cope with the problem of autocorrelation.

3 RESULTS AND DISCUSSION

Firstly, the use of pesticides during the dissemination of IPM technology is depicted in Fig. 1. It can be seen that there is a sharp fall in the use of pesticides at the beginning of the period. This sharp fall in pesticide use is probably caused by the elimination of pesticide subsidy. Thereafter, pesticide use tends to decrease moderately. The average fall in the use of pesticides could be jointly influenced by the elimination of the subsidy and the dissemination of IPM technology. The joint effect of these two factors can be analysed using demand models for pesticides.

Table 2 presents the demand for pesticides estimated using the recursive model. Each variable (relative price of pesticides, level of pest infestation, growth in IPM technology and rice-planted area) significantly influences the demand for pesticides. The relative price of pesticides has a significant effect in reducing the demand for them. It is theoretically justified that farmers are rational. As the marginal product of pesticides declines, farmers will respond by reducing the amount of pesticides used until the marginal product of pesticides equals the relative price of pesticides. Pest infestation shows a significant effect on the increase in pesticide demand. This is still consistent with the IPM concept that pesticides will be applied when serious pest infestations exist.

Dissemination of IPM technology has significantly reduced the amount of pesticide use. This implies that the dissemination of IPM technology has a positive impact on reduction in pesticide use. This is interesting because, although the IPM FFS for rice covers only a small portion of farmers compared with the total number of farmers, it has a significant impact on the decrease in pesticide use. This is an indication that

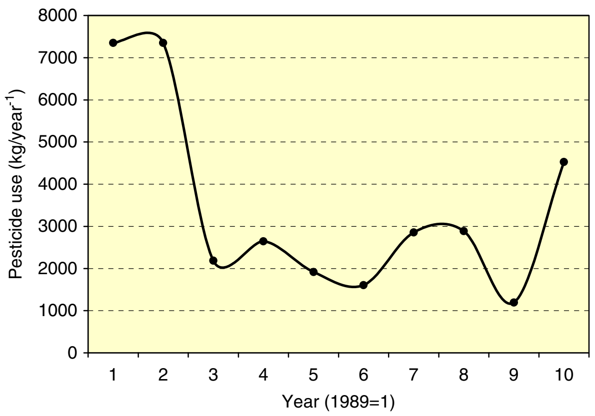

Figure 1. Pesticide use in the study area.

Table 2. Recursive model of demand function for pesticides

Variable[a]	Coefficient	Standard error	*z*-value[b,c]
Intercept	1708.66	572.98	2.98***
Relative price	−57.86	25.23	−2.29**
Pest infestation	82.38	16.43	5.01***
Growth in IPM technology	−490.52	108.68	−4.51***
Rice-sown area	10.56	3.86	2.74***
Likelihood	−262.19		
Chi-squared	104.11***		
Observation	36		

[a] Dependent variable is pesticide use.
[b] *z*-value is the ratio of the estimated coefficient to the standard error. When the *z*-value is greater than *z*-critical, the estimated coefficient is significantly different from zero.
[c]*** significant at 1%; ** significant at 5%.

IPM technology has been widely adopted by farmers and that diffusion of IPM technology among farmers does occur.

The rice-sown area has significantly affected the demand for pesticides. This is reasonable because land represents economies of scale. When the scale of rice agriculture increases, the use of pesticides also increases.

Using the reduced forms of the simultaneous demand equations, the estimated pest infestation $\hat{I}$ and pesticide use $\hat{X}$ for a given period of analysis and different districts can be obtained (Table 3). These estimated values, which have been endogenous effect free, are then used to estimate the relationship between pesticide use and pest infestation. Such a relationship represents a demand function for pesticides, as the price of pesticides is involved.

Table 4 indicates that pest infestation significantly increases along with increase in pesticide application. This seems to be a strange phenomenon – pesticides do not reduce pest infestation. In the case of Indonesian rice agriculture, however, this has always been reported as pest resurgence.[9] Unexpectedly, IPM technology also has a significant effect in increasing pest infestation, indicating that IPM is not a technique for controlling pest infestation.

Table 5 shows that the increase in pesticide use is significantly caused by the increase in pest infestation. This is understandable because, under IPM, farmers will apply pesticides only when severe pest infestation exists, in contrast to the conventional notion of farmers that the scheduled application of pesticides is a primary measure for crop protection regardless of the level of pest infestation.

As one of the conditions by which IPM technology should be able to reduce pest infestation does not hold, the simultaneous equation model of pesticide demand does not apply. In addition, it can be seen from the relationship between pesticide use and pest infestation (Tables 4 and 5) that the demand for

Table 4. Impacts of pesticide and IPM technology on pest infestation (second stage)

Variable[a]	Coefficient[b]	Standard error	*z*-value[b]
Intercept	0.0669	2.2637	0.03
Pesticide use (predicted)	0.0036	0.0015	2.45**
Growth in IPM technology	1.6943	0.8120	2.09**
Likelihood	−81.39		
Chi-squared	6.00**		
Observation	36		

[a] Dependent variable is pest infestation.
[b]** significant at 5%.

Table 5. Simultaneous model of demand function for pesticides (second stage)

Variable[a]	Coefficient[b]	Standard error	*z*-value[b]
Intercept	−6035.10	1310.06	−4.61***
Pest infestation, (predicted)	188.44	40.98	4.60***
Relative price	857.23	182.84	4.69***
Rice-sown area	−30.40	11.38	−2.67***
Likelihood	−270.5572		
Chi-squared	31.87***		
Observation	36		

[a] Dependent variable is pesticide use.
[b]*** significant at 1%.

Table 3. Regression results of reduced forms (first stage)

	Dependent variables			
	Pest infestation		Pesticide use	
Independent variable	Coefficient[a]	*z*-value[a]	Coefficient[a]	*z*-value[a]
Intercept	10.4245	2.89**	2901.1750	3.61***
Relative price	−0.3270	−1.92*	−91.8690	−2.47**
Growth in IPM technology	−0.8116	−1.24	−695.7251	−4.69***
Rice-sown area	0.0516	1.48*	13.8411	2.49**
Likelihood	−81.38		−270.56	
Chi-squared	5.98*		31.87***	
Observation	36		36	

[a]*** significant at 1%; ** significant at 5%; * significant at 10%.

pesticides in rice farming is opposed to the law of demand. Demand for pesticides increases as the price rises. This could arise if current pesticides were ineffective and farmers tended to buy more expensive pesticides with the expectation of being able to reduce pest infestation. It can also be seen that an increase in rice-sown land leads to a decrease in demand for pesticides. This is also an unlikely phenomenon, and could only have arisen because farmers were tending not to use pesticides because they were ineffective. Thus, both of these uncommon phenomena could only be explained by current pesticides being ineffective in reducing pest infestation.

Thus, the decrease in the use of pesticides in rice agriculture can logically be explained by the recursive demand model, but this is not the case with the simultaneous model, which leads to several improbable scenarios. Recursive demand analysis implicitly shows that IPM technology improves the process of rice production. The same marginal product of pesticides can be achieved with a lower level of pesticide use. In other words, pesticides have become more efficient as farmers have understood how they can be appropriately used. IPM technology is not considered to be a pest control technique because it does not directly reduce pest infestation.

4 CONCLUSION

Aggregate regional data have been used to analyse the impact of IPM technology in Indonesia. By using a recursive model of demand for pesticides, it is found that the IPM technology reduces the application of pesticide. Dissemination of IPM technology has significantly reduced the amount of pesticide use, which implies that the introduction of IPM has a positive impact on pesticide use reduction in rice farming. Although IPM farmer field schools (FFSs) for rice cover only a small portion of the area, increase in IPM FFSs for rice has significantly reduced the use of pesticides. It could be that IPM technology has been adopted by FFS farmers and diffused from them among others.

According to the simultaneous demand equations, IPM technology does not reduce the application of pesticide, because this technology is not able to reduce the intensity of pest infestation. However, this approach leads to a number of inconsistencies. In particular, the demand for pesticides appears to be counter to the law of demand, as an increase in the relative price of pesticides leads to a rise in the amount of pesticide use.

In neither model is IPM technology considered a pest control technique, rather it is considered to be a production technology that improves the efficiency of all input factors including pesticides.

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