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How much is too much? Quantifying pesticide overuse in vegetable production in Southeast Asia

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A B S T R A C T

This paper quantifies the extent of pesticide overuse in vegetable production systems in Southeast Asia. Pesticide overuse was defined as levels of use in excess of an economic (profit-maximizing) optimum. A production function with an exponential damage abatement term was estimated. Data come from a representative sample of 1000 farmers producing leaf mustard and yard-long bean in Cambodia, Laos and Vietnam. The results show that 100% of the sampled farmers in Vietnam, 73% in Cambodia and 59% in Laos overused pesticides. Pesticide expenditure in excess of the economic optimum was 96% for Vietnam, 92% for Cambodia, and 42% for Laos. Pesticide overuse was positively associated with men in charge of pest management decisions, farmers seeking advice from pesticide sellers and a strong belief that pesticides are effective. It was negatively associated with the use of non-chemical methods of pest control. These results imply that farmers in Southeast Asia are spraying excessively and inefficiently and could increase their profits by applying fewer pesticides.

1. Introduction

High and rising levels of agricultural pesticide use in developing (as well as developed) countries poses enormous challenges to the health of farm families, consumers, and the environment (Akter et al., 2018; Bonner and Alavanja, 2017; Popp et al., 2013). Pesticide exposure is linked to various short-term and chronic health hazards including cancer (Kim et al., 2017; Wesseling et al., 1997). The health of farm workers in developing countries is particularly at risk because of high levels of occupational exposure. Consumers are also increasingly concerned about the safety of the food they eat as studies regularly find pesticide residues above acceptable levels (Wanwimolruk et al., 2015, 2016).

The extent of the problem is large in Southeast Asia, and particularly in vegetable production systems (Hoi et al., 2009b; Migheli, 2017; Riwthong et al., 2015; Schreinemachers et al., 2014). A study for Thailand showed that the health and environmental costs of pesticide use is about five times higher for a hectare of vegetables than for a hectare of rice (Praneetvatakul et al., 2013). Another study on vegetable production in Thailand estimated that 79% of the quantity of pesticides applied was in excess of the economic optimum (Grovermann et al., 2013).

Only very few studies have provided such quantitative estimates of pesticide overuse in vegetable production systems. The present study therefore extents this analysis to vegetable production systems in Cambodia, Laos and Vietnam with the objective to provide quantitative estimates of pesticide overuse and to identify farm-level determinants of it. Such information is important to inform policy makers. Existing policies in Southeast Asia, and elsewhere, tend to treat chemical pesticides like any other agricultural input—for instance, by not applying a sales tax or import tax or

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making it easy to import and trade pesticides; such policies can encourage overuse (Schreinemachers et al., 2015; Schreinemachers and Tipraqsa, 2012).

The paper starts by describing the damage abatement approach used to quantify pesticide overuse and the regression analysis used to identify its determinants. It then describes the data set we collected in Cambodia, Laos and Vietnam. The results section quantifies overuse in terms of the percentage of the total value of pesticides used in excess of the economic optimum and identifies drivers of overuse. The discussion puts these results in a wider context and describes the strengths and weaknesses of the taken approach. The paper ends with a conclusion and policy recommendation.

2. Material and methods

2.1. Quantification of overuse

From an economic point of view, pesticide overuse is expressed as the application of pesticides in excess of the economic optimum. This optimum is defined as the quantity at which the marginal returns equal marginal costs: meaning that for a farmer producing at the optimum, every additional dollar spent on pesticides would yield less than a dollar in revenues (that is, overuse) while every dollar spent less on pesticides would reduce revenues by more than a dollar (that is, underuse).

This economic optimum is farmer-specific, depending on prices and resource endowments, and can be calculated from the coefficients of a production function. Following Lichtenberg and Zilberman (1986), we specified pesticide use of farmer i as a damage control agent $G(X_i)$ and all other inputs ($j = 1, \ldots, m$) as regular productive inputs $F(Z_{ij})$ using a Cobb-Douglas functional form:

$$Y_i = F(Z_{ij})G(X_i) \quad (1)$$

where Y_i is the output value for farmer i, Z_{ij} is the value of regular input j (land, labor, seed, fertilizer) applied by farmer i, and X_i is pesticide expenditures. $G(X_i)$ is a cumulative distribution function that takes on values between zero and one, representing the effectiveness of damage abatement methods to limit yield losses. Previous studies have used alternative specifications for this damage control term, such as exponential, logistic, Pareto and Weibull with the choice known to affect estimates of pesticide productivity (Lichtenberg and Zilberman, 1986). We chose the exponential specification for this study because it allows for clearly decreasing marginal returns to pesticide use (meaning that pesticide productivity is unlikely to be overestimated). This is the most commonly applied specification and previous studies have shown that it produces robust results (Pemsl et al., 2005; Skevas et al., 2012). Therefore, the following production function was estimated:

$$\ln Y_i = \alpha + \sum \gamma_i C_i + \sum_{ij} \beta_{ij} \ln Z_{ij} + \ln[1 - \exp(-\lambda_i X_i)] + \varepsilon_{ij} \quad (2)$$

In which α, γ_i, β_{ij} and λ_i are the coefficients to be estimated, and ε_{ij} is a standard normal error term. The indicator variables C_i were introduced alongside productive inputs Z_j and pesticide costs X_i to control for farm characteristics, including farm size, household size and dummies to capture structural differences between the locations covered in the survey. Crop output (Y) and pesticides (X) were both expressed in monetary terms.

For the exponential specification, the marginal value product (MVP) was calculated following Qaim and De Janvry (2005) as:

$$MVP_{ij} = F(Z_{ii})^* \lambda_i [\exp(-\lambda_i X_i)] / [(1 - \exp(-\lambda_i X_i)] \quad (3)$$

The economic optimum level of pesticide use was calculated as the point at which the MVP equals unity. The MVP of pesticides is observation-specific because it depends on the level at which all other inputs are applied. It is therefore possible that two farmers using the same quantity of pesticides will have different levels of overuse.

Overuse and underuse were thus calculated as the difference between the observed quantity of pesticide use X_a and the optimal quantity X^*, which is consistent with previous studies (Grovermann et al., 2013; Sexton et al., 2007; Zhang et al., 2015). The MVP cannot be calculated for farmers who did not use pesticides. Their quantity of underuse was estimated using an MPV value based on the predicted values for $F(Z_{ii})$ averaged over all non-zero observations. This average lies at US$ 953 for leaf mustard and US$ 3125 for yard-long bean."

2.2. Determinants of pesticide overuse

Determinants of pesticide overuse were identified using a linear regression model with the quantity of overuse as the dependent variable. Our data had a large number of observations with zero pesticide use, which made it unsuitable to apply a standard regression model as the outcomes would be biased. The correct estimator depends on the reason for the zeros in the data. Humphreys (2013) described three explanations: the zeros represent the true choice of the farmers, the zeros represent either missing or non-response outcomes, or the zeros represent a decision that the farmer had no control over for some reason. The first explanation is the most plausible for our data because the use of pesticides is very common in our study sites and the decision not to spray is therefore the result of farmers' choice.

In the context of pesticide overuse, we assumed that the decisions whether and how much to apply are made simultaneously. This then allows the use of a linear hurdle model as set out by Humphreys (2013) and originally proposed by Cragg (1971). In this model, the choice of individuals results in either a zero quantity or a positive quantity of use, with a range of factors determining the choice. The model is formally described as:

$$S_i = \begin{cases} 1 \;\; if \;\; Z_i\gamma_i + \in_i > 0 \\ \;\; 0 \;\; otherwise \end{cases} \quad (5)$$

in which S_i is the selection variable, which equals 1 if overuse is observed and zero otherwise. If $S_i = 1$, the following linear outcome model is estimated:

$$Overuse = \beta_i X_i + u_i \quad (6)$$

where X_i is a vector of explanatory variables, β_i is a vector of coefficients, and u_i is a standard normal error term. Using this model, the regression results are interpreted as the effect of a variable X on the quantity of overuse conditional on the farmer overusing pesticides. A positive level of overuse is observed if the farmer has the potential to apply pesticides above the optimum and actually does so. Different from the Heckman selection model (Heckman, 1979), in which zeros are not affected by the decision to use, observed zero values are the result of either selection or consumption decisions and farmers with potential overuse may have zero pesticide expenditures. The linear hurdle model is thus appropriate for examining determinants of overuse. A relatively large number of explanatory variables was tested. Crop experience, training and knowledge of pests as well as alternative pest management methods, and high pesticide prices were all hypothesized to have a negative association with overuse. Advice from pesticide sellers and belief in the effectiveness of pesticides are hypothesized to increase overuse.

2.3. Data and analysis

Data come from a survey conducted in Cambodia, Laos, and Vietnam among farmers producing leaf mustard (*Brassica juncea* (L.) Czern. et Coss.) or yard-long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdc.). A stratified random sampling strategy was used to select a sample of farmers representative for the main production areas and main production season per country. Two provinces per country were selected based on secondary data on the area planted. For each province, the main production districts were identified in consultation with local extension officers, and a list was made of all villages where the crop was produced. This list was randomized and visited in descending order. For each village a list was made of all farmers who had produced the crop in the most recent season. Ten farmers were randomly selected from this list per village, though sometimes fewer farmers were available. Additional villages were visited until there were 150 completed questionnaires per crop (200 in the case of Cambodia). The total sample size was 1000 households spread over 93 villages in 31 districts in 3 countries. There was no overlap between the samples of bean and mustard farmers.

Data were collected using a structured questionnaire from July to October 2015. The questionnaire was drafted in English and then translated into Lao, Khmer and Vietnamese and tested with farmers before the start of the data collection. Minor adjustments were made to tailor the questions to each country. Interviews took about 90 min on average. At the start of the interview, enumerators explained the purpose and contents of the questionnaire and ensured confidentiality of the data provided. All respondents were explicitly asked for their verbal consent to participate. Answers were recorded on paper questionnaires and entered in a customized MS Excel workbook after the interviews. The anonymized data are available from the authors upon request.

The data included information about crop output (quantities and values), and input use including pesticides. Pesticide use was quantified by asking for the frequency of pesticide application and the average amount applied per time as well as for the total expenditures on pesticides. The questionnaire also tested respondents' ability to distinguish between arthropods that damage crops and those that are beneficial, as well as data on spraying practices and attitudes about pesticides. A previous study analyzed the same data set and described farmers' knowledge, attitudes, and practices regarding agricultural pest management and synthetic pesticide use (Schreinemachers et al., 2017).

Data were analyzed using the statistical software STATA. Local currency values were converted to US dollars using official exchange rates and local area units were converted to hectares. The production function analysis was done separately for each crop as well as for the pooled data while introducing a crop dummy. The analysis of determinants of pesticide overuse was done using the pooled data. Outliers were identified for the pesticide price variable by tabulation. Three observations that were 5 times higher than the next highest value were deleted. A further two observations were dropped because of missing values. The eventual sample therefore consisted 995 farm-level observations.

3. Results

3.1. Summary statistics

Summary statistics show that the average quantity of pesticide use per hectare is much higher in Vietnam and Cambodia than in Laos, but output per hectare is also much higher in these two countries (Table 1). The range of values for inputs and outputs in our data is generally large. However, standard deviations in the Vietnam data are much lower than in those in the Cambodia and Laos data. This is most likely explained by the fact that the Vietnam data were collected from a relatively small geographical area in peri-urban districts of Hanoi.

3.2. Estimates of pesticide overuse

The estimated coefficients for the production functions are shown in Table 2. Positive coefficients indicate a positive association between an input and the output per hectare per cropping cycle while negative coefficients indicate a negative association. The goodness of fit of the model was 0.65 for leaf mustard and the pooled data and 0.59 for yard-long bean. The country dummies are large and significant ($p < 0.01$) across the three models, pointing at substantial differences in land productivity between the countries.

For the logged variables, the coefficients can be interpreted as marginal effects (meaning the % change in output resulting from a 1% increase in input). Fertilizer and seed expenditures were significantly ($p < 0.01$) associated with greater output values with seed expenditures having the largest effect. All productive inputs had the expected positive effect on output and most were significant. However, labor costs were only significant for leaf mustard, not for yard-long bean and other input costs were only significant for yard-long bean.

The damage control term (λ) was positive and significant for both crops ($p < 0.01$ for leaf mustard and the pooled data and $p < 0.05$ for yard-long bean), but the size of the coefficient was higher for leaf mustard. Fig. 1 exhibits the damage abatement effect by levels of pesticide expenditure. For both crops the abatement function levels off at a relatively low pesticide expenditure. At a pesticide expenditure of about US$ 20 per hectare, the abatement is close to 100%. Compared to a mean pesticide expenditure of US$ 172 for leaf mustard and US$ 249 for yard-long bean this provides a first indication of substantial overuse.

The marginal value product of pesticides was calculated for each farmer in the sample. It was below unity (indicating overuse) for 81.5% of the observations for leaf mustard and for 90.0% of the observations for yard-long bean. The average marginal value product was US$ 7.8 for leaf mustard and US$ 6.3 for yard-long bean.

For each farmer we calculated the profit-maximizing level of pesticide expenditure based on the estimated regression coefficients and observed resource amounts. This optimum value was then compared to the actual pesticide expenditure of the farmer to determine overuse/underuse. The results show that the average optimum value was about US$ 11.2/ha for leaf mustard and US$ 21.7/ha for yard-long bean (Table 3). In Vietnam, 100% of the sampled farmers were above this optimum and thus overused pesticides. In Cambodia, about 73% of the farmers overused pesticides for both vegetables, while in Laos this was 75% for yard-long bean, but only 38% for leaf mustard.

Pesticide expenditures in excess of the economic optimum per cropping cycle were the smallest for vegetable farmers in Laos at US$ 33.3/ha for the pooled data, which equates to 42% of total pesticide expenditure (Table 3). Vegetable farmers in Cambodia overspent about 92% on pesticides (US$ 218.5/ha/cycle) while their counterparts in Vietnam could save about 96% of their pesticide expenditures (US$ 329.0/ha/cycle) by optimizing pesticide use.

3.3. Determinants of pesticide overuse

In the analysis of factors associated with pesticide overuse, five observations with unrealistic pesticide prices were removed.

Table 1
Summary statistics of variables used in the production function analysis, means with standard deviations in italics.

Variables	Leaf mustard			Yard-long bean		
	Cambodia	Laos	Vietnam	Cambodia	Laos	Vietnam
Crop revenues (1000$/ha/cycle)	0.47	0.77	4.51	5.05	2.99	7.84
	5.38	*0.83*	*2.30*	*5.97*	*3.19*	*2.49*
Labor costs (1000$/ha/cycle)	0.36	0.15	0.29	0.19	0.66	0.59
	0.77	*0.12*	*0.11*	*0.25*	*0.43*	*0.16*
Seed costs (1000$/ha/cycle)	0.13	0.03	0.10	0.18	0.11	0.23
	0.28	*0.03*	*0.06*	*0.19*	*0.11*	*0.10*
Fertilizer costs (1000$/ha/cycle)	0.58	0.10	0.49	0.37	0.44	0.81
	1.29	*0.23*	*0.25*	*0.48*	*0.62*	*0.44*
Pesticide cost (1000$/ha/cycle)	0.36	0.03	0.21	0.25	0.09	0.48
	0.59	*0.04*	*0.17*	*0.48*	*0.10*	*0.29*
Other costs (1000$/ha/cycle)	0.57	0.16	0.34	1.00	0.62	1.16
	0.81	*0.34*	*0.28*	*1.04*	*0.63*	*0.45*
Household size (persons)	5.02	4.65	4.27	5.00	4.80	4.18
	1.89	*1.65*	*1.49*	*1.61*	*1.35*	*1.35*
Farm size (ha)	0.33	0.51	0.29	0.52	0.52	0.32
	0.44	*0.56*	*0.29*	*0.61*	*0.44*	*0.28*

Table 2
Production function estimates with exponential damage control specification.

Independent variables	Leaf mustard		Yard-long bean		Pooled data	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant term	4.211***	13.15	3.792***	8.38	3.534***	13.38
Labor (ln, $/ha/cycle)	0.099**	2.36	0.066	1.21	0.165***	4.80
Seeds (ln, $/ha/cycle)	0.343***	8.01	0.408***	8.19	0.373***	11.23
Fertilizers (ln, $/ha/cycle)	0.0843**	2.39	0.154***	3.79	0.117***	4.57
Other inputs (ln, $/ha/cycle)	−0.001	−0.02	0.110**	2.57	0.016	0.67
Pesticide ($/ha/cycle) damage control term (lambda)	0.548***	2.74	0.311**	2.03	0.585***	2.95
Household size (persons)	0.033	1.55	−0.053**	−2.24	−0.003	−0.19
Farm size (ha)	−0.102	−1.25	0.177**	2.23	0.060	1.08
Cambodia (=1)	1.065***	9.84	0.566***	4.27	0.915***	11.33
Vietnam (=1)	1.167***	9.61	0.761***	7.20	0.998***	12.77
Yard-long bean (=1)					0.069	1.25
N	421		422		843	
Adjusted R^2	0.654		0.588		0.646	

Notes: Dependent variable is output in ln ($/ha/cycle). Significance levels: *p < 0.10, **p < 0.05, ***p < 0.01.

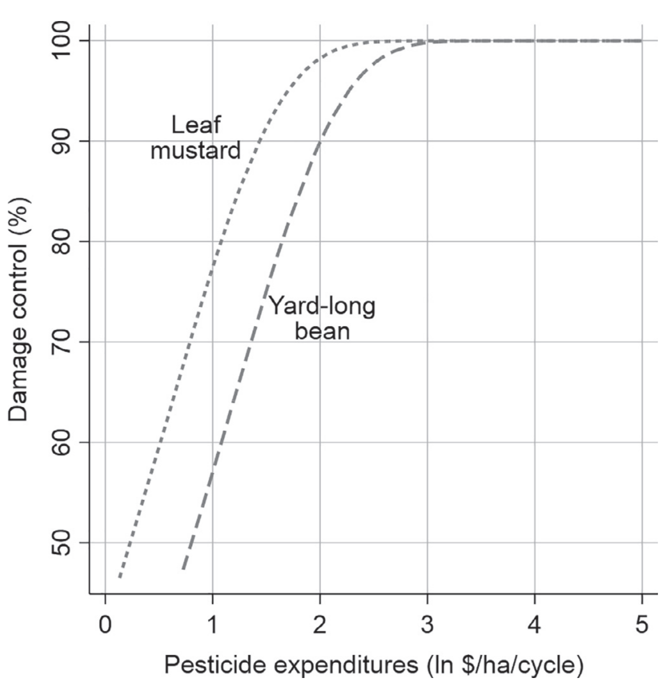

Fig. 1. Damage abatement effect of chemical pesticides at different application rates for leaf mustard and yard-long bean in Cambodia, Laos and Vietnam, 2015.

Country dummies for Cambodia and Laos as well as a crop dummy for leaf mustard were added to control for the structural variations in the data.

Table 4 shows the regression results from the double hurdle model. The first stage identifies the type of farmers overusing pesticides. It shows that the likelihood of zero overuse is higher if the person in charge of pest management is a woman, if the farmer had previous training on good agricultural practices, and if the farmer received advice from extension agents. The results also show that the use of biopesticides, rotation with non-host crops, the use of insect nets, higher pesticide prices, and hand picking of insects were associated with a reduced likelihood of overuse. Conversely, an increased likelihood of pesticide overuse was associated with advice from pesticide retailers, a belief that pesticides are effective, the total number of trainings attended, and better knowledge about insect pests. The first two factors are in-line with expectations, while the last two appear to contradict expectations.

The second stage analyzed the extent of overuse for those farmers that overused. Farmers with a longer experience producing the crop had significantly lower levels of pesticide overuse than farmers with less experience. The use of insect nets was also associated with significantly lower overuse, but other pest management methods had no significant effect.

Table 3
Estimates of pesticide overuse in leaf mustard and yard-long bean production in Cambodia, Laos, and Vietnam, 2015.

Crop and country	Optimal pesticide use (US$/ha/cycle)	Estimates of pesticide overuse			
		% of farmers overusing	Overuse(US$/ha/cycle)	Overuse(US$/farm)	% of pesticide expenditures that is overused
Leaf mustard:					
-Laos	10.58	37.6	7.13	1.67	12.5
-Cambodia	11.35	72.5	262.25	15.64	93.5
-Vietnam	11.73	100.0	194.49	5.55	93.4
-Combined	11.21	69.3	160.77	8.23	65.6
Yard-long bean:					
-Laos	20.75	74.8	60.16	13.36	59.9
-Cambodia	21.24	68.5	169.04	16.90	85.4
-Vietnam	23.02	100.0	455.42	16.64	95.3
-Combined	21.65	80.0	227.30	16.76	80.1
Pooled data:					
-Laos	12.82	58.7	33.32	7.22	41.5
-Cambodia	13.43	72.5	218.51	16.77	91.9
-Vietnam	13.38	100.0	328.95	12.78	96.2
-Combined	13.23	76.6	196.08	12.71	76.9

Table 4
Double hurdle estimation of drivers of pesticide overuse.

Covariate	Stage 1: Pesticide overuse (Yes/No)		Stage 2: Pesticide overuse (Ln, kg/ha)	
	Coefficient	SE	Coefficient	SE
Farm size (ha)	−0.194**	−0.097	−0.069	−0.119
Household size (persons)	0.01	−0.034	−0.056*	−0.029
Education (high = 1)	0.114	−0.122	0.091	−0.093
Crop experience (years)	0.001	−0.006	−0.009**	−0.004
Plot size (ln, ha)	−0.093	−0.059	0.568***	−0.053
Pest manager (female = 1)	−0.231**	−0.115	−0.127	−0.087
Training (number)	0.391*	−0.206	−0.07	−0.15
IPM Training (yes = 1)	−0.227	−0.214	0.021	−0.112
GAP training (yes = 1)	−0.464*	−0.26	−0.259	−0.167
Other training (yes = 1)	0.159	−0.218	0.176	−0.111
Advice from friend (yes = 1)	−0.119	−0.13	0.166	−0.106
Advice from lead farmers (yes = 1)	0.076	−0.186	0.042	−0.145
Advice from extension service (yes = 1)	−0.484**	−0.208	−0.054	−0.121
Advice from pesticide seller (yes = 1)	0.385***	−0.134	0.362**	−0.154
Belief that pesticides are effective (index)	0.010***	−0.003	0.012***	−0.002
Concern about adverse health effects (index)	0.005	−0.003	0.000	−0.003
Knowledge about arthropods (index)	0.006*	−0.003	0.005*	−0.002
Knowledge about insect pests (index)	0.024***	−0.005	0.001	−0.003
Pesticide price (US$/kg)	−0.006***	−0.002	−0.006***	−0.002
Use of biopesticides (yes = 1)	−0.676***	−0.171	0.047	−0.12
Rotation with non-host crop (yes = 1)	−0.743***	−0.163	0.174	−0.132
Use of insect nets (yes = 1)	−0.386*	−0.21	−0.312**	−0.141
Hand picking of insects (yes = 1)	−0.338***	−0.131	−0.106	−0.1
Cambodia (yes = 1)	−6.916	.	−0.171	−0.172
Laos (yes = 1)	−7.680	.	−1.157***	−0.259
Mustard (yes = 1)	−0.587***	−0.121	−0.456***	−0.094
Constant	3.898***	−0.101	3.418***	−0.445
N	995		763	
Adjusted R2			0.167	
Ln sigma			0.111***	

Notes: Robust standard errors shown in brackets; Significance levels: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

4. Discussion

4.1. Reflection on the results

Our results provide evidence of widespread pesticide overuse in vegetable production systems in Southeast Asia. It suggests that chemical pesticide use can be reduced substantially without negative effects on farmers' profits from vegetable production. The largest level of overuse was observed in Vietnam with 100% of vegetable farmers there found to be overusing pesticides and 96% of pesticide expenditures above the profit-maximizing optimum. The second largest level was observed for Cambodia, with 73% of the sample of vegetable farmers overusing pesticide and 92% of pesticides expenditures above the optimum. The lowest level of overuse was observed for Laos, with 59% of the sampled vegetable farmers spending more on pesticides than needed and 42% of pesticides expenditures above the optimum. These differences between countries reflect average national levels of pesticide use documented in Schreinemachers et al. (2017).

These results confirm those of earlier studies in Asia that used similar methods: Grovermann et al. (2013) estimated pesticide overuse to be 79% for vegetable production in Thailand, and Jha and Regmi (2009) estimated pesticide overuse in vegetable production in Nepal to be 70%. It is important to note that high levels of pesticide overuse are not restricted to developing countries. A recent study for France, for instance, estimated that pesticide use can be reduced by 42% without negative effects on productivity or profitability (Lechenet et al., 2017).

Quantitative estimates of pesticide overuse are an important indicator of pesticide misuse but are only a partial indicator of pesticide risk. It is also important to consider the relative toxicity and environmental impact of the pesticides that are used and the level of exposure as determined by the methods of handling and application. Such factors were not included in our study.

Several previous studies show that farmers in Southeast Asia select broad spectrum pesticide products with known toxicity to humans. For instance, it was shown for Cambodia that vegetables sold in markets were contaminated with high levels of organochlorine pesticides (Wang et al., 2011) as well as organophosphate and carbamate pesticides (Neufeld et al., 2010), although there is evidence for Vietnam that vegetable farmers have slowly moved from highly toxic to less toxic pesticide substances over time (Hoi et al., 2009a). Using the same dataset as used for this study, Schreinemachers et al. (2017) showed that most applicators reported a range of pesticide poisoning symptoms experienced after spraying. There is therefore a clear situation of pesticide misuse and high human health risk in vegetable production. These external effects are not reflected in the market price of pesticides as used in our analysis; if included, then this would result in even higher amounts of overuse.

The finding that the marginal effect of pesticide prices on overuse is small confirms that the demand for pesticides is inelastic, as shown by several other studies (Böcker and Finger, 2017; Finger et al., 2017). Nevertheless, some authors have argued that if the revenues of a pesticide tax would be re-invested in the development and extension of alternative pest management methods then the effect may be more substantial (Grovermann et al., 2017). Some studies have found that pesticide use is positively associated with higher levels of risk aversion (Praneetvatakul et al., 2016), but our study did not collect data on this.

4.2. Strengths and weaknesses of the study

This paper provided the first quantitative assessment of pesticide overuse in vegetable production systems in Cambodia, Laos and Vietnam. It is also one of few papers that analyzed determinants of pesticide overuse in a second stage of the analysis (an exception being Wang et al., 2018).

The method applied is standard and well-accepted in the literature. The strength of the method used is that it considers substitution effects between various inputs and recognizes that the optimum level of pesticide use is farmer-specific. The use of the damage abatement term is known to avoid overestimating pesticide productivity (Sexton et al., 2007). Furthermore, the method is parsimonious in its data requirement and the optimum is objectively defined in terms of a profit maximizing principle.

It is important to bear in mind that the data are based on surveys and not on the actual measurement of the pesticides used. Such survey data have a high degree of measurement error, as farmers have difficulties recalling how much pesticide they used on a particular crop. This is shown by the high standard deviations of the means. It is also possible that some farmers may underestimate the actual amount applied if they feel that they were using too much (called social desirability bias), but we had the impression that farmers generally tried to give honest answers.

On the downside, the method does not use data on pest pressure or pest infestation levels. Norwood and Marra (2003) wrote that the absence of such information may underestimate pesticide productivity. In our defense, good indicators of pest pressure are difficult to obtain and most spraying is done for preventative rather than curative purposes, so farmers tend to spray irrespective of the actual pest pressure (Grovermann et al., 2013).

4.3. Implications

It is estimated that farmers globally lose about 25% of their production to pathogens, viruses and animal pests (Oerke, 2006). Farmers try to reduce these losses by practicing crop protection and pesticides are an important tool for this. Yet the widespread use of pesticides in agriculture is problematic for they pollute the soil and water and kill non-target organisms that are essential for a healthy agricultural system. Pesticides also adversely affect the health of consumers of agricultural products and the health of farmers and their families. It is therefore important to rationalize pesticide use and implement interventions to address the issue.

Our results show the probability of a farmer overusing chemical pesticides is greatly reduced if farmers use biopesticides (−68%), rotate beans and leaf mustard with other non-host crops (−74%), use insect nets (−39%), or hand-pick insects in the field (−34%). This shows the promotion of these good agricultural practices (GAP) may be an effective strategy to reduce pesticide overuse. GAP training also had a strong association to less pesticide overuse (−47%), although the effect was only significant at a 90% confidence interval. These results are important because they demonstrate that the development of alternative pest management methods and capacities can lead to more sustainable production systems. Increased investments are needed to accelerate this process and gradually bring down levels of pesticide overuse. However, more research would be helpful to confirm the effectiveness and impact of various IPM methods on crop gross margins, pesticide use and ultimately on the long-term efficiency and resilience of cropping systems.

5. Conclusions

For a random sample of 1000 vegetable farmers across three countries in Southeast Asia, pesticide overuse was reported for 100% of the sampled farmers in Vietnam, 73% in Cambodia and 59% in Laos. Pesticides can help farmers to create economic gain, but interventions are needed to reduce the extent of pesticide overuse to protect farm workers, consumers and the environment as well as to reduce unnecessary farm expenses on inputs. The use of alternative pest management methods (biopesticides, insect nets, and rotation with non-host crops) is significantly associated with less overuse and these need to be promoted. On the other hand, the advice from pesticide shops to farmers and a widespread belief among farmers in the effectiveness and necessity of pesticides is significantly associated with more pesticide overuse. Farmers thus need alternative and unbiased sources of information to guide them in their management decisions and change ingrained beliefs.

Declaration of competing interest

The authors declare no conflict of interest.

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