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ABSTRACT

Decisions about pesticide application for pest control is an issue of major concern, but research on factors affecting decision making is limited. This study investigates jointness in farmers' decision to apply pesticides in multiple crops and socio-economic determinants of pesticide use across crops using a survey of 2083 farms from 17 districts in Bangladesh applying a multivariate Tobit model. Overall, 75.4% and 12.7% of the farmers applied pesticides in one and two crops, respectively. The decision to apply pesticides in multiple crops was found to be negatively correlated, providing evidence of jointness. Also, individual socio-economic factors exerted variable influences on pesticide use in different crops. Output price significantly increases pesticide use whereas the influence of fertilizer price and labour wage is varied. Educated farmers use significantly more pesticides in rice and oilseed. Marginal and small farmers use significantly less pesticides in wheat/maize and pulse. Policy implications include price policies to reduce fertilizer prices and engaging agricultural extension agencies and non-governmental organisations to disseminate information on specific crop combinations which will synergistically reduce pesticide use.

KEY WORDS: Chemical pest control, pesticide application, socio-economic determinants, multivariate Tobit model.

1. Introduction

Pesticide use has become an integral part of modern farming due to a host of reasons including increased pest and/or disease attack, reduced production costs by saving labour, maintenance of current yield and production levels, increased competitive advantage in agriculture, protection of food and commercial produce and improvement of nutritional value of food (Alavanja, 2009; Damalas and Eleftherohorinos, 2011; Rahman, 2013; Delcour et al., 2014). The consequence is a continuous increase in pesticide use worldwide from only one million metric ton (mmt) in 1965 to nearly 6 mmt in 2005 (Carvalho, 2006). The worldwide consumption of pesticides is about two mmt per year, out of which 45% is used in Europe alone, 25% is consumed in the USA, and 25% in the rest of the world (De, 2014). On the other hand, there is widespread claim of adverse effects from pesticides, e.g., destruction of natural enemies of pests, development of pest resistance and harm to human health and the environment (Antle and Pingali, 1994; Pimentel, 2005; Hou and Wu, 2010). Wilson and Tisdell (2001) predicted that pesticide use in the developing countries will continue mainly due to an ignorance of its sustainability, a lack of viable alternatives to pesticides, an underestimation of its short and long term costs, and weak enforcement of laws and regulations governing its use. An important element of any attempt to reduce pesticide is the communication of safety issues and management options to individual pesticide users (Huan et al., 2005). Accurate information about pesticide use, pest control alternatives, and farmers' perceptions are important in identifying problems related to decision to control pests and developing improved handling practices (Damalas and Hashemi, 2010; Hashemi and Damalas, 2011; Hashemi et al., 2012). For example, Hashemi and Damalas (2011) noted that perceptions of pesticide efficacy played a major role in the behaviour of farmers towards the use of pesticides and the adoption of alternative methods of pest control, such as, Integrated Pest Management (IPM).

Pesticide use in Bangladesh, negligible until the 1970s, has recorded a dramatic rise over the past few decades. For example, total insecticide use in Bangladesh increased from 955 mt in 1990 to 2681.89 mt in 2010 (FAOSTAT, 2013). Similarly, pesticide use rate increased from 0.26

kg of active ingredients per ha in 1977 to 1.23 kg per ha in 2002 (Rahman, 2010). In fact, pesticide use grew at an alarming rate of 10.0% per year during the period 1977–2009 (Rahman, 2015). Rahman (2013) noted that despite growth in pesticide use rate, pesticide productivity (i.e., 'gross value added from crops at constant prices' per 'kg of active ingredients of all pesticides used') has actually declined steadily at a rate of −8.6% per year during the period 1977–2009, which is a source of concern.

A limited number of studies are available on socio-economic determinants of pesticide use at the farm level in Bangladesh (e.g., Hossain et al., 1999; Rahman and Hossain, 2003; Rahman, 2003; Mahmoud and Shively, 2004; Dasgupta et al., 2005; Rahman, 2015). Although these studies provide valuable information on the socio-economic factors influencing pesticide use in individual crops or in the whole farm, none of them investigated whether farmers' decision to apply pesticides in multiple crops are interrelated. This is because identifying the factors influencing farmers' decision regarding chemical pest control in crops is important as such information is useful in finding out critical points of intervention to promote safety and reduction in pesticide use (Damalas and Koutroubas, 2014).

Given this backdrop, the principal aims of this study are to: (a) investigate jointness in farmers' decision to apply pesticides in multiple crops and (b) determine whether the influence of individual socio-economic factors on pesticide use is uniform across crops. A recently conducted large survey data of 2,083 farm households from 17 districts (or 20 sub-districts) of Bangladesh was used. The specific contribution of this study to the existing literature is that it explicitly investigates evidence of jointness in farmers' decision to use pesticides in multiple crops, which if true, will point towards the need to address the issue holistically rather than focusing on a single dominant crop, which is the norm. In fact, farms are businesses where decisions are made and implemented by the farmer alone under relatively more external pressures than any other businesses (Groenewald, 1987; Errington, 1991). Therefore, such a complex decision making process cannot be realistically accommodated by examining factors influencing pesticide use on each crop separately. This approach, therefore, provides a closer approximation of the true production and decision making behaviour of the farmers who generally produce multiple crops to make ends meet.

2. Methodology

2.1 Study area and data collection

Data for this study was taken from a recently completed NFPCSP-FAO project. The data was collected during February–May 2012 through an extensive farm-survey in 17 districts covering 20 sub-districts (*upazillas*) of Bangladesh. A multistage stratified random sampling technique was employed. At the first stage, districts where the specified crops are dominant were selected. The selection of the districts also took into account other specified characteristics, i.e., land elevation types of the region and type of technology. At the second stage, sub-districts were selected according to highest concentration of these specified crops in terms of area cultivated based on information from the district offices of the Directorate of Agricultural Extension (DAE). At the third stage, unions (lowest tier of the local government administration unit comprising of more than one village) were selected using the same criteria at the union/block level which was obtained from the sub-district offices of the DAE. Finally, the farmers were selected at random from the villages with the same criteria classified into three standard farm size categories used in Bangladesh. These are: marginal farms (farm size 50–100 decimals), small farms (101–250 decimals), and medium/large farms (>250 decimals). To ensure equal representation of all farm size categories, a target of 105 farmers from each sub-district was set as follows: 35 marginal farms, 35 small farms, and 35 medium/large farms. This provided a total of 2,083 farm households (Table 1). The questionnaire used was pre-tested with 25 farmers in Tangail district near capital Dhaka prior to finalization mainly focusing on the clarity of the questions and ease of response by the farmers. Based on the outcomes of the pre-test, some questions were reconstructed, some were deleted and some new questions were added in the final version. The survey was carried out by trained enumerators who were graduate students of the Sher-e-Bangla Agricultural University, Dhaka and Bangladesh Agricultural University, Mymensingh.

2.2 Theoretical framework

The study utilizes a farm production model based on profit maximizing behaviour of the farmers adopted by Rahman (2003, 2015).

We begin by specifying a model with two variable input vectors: pesticides, *H* and 'other inputs', *X*, and one fixed input of land, *L* to produce n number of crops ($i = 1 \ldots n$) where L_i is land area allocated to the i^{th} crop.

Farmer *j* maximizes total profits:

$$\sum_{i=1}^{n} p_i Q_{ij} - w^Q H_j - w^O X_j$$

s.t. $Q_{ij} = f(H_{ij}, X_{ij}, L_{ij}, S_j, E_j)$ for $i = 1 \ldots. n$ (1)

and $\sum_{i=1}^{n} L_{ij} \leq L_j$ (2)

where $H_j = H_{1j} + \ldots. + H_{nj}$

and $X_j = X_{1j} + \ldots. + X_{nj}$

Equation (1) is an individual production function for each crop *i*. The production function Q depends on pesticide (H) applied to that crop, 'other variable inputs (X's)' applied to that crop, land (L) allocated to that crop, and a set of exogenous socio-economic variables (S_j) that shift the production function. Equation (2) simply states that land allocated to various crops must be equal or less than the total land cultivated by the producer.

The first order conditions lead to the corresponding demand functions for pesticides and 'other inputs' for individual crops:

$$Q_j = Q_j\,(w^Q, w^O, p_1 \ldots p_n, L_{1j} \ldots, L_{nj}, S_j, E_j) \qquad (3)$$

$$O_j = O_j\,(w^Q, w^O, p_1 \ldots p_n, L_{1j} \ldots, L_{nj}, S_j, E_j) \qquad (4)$$

where p's and w's are output and input prices, respectively.

The assumption of the separability of inputs (pesticide on one hand, and all 'other inputs' on the other) enables the pesticide demand equation to be estimated separately[1].

2.3 The empirical model: a multivariate Tobit approach

Since not all farmers use pesticides in their production processes or in all crops (see Table 2), the application of Ordinary Least Squares regression on Eq (3) will result in biased and inconsistent estimates because the dependent variable is censored at zero. Therefore, we postulate a multivariate Tobit model that not only allows for zero observations on pesticide use by some farmers on each crop, but also identifies jointness in farmers' decision to apply pesticides in multiple crops.

We postulate that farmers follow sequential decisions; first 'whether to apply pesticide in a particular crop or not'; and second, conditional on application, 'what is the level or intensity of application'? In such a case, a censored regression model is required. A Tobit model is the most suitable because it uses all observations, both those at the limit, usually zero (e.g., non-user of

[1] Individual estimation of factor demand functions utilizing separability assumption has been widely used in empirical studies (e.g., Rahman, 2003, 2015).

pesticides), and those above the limit (e.g., pesticide users), to estimate a regression line as opposed to other techniques that use observations which are only above the limit value (McDonald and Moffit, 1980). The procedure also captures latent level of intensity of potential farmers who decide not to apply pesticides on a particular crop.

Let the outcome function for pesticide application rate in a particular crop (measured as value of pesticide used per ha) be given by:

$$Q_i^* = \gamma' X_i + \mu_i \qquad (5)$$

where X_i is the vector of regressors, γ is the vector of parameters to be estimated, and μ_i is the error term. For households applying pesticides in rice, Q_i^* equals the actual amount of pesticide used (Q_i). For those who are not applying pesticide in rice Q_i^* is an index reflecting potential application such that:

$$\begin{aligned} Q_i \quad &= Q_i^* \quad \text{if } \gamma' X_i + \mu_i > 0 \\ &= 0 \quad \text{if } \gamma' X_i + \mu_i < 0 \end{aligned} \qquad (6)$$

The advantage of the Tobit model as in Eq (6) is that it captures the decision to apply pesticide as well as its level of application or intensity, whereas a probit model will provide information on the decision to apply only. Since we see that a substantial proportion of farmers applied pesticides in at least two crops at the same time (Table 2) and the farmers grew a total of four different crop groups[2] (i.e., traditional and High Yielding Varieties (HYV) of rice grown in Aus (pre-monsoon), Aman (monsoon) and Boro (dry winter) seasons and aromatic rice also in Aman season mainly, traditional and HYV wheat and/or maize, mustard and lentil) we postulate a multivariate Tobit model in order to capture this phenomenon of joint outcome:

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[2] A total of 293 farmers also produced jute, but pesticide use in jute was minimal. Only 11.95% of the total farmers applied pesticide in jute, and hence, dropped from the analysis.

$$
\begin{aligned}
&Q_{1i}^{*} = \gamma' X_{1i} + \mu_{1i} \\
&Q_{1i} = Maximum\,(Q_{1i}^{*}, 0) \qquad (the\,usual\,Tobit\,specification\,as\,in\,6). \\
&Q_{2i}^{*} = \gamma' X_{2i} + \mu_{2i} \\
&Q_{2i} = Maximum\,(Q_{2i}^{*}, 0) \qquad (the\,usual\,Tobit\,specification\,as\,in\,6). \\
&Q_{3i}^{*} = \gamma' X_{3i} + \mu_{3i} \\
&Q_{3i} = Maximum\,(Q_{3i}^{*}, 0) \qquad (the\,usual\,Tobit\,specification\,as\,in\,6) \\
&.Q_{4i}^{*} = \gamma' X_{4i} + \mu_{4i} \\
&Q_{4i} = Maximum\,(Q_{4i}^{*}, 0) \qquad (the\,usual\,Tobit\,specification\,as\,in\,6) \\
&\mu_{ii}, \mu_{2i}, \mu_{3i}, \mu_{4i} \approx N[0,0,0,0,\sigma_1^2, \sigma_2^2, \sigma_3^3, \sigma_3^4 \rho_{12}, \rho_{13}, \rho_{14}, \rho_{23}, \rho_{24}, \rho_{34}]
\end{aligned}
\tag{7}
$$

where Q_{1i}^{*} denotes pesticide application rate of the *i*th household that applied pesticides in rice; Q_{2i}^{*} denotes pesticide application rate of the *i*th household that applied pesticides in wheat/maize, Q_{3i}^{*} denotes pesticide application rate of the *i*th household that applied pesticides in lentil, Q_{4i}^{*} denotes pesticide application rate of the *i*th household that applied pesticides in mustard; ρ_{12} is the correlation between the error terms μ_{1i} and μ_{2i}, ρ_{13} is the correlation between the error terms μ_{1i} and μ_{3i}, ρ_{14} is the correlation between the error terms μ_{1i} and μ_{4i}, ρ_{23} is the correlation between the error terms μ_{2i} and μ_{3i}, ρ_{24} is the correlation between the error terms μ_{2i} and μ_{4i}, and ρ_{34} is the correlation between the error terms μ_{3i} and μ_{4i}. The distributions are independent if and only if $\rho_{12} = \rho_{13} = \rho_{14} = \rho_{23} = \rho_{24} = \rho_{34} = 0$.

This modelling framework enables us to accommodate farmer's decision to apply pesticides in a single or a combination of crops at the same time. The other advantage of this multivariate approach, as opposed to the univariate approach (i.e., single equation Tobit/probit/logit models), is that it is more efficient, because it not only nests individual univariate models, but also enables us to demonstrate jointness of the decision making process by providing an estimate of the correlation between the error terms of the individual univariate models.

The model is estimated with a program code developed by Barslund (2007) in Stata V10 software (Stata Corp, 2007). The procedure involves simulation using Halton draws to generate random numbers for evaluation of the multi-dimensional Normal integrals in the likelihood function. For each observation, a likelihood contribution is calculated for each replication. The simulated likelihood contribution is the average of the values derived from all replications. The simulated likelihood function for the sample as a whole is then maximized using a standard Maximum Likelihood procedure.

2.4 Variables

The value of pesticide use rate per hectare (BDT ha^{-1}) was specified as the dependent variable in the econometric model. Such specification of the dependent variable removes variation in actual amount of pesticides used in different crops and it is now specified as an application rate per unit of land area under a specific crop. Further, this specification also removes variation in actual cultivated area under individual crops.

Explanatory variables: Input and output prices and other socio-economic factors

The list of variables included in the individual pesticide demand functions are: (a) input prices – prices of urea, Triple Super Phosphate (TSP), Muriate of Potash (MP), Diammonium Phosphate (DAP), gypsum fertilizers, and labour wage; (b) output prices – weighted average prices of all varieties of rice grown in all three seasons, weighted average prices of all varieties of wheat and maize, lentil price and mustard price; and (c) a set of socio-economic characteristics which include age of the farmer as a proxy for experience, education of the farmer, use of organic manure per ha, family size of the household, land fragmentation measured by number of plots, dummy variables to represent farm size category (i.e., marginal, small and medium/large farms) and a dummy variable to account for membership in non-governmental organisations (NGOs).

Table 3 presents the definition, measurement and summary statistics of all the variables used in the econometric model.

Fertilizers (various types) and labour are the major inputs in crop production and contribute significantly to the production costs. Farmers seeking to maximize profits are expected to respond to input price changes and adjust their input use accordingly (Rahman, 2003, 2015). Therefore, prices of various fertilizers and labour wage price are included in the pesticide demand function of each crop[3]. Similarly, prices of crops produced have a direct bearing on the profit generated from farming and farmers are expected to respond to changes in the crop prices when choosing their cropping portfolio. Therefore, output prices of the crops produced are included in the respective pesticide demand function of individual crops.

We have also included organic manure application to identify its independent influence on pesticide use. This is because farmers are increasingly using organic manure to enhance/conserve soil fertility as well as economise on the use of inorganic fertilizers in farming (Rahman and Hasan, 2008). However, the use of organic manure may itself attract pests which will have a bearing on farmers' pesticide application rate.

Farm size was found to have significant influence on pesticide use (Rahman, 2003). However, it is not clear which farm size categories use more pesticides. In Bangladesh, average farm size is declining consistently and the proportion of marginal and small farms are rising (Rahman 2010). Therefore, we have included two dummy variables to capture the individual influence of small and medium/large farms on pesticide demand in individual crops. The influence of the medium/large farms is subsumed in the intercept/constant term.

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[3] We did not include animal power price because it tends to be uniform and less variable across farms.

The use of age and education level of farmer as explanatory variables is common in the literature (Rahman, 2009). These variables, acting as a group or separately, are expected to have an influence on pesticide demand in the following ways. For instance, education is used as a surrogate for a number of factors. At the technical level, access to information and capacity to understand the technical aspects related to farming may influence crop choices and hence pesticide use in each crop (Rahman, 2015). The age of the farmer is incorporated to account for the maturity of the farmer in his/her decision-making ability related to pesticide use.

Family size is included in the pesticide demand function for two reasons. First, according to Chayanovian theory, higher subsistence pressure (measured by family size) generally leads to adoption of modern technologies (Hossain, 1989) which may in turn lead to increased use of pesticides. On the other hand, large family size may also imply availability of extra labour which may influence pesticide use, either positively or adversely (Rahman, 2003, 2015).

Finally, a dummy variable of membership in NGOs is specified to identify its independent influence on pesticide use although we do not have any hypothesized direction of effect of this variable. Membership in NGOs may either promote pesticide application or reduce it if the members are exposed to information on pesticides and hazards associated with it (Rahman, 2015).

3. Results and discussion

3.1 Pesticide use rates in crops

Use of pesticides in crops is dependent upon pest infestations and prevalence of diseases and the type of crops grown (Rahman, 2003). Table 2 presents information on the extent and magnitude of pesticide use in different crops by all the sampled farmers. Since rice crop dominates amongst farmers, the highest proportion of only rice producers applied pesticides in rice (55.8% of them) followed by only wheat/maize farmers (22.0% of them). Overall 75.4% of the total farmers used pesticides in any one crop at least followed by 12.7% who used in any two crops, thereby demonstrating proof of applying pesticides in multiple crops.

Within the pesticide users of each individual crop, Table 2 shows that the highest rate of pesticide use is in oilseed (BDT 2453.2 ha^{-1}) followed by rice and oilseed combination (BDT 2532.7 ha^{-1}) followed by rice (BDT 1122.6 ha^{-1}). The overall pesticide use rate is BDT 1090.5 ha^{-1}.

3.2 Jointness in farmers' decision to apply pesticides in multiple crops and its determinants

Table 3 presents the summary statistics of all the variables used in the econometric model. The point to note in Table 3 is that the cereal prices are very similar and so are the prices of the pulse and oilseed which are very close to each other. Also, noteworthy is the use rate of organic manure in crops which was not a common feature in the past in Bangladesh agriculture.

Table 4 presents the joint parameter estimates of the pesticide demand functions of multiple crops. The corresponding elasticities are presented in Table 5. A total of 70.9% of the coefficients on the variables are significantly different from zero at least. The key hypothesis of 'correlation of the disturbance term between the pair of equations is zero {i.e., $\rho_{jk} = 0$}' is rejected at the 1% level of significance for four pairs out of a total of six, justifying our multivariate Tobit specification. The Likelihood Ratio test result, presented at the bottom panel (last row) of Table 4, also statistically validates that the decision to apply pesticides in multiple crops are strongly correlated. However, the nature of correlation is not the same across crop combinations. For example, the negative correlation between rice and wheat/maize implies that unobservable factors which increase the probability of applying pesticides in rice significantly reduces the probability of applying pesticides in wheat/maize. This particular set of information can be exploited to promote crop diversification using specific combination of crops which will jointly reduce pesticide use intensity in agriculture.

Output prices are significant determinants of pesticide use in most crops as expected and all are in the high elastic range (Table 5). The responsiveness is highest for mustard price (elasticity value 9.8) implying that a 1% increase in mustard price will increase pesticide demand by 9.8%, which perhaps explains the highest rate of pesticide use in mustard crop reported in Table 2. The finding conforms to Rahman (2003) who reported positive influence of lentil and jute prices on pesticide use. In our study, influence of lentil price on pesticide use is the second highest with an elasticity value of 6.4. Rahman and Hossain (2003) also noted significant influence of cereal and vegetable prices on pesticide demand.

Farmers treated pesticides as substitutes for labour in rice only and as complements for the other three crops and all responses were in the high elastic range with highest elasticity value for rice estimated at 9.6 (Table 5). The implication is that a rise in labour wage (which is a desired goal for supporting landless and marginal farmers through the hired labour market as wage labourer) will induce a significant rise in pesticide use in rice (which is the dominant crop) mainly to reduce the amount of labour for various farm operations, particularly intercultural operations, such as weeding, hoeing, topping etc. This finding partly lends support to the argument raised by Damalas and Eleftherohorinos (2011) that pesticide is also used to save labour. Rahman (2003) found substitute relationship of labour wage on overall pesticide use, but the influence was not significant. Since, we have jointly investigated determinants of pesticide use in multiple crops using a multivariate framework, we are able to isolate variable effects of a rise in labour wage on individual crops.

Among the inorganic fertilizers, farmers treated phosphate fertilizers as substitutes for cereals and lentil, but as complement for mustard. Similarly, farmers treated other fertilizers as either substitutes or complements depending on the crops, but the influences were largely in the elastic range, which is a cause of concern. This finding partly conforms to Rahman (2003) who aggregated all fertilizers into one category. Since we have separated each fertilizer type, we can isolate individual and variable influences of pesticide demand on each crop. Rahman and Hossain (2003) noted complementary relationship between fertilizers and pesticides in the production of hybrid seeds of cereals and vegetables in Bangladesh. The prices of all fertilizers are on the rise in Bangladesh following the liberalization of the fertilizer market and removal of subsidy since 1992 (Rahman, 2003). Nevertheless, the government is reverting to control prices indirectly by facilitating distribution of urea fertilizer in recent years, a fact which will have a favourable impact on reducing pesticide use.

The influence of socio-economic factors on pesticide demand varied equally depending on the crops grown. In general, the likelihood of applying pesticide was higher for farmers growing rice and mustard, but not for farmers growing wheat/maize. Educated farmers used more pesticides in rice and mustard with no influence on other crops. Rahman (2003) and Dasgupta et al. (2005) did not find any significant influence of education on overall pesticide use, although Rahman and Hossain (2003) noted negative influence of education on pesticide use. Family size increases the likelihood of applying pesticides in mustard, but not in lentil. Land fragmentation increases pesticide use in rice, but not in wheat/maize. Pesticide use increase significantly with an increase in organic manure use in wheat/maize. This may be due to the fact that application of organic manure (which is mostly cow dung) increase pest infestation, thereby, leading to higher pesticide use. In fact, farmers use considerable amount of organic fertilizers in maize to improve productivity (Rahman et al., 2012). Farm size categories have variable influence on pesticide use in different crops. Both marginal and small farms use significantly more pesticides in mustard, but significantly less in wheat/maize and lentil. Rahman (2003) reported that pesticide use increases with farm size although Dasgupta et al. (2005) did not find any influence of farm size on overuse of pesticides. Since we have evaluated the effect of farm size categories on individual crops, we established a variable role of farm size categories on the use of pesticides on different crops. Similarly, membership in NGOs has significant, but variable influences on pesticide demand on individual crops.

4. Conclusions and policy implications

Reduction of pesticide use is an important policy agenda of the government of Bangladesh. The principal aim of this study is to explicitly investigate the jointness in farmers' decision to apply pesticide in multiple crops and to test whether the influence of various socio-economic factors on pesticide use is uniform across crops based on a large sample of 2,083 farms from 17 districts in Bangladesh, which is non-existent in the literature.

Although the overall proportion of farmers applying pesticides (75.4% of total sample) seems to be the closely similar to the estimate of 77.3% by Rahman (2003), we find that 12.7% of the total farmers applied pesticides in any two crops at least which implies jointness in the decision making process in pesticide application. The use rate of pesticide was found to be highest for mustard followed by rice–mustard combination instead of rice alone, which is somewhat unexpected. The implication is that a boost in the production of mustard, a high value added crop, will lead to an increase in pesticide use.

The key finding of this study is the evidence of jointness in farmers' decision to use pesticides in multiple crops, but the effects were variable depending on the crop combinations.

The likelihood of pesticide use was negatively related with rice–wheat, rice–lentil and wheat–mustard combinations, implying that such crop combinations would lead to a significant reduction in pesticide use. Another key finding is the establishment of the fact that the influence of individual socio-economic factors was not uniform across crops, which reveals the need to model farmers' decision making process in a multivariate framework that allows farmers to produce multiple crops and apply pesticides selectively in them as a closer approximation to the true production practices.

The following policy implications can be drawn from this study. First, the agricultural extension message can be modified to disseminate information on specific crop combinations which will synergistically reduce pesticide, e.g., rice–wheat, rice–pulse and wheat–oilseed combinations. Rahman (2009) noted that crop diversification is a desired policy for promoting agricultural growth in Bangladesh as it improves economies of scope and production efficiency. Therefore, the observed increase in area under wheat and maize (Rahman, 2010) is a step to the right direction and should be further promoted including thrust in increasing pulse and oilseed areas (Rahman, 2010). Second, price policies for reducing prices of all types of fertilizers will significantly reduce pesticide use in individual crops in one way or the other. Third, a reduction in pesticide use can also be promoted through engaging NGOs, given that our results revealed significant, but variable influence of NGO membership on pesticide use in crops. However, the message delivered through NGOs need to be modified towards a general reduction in pesticide use in all crops. This can be achieved by disseminating information regarding alternative pest control strategies, e.g., IPM. Rahman (2013) noted that widespread use of IPM is a way forward for pest control in Bangladesh but its reach is still very limited, considering that only 7.4% of the total farmers are covered after 30 years of effort. NGOs can also be involved in promoting crop diversification highlighting combination of crops that favour reduction of pesticide use. Generally, the main thrust of the agricultural programs of NGOs (e.g., BRAC, Proshika, Helen Keller International) is to promote kitchen gardening focused on vegetable production as a means to alleviate poverty and raise incomes of the poor (Rahman, 2003) which can be extended further to disseminate information on how to reduce pesticide use for field crops as well.

Although achievement of these policies are challenging, a significant reduction in pesticide use is important to sustain the agricultural sector and the farming population, which is a goal worth pursuing.

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REFERENCES

Alavanja MCR. 2009. Pesticide use and exposure extensive worldwide. Rev Env Health. 24:303–309.

Antle JM, Pingali PL. 1994. Pesticides, productivity and farmer health: a Philippine case study. Amer J Agric Econ. 76:418-430.

Barslund MC. 2007. MVTOBIT: Stata module to calculate multivariate Tobit models by simulated maximum likelihood (SML). Statistical Software Components S456875, Boston College Department of Economics, revised 13 Oct 2009. Available from: http://ideas.repec.org/f/pba424.html

BB 2013. Economic Trends (monthly publications) 2013. Dhaka: Bangladesh Bank.

Carvalho FP. 2006. Agriculture, pesticides, food security and food safety. Env Sci Policy. 9:685–692.

Damalas CA, Eleftherohorinos IG. 2011. Pesticide exposure, safety issues, and risk assessment indicators. Int J Env Res Public Health. 8:1402-1419.

Damalas CA, Koutroubas SD. 2014. Determinants of farmers' decisions on pesticide use in oriental tobacco: a survey of common practices. Int J Pest Manag. 60:224–231.

Damalas CA, Hashemi SM. 2010. Pesticide risk perception and use of personal protective equipment among young and old cotton growers on northern Greece. Agrociencia 44:363-371.

Dasgupta S, Meisner C, Huq M. 2005. Health effects and pesticide perception as determinants of pesticide use: evidence from Bangladesh. Washington, DC: The World Bank Policy Research Working Paper #3776.

De A. 2014. Worldwide pesticide use. In De A, Bose R, Kumar A, Mozumdar S. (Eds.) Targeted Delivery of Pesticides Using Biodegradable Polymeric Nanoparticles. Springer. pp. 5–6.

Delcour I, Spanoghe P, Uyttendaele M. 2014. Literature review: Impact of climate change on pesticide use. Food Res Int. 68:7–15.

Errington A. 1991. Getting out of farming? Part two: the farmers. Study No. 27, Department of Agriculture, University of Reading, Farm Management Unit.

FAOSTAT. 2013. FAOSTAT database (inputs). FAO, Rome. Available from: www.faostat.fao.org.

Groenewald JA. 1987. The producer as decision maker. Agrekon. 26:43–46.

Hashemi SM, Rostami R, Hashemi MK, Damalas CA. 2012. Pesticide use and risk perceptions among farmers in southwest. Iran Hum Ecol Risk Assess. 18:456–470.

Hashemi SM, Damalas CA. 2011. Farmers' perceptions of pesticide efficacy: Reflection on the importance of pest management practices adoption. J Sust Agric. 35:69–85.

Hossain M. 1989. Green Revolution in Bangladesh: Impact on Growth and Distribution of Income. University Press Limited, Dhaka.

Hossain MI, Shively G, Mahmoud C. 1999. Factors influencing pesticide use in rice-vegetable farming system in Bangladesh. Bangladesh J Agric Econ. 22:87–98.

Hou B, Wu L. 2010. Safety impact and farmer awareness of pesticide residues. Food Agric Immuno. 21:191-200.

Huan NH, Thiet LV, Chien HV, Heong KL. 2005. Farmers' participatory evaluation of reducing pesticides, fertilizers and seed rates in rice farming in the Mekong Delta, Vietnam. Crop Prot. 24:457–464

Mahmoud C, Shively G. 2004. Agricultural diversification and integrated pest management in Bangladesh. Agric Econ. 30:187–194.

Pimentel D. 2005. Environmental and socio economic costs of the applications of pesticides primarily in the United States. Env Dev Sust. 7:229–252.

Rahman S. 2003. Farm-level pesticide use in Bangladesh: determinants and awareness. Agric Eco Env. 95:241–252.

Rahman S. 2009. Whether crop diversification is a desired strategy for agricultural growth in Bangladesh. Food Pol. 34:340-349.

Rahman S. 2010. Six decades of agricultural land use change in Bangladesh: Effects on crop diversity, productivity, food availability and the environment, 1948-2006. Singapore J Trop Geog. 31:254–269.

Rahman S. 2013. Pesticide consumption and productivity and the potential of IPM in Bangladesh. Sci Tot Env. 445–446:48–56.

Rahman S. 2015. Agroecological, climatic, land elevation and socio-economic determinants of pesticide use at the farm level in Bangladesh. Agric Eco Env. 212:187–197.

Rahman S, Hossain MZ. 2003. Pesticide demand in hybrid seed production technology. J Food Agric Env. 1:174–179.

Rahman S, Rahman MS, Rahman MH. 2012. Joint determination of the choice of growing season and economic efficiency of maize in Bangladesh. J Asia Pacific Econ. 17:138–150.

Stata Corp, 2007. Stata Version 10. Stata Press Publications, College Station, Texas, USA.

Wilson C, Tisdell C. 2001. Why farmers continue to use pesticides despite environmental, health and sustainability costs? Ecol Econ. 39: 449–462.

Table 1. Distribution of sample according to farm type by districts

District	Sub-district	Farm Type			
		Marginal	Small	Medium / Large	Total surveyed Farms
Tangail	Mirzapur	35	35	35	105
Mymensingh	Phulpur	34	36	35	105
Kishoreganj	Karimganj	35	35	35	105
Netrokona	Khaliajuri	21	38	46	105
Faridpur	Bhanga	35	35	35	105
	Boalmari	20	20	20	60
Rajshahi	Charghat	35	35	35	105
Natore	Lalpur	34	35	36	105
Sirajganj	Ullapara	35	35	35	105
Bogra	Sherpur	31	34	33	98
	Sariakandi	35	35	35	105
Jaipurhat	Kalai	35	35	35	105
Dinajpur	Chirirbander	36	30	39	105
	Birganj	70	35	35	140
Thakurgaon	Balia Dangi	35	35	35	105
Lalmonirhat	Hatibandha	34	34	37	105
Barisal	Bakerganj	35	35	35	105
Kushtia	Sader	35	35	35	105
Sunamganj	Derai	35	35	35	105
Habiganj	Baniachang	31	38	36	105
	Total	696	685	702	2083

Table 2. Pesticide users and use rates in multiple crops.

Crops	% of total farmers using pesticides	Pesticide use rate per ha by those who applied pesticides
Rice (all types)	55.83	1122.62
Wheat and/or maize (all types)	21.98	864.71
Lentil	4.80	693.36
Mustard	5.04	2453.19
Rice and wheat/maize	6.19	924.71
Rice and lentil	0.86	1074.56
Rice and mustard	2.69	2532.70
Wheat/maize and lentil	2.98	719.49
Wheat/maize and mustard	0.00	00.00
Mustard and lentil	0.01	561.36
Any single crop	75.37	1090.53

Note: Total number of farms is 2083 comprising of 2808 observations on crops (i.e., 1652 rice growers, 690 wheat/maize growers, 255 lentil growers, 211 mustard growers).
The exchange rate is USD 1 = BDT 81.86 (BB, 2013)

Source: NFPCSP Field Survey, 2012.

Table 3. Definition, measurement and summary statistics of the variables used in the empirical model.

Variables	Definition and measurement	Mean	Standard Deviation
Dependent variable			
Pesticide use rate in all rice	BDT ha^{-1}	691.65	922.23
Pesticide use rate in all wheat/maize	BDT ha^{-1}	230.27	564.89
Pesticide use rate in lentil	BDT ha^{-1}	28.63	216.29
Pesticide use rate in mustard	BDT ha^{-1}	126.45	553.31
Output prices			
Rice price	BDT kg^{-1} (Weighted average price of all varieties)	16.90	2.77
Wheat/maize price	BDT kg^{-1} (Weighted average price of all varieties of wheat and maize)	17.96	1.61
Lentil price	BDT kg^{-1}	48.99	2.47
Mustard price	BDT kg^{-1}	47.95	1.56
Input prices			
Urea price	BDT kg^{-1}	14.23	3.40
Triple Super Phosphate price	BDT kg^{-1}	23.55	2.26
Muriate of Potash price	BDT kg^{-1}	15.87	1.60
Diammonium Phosphate price	BDT kg^{-1}	37.90	10.01
Gypsum price	BDT kg^{-1}	8.75	7.15
Labour wage	BDT person day^{-1}	236.62	55.98
Area cultivated			
Rice area	ha	0.77	1.11
Wheat and/or maize area	ha	0.14	0.40
Lentil area	ha	0.04	0.15
Mustard area	ha	0.06	0.25
Socio-economic characteristics			
Age of the farmer	Years	44.87	12.78
Education level of the farmer	Years of completed schooling	5.59	3.92
Family size	Number of person per household	5.04	1.93
Marginal farms	Dummy (1 = if farm size is 50 – 100 decimals; 0 = otherwise)	0.33	--
Small farms	Dummy (1 = if farm size is 101 – 250 decimals; 0 = otherwise)	0.34	--
Medium/large farms	Dummy (1 = if farm size is 251 decimals and above; 0 = otherwise)	0.33	--
Organic manure use rate	kg ha^{-1}	2273.28	4462.32

Variables	Definition and measurement	Mean	Standard Deviation
Membership in NGOs	Dummy (1 = if member in an NGO; 0 = otherwise)	0.12	--
Number of observations		2083	--

Note: The exchange rate is USD 1 = BDT 81.86 (BB, 2013)
Source: NFPCSP Field Survey, 2012.

Table 4: Joint determination of factors influencing decision to apply pesticides on multiple crops: a multivariate Tobit model

Variables	**Dependent variable: Pesticide use rate per ha**							
	Rice		**Wheat/Maize**		**Lentil**		**Mustard**	
	Coefficient	**t-ratio**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**	**Coefficient**	**t-ratio**
Constant	912.3955	1.32	-1878.3650***	-2.60	-6878.9430***	-5.13	-35799.1100***	-4.87
Prices								
Output price	37.8213***	3.51	-36.3426	-1.62	48.4373***	3.17	471.2424***	6.19
Urea price	4.3172	0.39	49.3383***	2.98	-147.2028***	-3.36	1913.8720***	5.95
Triple Super Phosphate price	61.2773***	3.47	171.3539***	7.12	244.1828***	6.32	-1368.2510***	-7.54
Muriate of Potash price	-37.1080	-1.35	-52.2498*	-1.75	98.2993***	3.10	629.4818***	4.08
Diammonium Phosphate price	-107.0184***	-9.37	26.0039***	7.36	--	--	-29.1975	-0.84
Gypsum price	-8.2631	-1.57	2.7503	0.49	--	--	--	--
Labour wage	4.5858***	7.12	-11.8159***	-10.54	-12.4206***	-5.49	-38.7440***	-8.40
Socio-economic factors								
Age of the farmer	7.2572***	2.61	-12.4768***	-3.09	-0.1962	-0.03	29.3797***	2.75
Education level of the farmer	35.0383***	4.06	4.0854	0.32	8.6410	0.44	51.0271*	1.67
Family size	7.7878	0.41	-18.9266	-0.67	-133.5630***	-2.57	201.7938***	2.90
Land fragmentation	17.9053***	3.66	-52.3015***	-3.82	9.4307	0.60	1.0630	0.07
Marginal farms	48.6086	0.55	-468.2433***	-3.68	-568.8753***	-2.88	789.5969**	1.96
Small farms	79.2905	0.94	-280.6222**	-2.33	-497.7010***	-2.53	838.6026**	2.33
Organic manure use rate	0.0091	1.18	0.0442***	4.61	--	--	--	--
Membership in NGOs	-169.6322*	-1.65	342.4619***	2.59	323.2504*	1.72	-1087.4460**	-2.00
Model diagnostics								
Log likelihood	-17033.6200							
Wald $\chi^2_{(55\ df)}$	741.54***							
Correlation between the error terms								
$\rho_{(rice,\ wheat)}$	-0.3452***	-10.29						
$\rho_{(rice,\ lentil)}$	-0.3181***	-5.10						
$\rho_{(rice,\ mustard)}$	0.0671	0.97						
$\rho_{(wheat,\ lentil)}$	0.3220***	4.17						
$\rho_{(wheat,\ mustard)}$	-0.5658***	-3.72						

Variables	Dependent variable: Pesticide use rate per ha							
	Rice		Wheat/Maize		Lentil		Mustard	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
$\rho_{(lentil,\ mustard)}$	-0.1991	-0.86						
Wald $\chi^2_{(6\ df)}$ (H_0: Correlation between pairs of disturbance terms are jointly 0)	126.7270***							
Number of observations	2083							

Note: *** Significant at 1% level (p<0.01),
** Significant at 5% level (p<0.05),
* Significant at 10% level (p<0.10).

Table 5: Elasticities of the determinants of pesticide use in multiple crops

Variables	Elasticity of pesticide use rate with respect to							
	Rice		Wheat/Maize		Lentil		Mustard	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Prices								
Output price	5.6436***	3.51	-0.9146	-1.62	6.4117***	3.17	9.7577***	6.19
Urea price	0.5424	0.39	0.8925***	2.98	-4.6476***	-3.36	15.6770***	5.95
Triple Super Phosphate price	12.7439***	3.47	6.0491***	7.12	16.7312***	6.32	-12.5499***	-7.54
Muriate of Potash price	-5.2012	-1.35	-1.2057*	-1.75	4.7751***	3.10	4.1959***	4.08
Diammonium Phosphate price	-35.8158***	-9.37	1.4312***	7.36	--	--	-0.0944	-0.84
Gypsum price	-0.6384	-1.57	0.0343	0.49	--	--	--	--
Labour wage	9.5817***	7.12	-3.4182***	-10.54	-5.2650***	-5.49	-3.2370***	-8.40
Socio-economic factors								
Age of the farmer	2.8752***	2.61	-0.7528***	-3.09	-0.0219	-0.03	0.6091***	2.75
Education level of the farmer	1.7291***	4.06	0.0349	0.32	0.1329	0.44	0.1387*	1.67
Family size	0.3465	0.41	-0.1252	-0.67	-1.4185***	-2.57	0.4654***	2.90
Land fragmentation	0.7618***	3.66	-0.1898***	-3.82	0.0404	0.60	0.0045	0.07
Marginal farms	0.1434	0.55	-0.2372***	-3.68	-0.5792***	-2.88	0.1066**	1.96
Small farms	0.2302	0.94	-0.1118**	-2.33	-0.3460**	-2.53	0.1270**	2.33
Organic manure use rate	0.1835	1.18	0.2694***	4.61	--	--	--	--
Membership in NGOs	-0.1827*	-1.65	0.0582***	2.59	0.2058*	1.72	-0.0161**	-2.00