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Pesticide Expenditures in a Rice-Vegetable Farming System: Evidence from Low-income Farms in Bangladesh

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Abstract

This paper studies patterns of pesticide expenditure on rice and vegetable farms in Bangladesh. Data come from a 1998/99 survey of 400 farm households. We focus on understanding the factors that help explain observed variation in patterns of pesticide expenditure. Three regression equations are estimated. Controlling for farmer characteristics, the results reveal positive and significant correlation between pesticide expenditures per hectare and farm size, non-agricultural income, and degree of vegetable commercialization. Access to credit is found to have no explanatory power in the regressions. Farmers' estimates of pest infestation and damage are only weakly correlated with pesticide expenditures.

1. Introduction

Since independence Bangladesh has achieved considerable growth in food production. Bangladesh's climate provides opportunities to produce a wide variety of crops. Favorable soil topography and typographies have facilitated area expansion and agricultural intensification, thereby increasing agricultural production. A shift toward irrigation, modern seed varieties, and inorganic fertilizers, together with government investments in infrastructure has helped move the country towards food sufficiency (Ahmed and Haggblade 2000).

Growth in food production has come about primarily through growth in production of rice and wheat. The average growth rate for rice and wheat combined was 2.25 percent between 1973/74 and 1997/98 Dorosh (2000). Rapid growth was registered during the 1980s, especially for rice. During the decade to 1990, rice output grew at an annual rate of 2.78 percent, even as wheat production declined. As a result, the average rate of growth in cereal production was 2.5 percent, which kept pace with population growth. Increases in rice production prior to the 1960s and 70s came about largely through area expansion and better water management. Gains in recent decades, in contrast, have come about through yield improvement (see Table 1). Indeed, most observers agree that area expansion for rice and wheat is no longer feasible. Furthermore, given that the entire *boro* rice harvest and most of the *aman* rice harvest is already produced using modern seed varieties, the scope and prospect for further yield improvement in rice via a shift from local to modern varieties seems somewhat limited. As a result, efforts to achieve food security in Bangladesh—as opposed to the more narrowly defined goal of self-sufficiency—now must emphasize ways to facilitate a shift from food grain production to the production of high-valued crops.

In fact, rapid growth is occurring in the production of some other crops, especially vegetables. Studies show that revenue per hectare can increase dramatically when land is converted to vegetable production. For example, Mahmud, Rahman, and Zohir (1994) estimate that vegetables crops—namely, brinjal (eggplant), radish, cucumber, tomato, long yard bean, and cabbage—rank among the highest valued crops grown in Bangladesh. They argue that, while the average net private return for modern varieties of *boro* and *aman* is approximately Tk. 7,000 per hectare, under the right conditions vegetables such as brinjal, tomato, cucumber, cabbage and radishes can provide an average return of Tk. 36,000 per hectare. When crops are valued at either export or import parity prices, returns for vegetables are considerably higher than for other crops, including modern varieties of rice and wheat.

In the case of vegetables, data show that output growth in Bangladesh is taking place mainly through area expansion, without much improvement in yield (see Table 1). Scope for yield improvement through development of better seeds, better methods of pest and disease control, and better harvest and post-harvest handling remain. However, one potential drawback associated with a shift toward more intensive vegetable production is the common reliance of most vegetable producers on heavy application of pesticides. Use of pesticides—a "catch-all" term that includes insecticides, herbicides, fungicides, molluskacides, and rodentacides—are a logical response to pest and disease outbreaks. Pest damage is particularly acute in the Asian region. For example, Table 2 lists representative amounts of crop loss due to a range of insect and disease outbreaks during different time periods in South and Southeast Asia. Faced with high potential crop losses, the application of pesticides would appear to be a rational response to pest outbreaks, given the absence of other options. Yudelman, Ratta, and Nygaard (1998) provide a very complete survey of past and (potential) future trends in pesticide use. Pesticides affect agricultural productivity and profitability in several ways. When properly used, pesticides reduce crop losses and thereby maintain yields. From an economic perspective, the proper level of pesticide use in agricultural production is that level for which the marginal benefit of application equals the marginal cost of application. But assessing the true benefits and costs of pesticide use can be problematic. If pesticides are improperly applied—for example due to misidentification of pest problems, poor timing, or improper dosage—they may generate significant production costs without concomitant yield benefits. For example, according to Pimentel and Levitan (1986) less than one percent of the amount of pesticides applied actually reaches the target pest population.

Pesticides can produce negative impacts, both private and social (Antle and Pingali 1994). For example, when farm workers are exposed to dangerous pesticides, this exposure can reduce farm productivity through effects on farmer health. One recent study from the Philippines suggests that, in some cases, health costs from pesticide exposure may completely offset the benefits derived from yield improvements (Rola and Pingali 1993). Excessive application of pesticide also can be ecologically damaging. Low dosages can lead to development of resistance in target populations and pesticide runoff can reduce the productivity of aquatic ecosystems.

In Bangladesh, pesticides are widely used by rice and vegetable growers. Although pesticide use is low compared with other countries, use is rapidly increasing. A study undertaken by the Ministry of Agriculture in the early 1990s concluded that 1.8 million hectares were treated with pesticides in 1992, and that between 1982 and 1992 the total amount of active ingredient used in the country increased by 66% (for insecticides), 260% (for herbicides), and 1467% (for fungicides) (GOB/MOA 1995a). Several observers have noted that, due to lack of knowledge, some farmers may be using the wrong pesticides, or using the correct pesticides at either sub-optimal or excessive rates (Ramaswamy 1992; Jackson 1991). A 1995 study indicated that while most water samples showed low concentrations of pesticide residues, approximately 11% of samples indicated pesticide residues that exceeded WHO-guidelines (GOB/MOA 1995b). A different study indicated slight organochloride pesticide pollution in floodplain ecosystems in the early 1990s, and some degree of bioaccumulation of pesticides in fish muscle tissue (GOB 1993). In addition to the risks that pesticides pose to the domestic food supply in Bangladesh, some export markets may be sensitive to the presence of pesticide residues on fresh vegetables. As a result, export potential may be impaired if pesticide use results in high pesticide residue on crops. Access to, and future growth in export markets will depend upon proper control and judicious application of pesticide use. As the majority of farmers lack knowledge regarding the proper use of specific pesticides, application tends to be indiscriminate and calendar-based rather than truly need-based. Misconceptions among farmers regarding pest behavior, coupled with lack of accurate information regarding pests, pest damage, and appropriate intervention means that farmers often incur unnecessary production costs. Some studies suggest that lack of education and training contribute to sub-optimal use of inputs in the face of technological change (Ramaswamy 1992). All of the aforementioned concerns suggest that the research and policy-making communities in Bangladesh could benefit from a better understanding of factors influencing pesticide use, especially as a foundation for developing appropriate pesticide policies and alternative pest management practices, such as Integrated Pest Management (IPM). The remainder of this paper focuses on an empirical study of factors influencing observed patterns of pesticide expenditures on low-income farms.

2. Model

To examine the issue of pesticide use more formally, consider the following model of agricultural production under pest pressure, which is based on Feder (1979). For convenience, we assume that damage is due to a single pest. This pest causes damage to the crop in an amount related to its number N. We denote the cost of damage by $D(N)$:

$$D(N) = dN \tag{1}$$

where d denotes the damage caused by a single pest. We assume this level of damage is independent of the total number of pests. Using x to denote the level of pesticide use, profit from agricultural production p can be expressed as:

$$p = p_0 - dN[1 - k(x)] - cx \tag{2}$$

where, p_0 denotes profits that would be realized if no pest were present (i.e. if $N = 0$). The number of pests surviving after pesticide application is $N(1 - k(x))$, where $k(x)$ (the so-called "kill rate") denotes the proportion of the target pest population killed. The unit cost of pesticide application is c, so that total expenditure on pesticide is simply the product of this unit cost and the level of application, i.e. cx. The farmer's objective is to choose the appropriate level of pesticide application in order to maximize expected utility of profit, defined as:

$$EU(p) = EU(p_0 - dN[1 - k(x)] - cx). \tag{3}$$

First order conditions for equation (3) imply that the optimal level of pesticide application is that for which the expected marginal benefit (in utility terms) of additional pesticide application equals the marginal cost of additional pesticide use. Given uncertain damage due to pests, three points regarding (3) are worth noting. One, the model implies the level of pesticide application is increasing in the level of infestation, i.e. $\partial x/\partial N > 0$. This pattern reflects the fact that the expected marginal benefit of pesticide use increases with the level of infestation (since the expected level of damage increases with infestation) while the marginal cost is constant.[1] Two, other things equal, an increase in the expected mean level of damage d will increase the level of pesticide application. And three, using a model based on (3), Feder (1979) argues that, for a given N and c, increases in the level of uncertainty regarding

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[1] The critical pest population level $\tilde{N}$ at which the decision maker will be indifferent between applying and not applying pesticide is referred to as the "economic threshold population," and is defined by:

$$EU'[d\tilde{N}k'(0) - c] = 0.$$

pest damages will elicit an increase in the amount of pesticide applied. This is because an increase in pesticide application reduces risk.

In the absence of constraints on operations, we would generally expect to observe levels of pesticide expenditure that maximize the expected net benefit of pesticide application, i.e. the difference between expected profits with and without pesticide application. This level of application should reflect actual levels of pest infestation. But in practice, information regarding pests and pesticides play a key role in pesticide application decisions. Information regarding pest infestation is nearly always imperfect. Furthermore, the quality of information may be influenced by farmer experience, training, or level of agricultural activity. We expect that farmers who heavily rely on agricultural income in general, and vegetable income in particular, may have greater incentives to apply pesticides as part of income-maintenance and risk-reduction strategies. Below, in Section 4 we explore the implications of this framework by examining per-hectare levels of pesticide expenditure, while specifically accounting for farm characteristics, farmer characteristics, and estimates of pest damage. Before reporting results, we briefly review the data used in the study.

3. Data

Data used in this study come from a 1998-99 survey of 400 vegetable producers in four villages of Bangladesh. Two villages were selected from each of two Union Parishads (Kahsimpur and Konabari) under Joydebpur Thana in the district of Gazipur. The Kashimpur Union Parishad was within a BADC pilot area and the Konabari Union Parishad was outside the BADC pilot area.[2] All the villages are located within the urban belt and have good communication linkages with markets at Dhaka. Prior to the survey, lists of farmers were collected from the respective Union Parishad offices and from the respective study villages. One hundred farmers were randomly chosen in each village. Among the 100 respondents in each village, 25 female respondents were chosen at random. Among remaining respondents, most were males.[3] Hossain and Shively (2000) provide Additional details regarding the survey and sample.

Characteristics of the farm households are reported in Table 3. All four villages in the sample are located within the urban belt and all grew vegetables. For sake of comparison, data in Table 3 are presented for two non-overlapping subsets of the sample: those farms that planted vegetables only (n=178) and those that planted both rice and vegetables (n=222). Looking to the final column of Table 3, which reports data for the full sample, one sees that the average age of the respondents was 40 years. Nearly 20 percent of respondents received some sort of training in agriculture, although the average level of education was reported to be only 3.5 years. Average experience in agriculture was 19 years.

Data indicate that, with the exception of the share of agricultural income in total income, average values for variables reported in Table 3 differed significantly between vegetable growers and rice-vegetable growers. Expenditures on pesticides by vegetable growers (mean = Tk 1,255/acre) were significantly greater ($p < 0.001$) than expenditures by those who grew both rice and vegetables (mean = Tk 879/acre). Incomes of vegetable growers (mean = Tk 26,264) were significantly lower ($p < 0.001$) than incomes of those who grew both rice and vegetables (mean = Tk 51,604). Similarly, the average area cultivated by vegetable growers (mean = 1.1 acres) was significantly lower ($p < 0.001$) than for farms that grew both rice and vegetables (mean = 1.7), as was total farm size. Data also show that, on average, farmers who grew both rice and vegetable received higher income outside of agriculture (Tk 9,958 vs. Tk 5,392; $p < 0.001$).

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[2] The name of the villages under Kashimpur were Enayetpur and Barenda-Noyaparea. Those under Konabari were Aahaki and Joyertek.

[3] The reader should not conclude that these households are female-headed. Instead, the sampling method merely aimed to ensure a high degree of reporting by females. Whether reported behavior in these households with respect to pesticide use differed from behavior reported by male respondents is examined below.

Education and experience among vegetable growers were lower than among farmers producing both rice and vegetables. More than twice as many rice-vegetable growers had received training of any kind compared with their vegetable-only counterparts (26% vs. 12%; $p < 0.001$). For farmers producing only vegetables, reported crop damage by diseases and pest attacks combined was on average lower than for those planting both rice and vegetables (7.6% vs. 18.1%). In terms of access to and use of credit, vegetable producers were more likely to use credit than those who grew rice and vegetables (9% vs. 2%; $p < 0.001$).

In most cases the characteristics of and information reported by female respondents differed from that of male respondents at statistically significant levels. As expected, females were younger, less well educated, less experienced in agriculture, and had received less formal training. They reported lower levels of household income and lower levels of non-agricultural household income. Female-reported cultivated area and share of vegetable income in total agricultural income did not differ from male-reported amounts, but a significantly higher proportion of female respondents reported use of credit. They also reported higher levels of insect and disease damage in vegetables. Whether these differences reflect true differences or different levels of awareness on the part of men and women is not known.

Finally, comparing respondents inside the BADC pilot area and those outside the BADC pilot area, one finds statistically significant differences. Respondents inside the BADC pilot area were younger, less well educated, and had less farming experience than those outside the BADC pilot area. Farms and cultivated areas in the BADC area were significantly smaller than those in the non-BADC area and incomes were lower. The importance of agriculture in general, and of vegetable sales in particular was greater inside the BADC pilot area.

4. Results

Table 4 presents results from three farm-level regressions. All regressions were estimated by ordinary least squares, using per-acre expenditure on pesticides (in Tk) as the dependent variable. The total variation in pesticide expenditure explained by the regressions is relatively low, as reflected in R^2 values ranging from 0.21 to 0.24.

Model 1 uses a set of basic farm-level variables as regressors. These include area cultivated, a BADC pilot area indicator, non-agricultural income, proportion of agricultural income in total income, degree of vegetable commercialization (as measured by the share of vegetable sales in the total value of agricultural production), access to credit, and gender of the respondent. With the exception of credit taken (0/1), all regressors are individually significant at the 95% confidence level. Per-acre pesticide expenditures are positively correlated with area cultivated, levels of non-agricultural income, share of agricultural income, and degree of vegetable commercialization. Controlling for these factors, male respondents reported significantly higher levels of pesticide expenditure than female respondents. Utilization of credit was not correlated with pesticide expenditures. In terms of elasticities, at the sample mean the share of agricultural income and the degree of vegetable commercialization show the largest strength of association. A one percent increase in the degree of vegetable commercialization was associated with a 0.45 percent increase in pesticide expenditure per hectare. A one percent increase in the share of agricultural income in total income was associated with a 1.08 percent increase in pesticide expenditure per acre.

Model 2 adds to Model 1 three farmer-specific variables as explanatory factors. These variables—education, experience in agriculture, and training—are individually insignificant at a standard test level. Furthermore, the null hypothesis that the three farmer-specific variables are jointly insignificant cannot be rejected using an *F*-test (the test value is 1.55, which falls below the critical value of 2.6). Adding these variables does not generally diminish the explanatory importance of the variables from Model 1, although the addition of education, experience, and training reduces the statistical significance of the gender variable below standard significance levels. In other words, a large part of the difference in pesticide expenditure observed for male respondents in Model 1 is likely due to underlying differences between men and women with regard to education, experience, and training.

Model 3 adds to Model 2 four variables measuring farmers' subjective estimates of disease and insect damage to rice and vegetables. Damages are measured as a percentage of the total crop lost. The value of these variables—and the degree of accuracy with which they measure actual disease and pest damage—must be viewed with caution since other information from the survey indicates that many farmers in the sample were unable to accurately identify common diseases and pests. Of the four variables, only the reported disease damage in rice helps to explain variation in pesticide expenditures. Higher perceived levels of disease in rice were positively correlated with pesticide expenditures. The null hypothesis that the three remaining damage variables are jointly insignificant cannot be rejected using an *F*-test (the test value is 1.14, which falls below the critical value of 2.6). The addition of the four damage variables improves the overall fit of the model somewhat, and does not greatly alter the interpretation of the remaining variables. In elasticity terms, however, the importance of damage appears extremely small: a 1 percent increase in the level of disease damage in rice is associated with only a 0.05 percent increase in pesticide expenditure at sample means.

5. Conclusions

This study examined the factors influencing levels of pesticide expenditure on low-income vegetable farms in Bangladesh. Least-squares regressions were used to study patterns of pesticide expenditure on 400 farms from four villages. We found positive and significant correlation between pesticide expenditures per acre and area cultivated, levels of non-agricultural income, agricultural income shares, and degree of vegetable commercialization. Pesticide use was significantly lower inside a BADC pilot area. With the exception of gender, the characteristics of farmer-respondents were not significantly correlated with pesticide expenditures. Farmers' perceived levels of disease and insect damage were only weakly correlated with pesticide expenditures. A clear pattern emerged with respect to intensive use of pesticides wherein farms focusing on agriculture as the main activity and production of vegetables for markets as a focus were more likely to be applying large amount of pesticides. Our results suggest that use of pesticides is somewhat indiscriminate, and only weakly related to experience, education, or training. The primary factors explaining levels of pesticide use are those related to a farmer's ability or capacity to use them. These results suggest that efforts to reduce pesticide use and promote technologies such as Integrated Pest Management (IPM) should be targeted at larger farms and those farms where a greater priority is being placed on agricultural activities, especially vegetable production and sales.

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Table 1: Growth of crop area and production (%), 1979-1990

Crop	**Area**	**Production**
Food grains	0.13	2.33
Paddy	0.05	2.42
Wheat	1.77	0.19
Non food grains	-1.73	-.28
Jute	-1.51	-0.44
Oilseeds	-1.55	-0.57
Pulses	-2.84	-1.82
Spices	-0.51	1.32
Fruits	1.30	-0.04
Vegetables	2.85	1.99
Tubers	-0.39	-0.15
Sugarcane	1.85	0.54
Tea	0.71	0.61

Minor cereals	-12.03	-11.42
All Crops	-0.28	1.62

Source : Faruquee (2000)

Table 2: Estimates of Crop Loss Due to Pests in Asia

Pest	**Country**	**Estimated losses**
Stem borers	Bangladesh (outbreak)	30-70%
	Bangladesh (no outbreak)	3-20%
	India	3-95%
	Malaysia	33%
	Philippines	6.6%
Leafhoppers and planthoppers	Bangladesh	50-80%
	India	1.1-32.5%
Rice bugs and gall midge larvae	India	10-35%
	Vietnam	50-100%
Blast	India	1% loss
	Japan	3%
	China	8-14%
	Philippines	50-85%
Tungro	Bangladesh	40-60%
	Philippines	30%
	Thailand	50%
Bacterial blight	Japan	20-30%
	India	6-60%
	China	5-6%
Sheath blight	Japan	20-25%
	Philippines	7.5-22.7%
	Sri Lanka	10%
	Mainland China	9-12%

Source: Based on various studies cited by Teng et al. (1990).
Note: Reference years for outbreaks vary.

Table 3: Characteristics of sample data for vegetable growers, 1998/99 sample means (standard deviations)

Variable	Vegetable farms only		Vegetable & rice farms		All farms	
Expenditures on pesticides (TK/Acre)	1,255	(766)	879	(1,286)	1,088	(1,046)
Farm size (acres)	1.5	(2.0)	1.8	(1.5)	1.7	(2.1)
Area cultivated (acres)	1.1	(1.6)	1.7	(1.5)	1.4	(1.6)
Income (Tk)	26,264	(34,497)	51,604	(46,969)	40,327	(43,690)
Non-ag income (Tk)	5,392	(11,620)	9,958	(15,887)	7,926	(14,313)
Ag income/Total income (%)	0.84	(0.30)	0.83	(0.22)	0.83	(0.26)
Education of respondent (yrs)	2.2	(3.1)	4.6	(4.3)	3.5	(4.0)
Age of respondent (yrs)	36.8	(10.8)	41.8	(14.4)	39.6	(13.5)
Experience in agriculture (yrs)	16.2	(8.9)	22.0	(12.3)	19.4	(11.3)
Training (0=no;1=yes)	0.12	(0.32)	0.26	(0.44)	0.20	(0.40)
BADC pilot area (0=no; 1=yes)	0.53	(0.50)	0.47	(0.50)	0.50	(0.50)
Gender of respondent (0=female; 1=male)	0.42	(0.49)	0.95	(0.21)	0.72	(0.45)
Veg sales/Total agri. production (%)	0.67	(0.38)	0.43	(0.25)	0.54	(0.34)
Utilized credit (0=no;1=yes)	0.09	(0.29)	0.02	(0.13)	0.05	(0.22)
Rice damaged by diseases (%)	—		4.37	(6.55)	—	
Veg. damaged by diseases (%)	16.52	(20.99)	7.94	(12.15)	11.76	(17.19)
Rice damaged by insects (%)	—		10.43	(10.55)	—	
Veg. damaged by insects (%)	19.76	(22.19)	7.53	(8.54)	12.97	(17.20)
Number of households	178		222		400	

Source: Survey data

Table 4: Regression results; dependent variable is expenditures on pesticides (Tk/acre)

Variable	Model 1	Model 2	Model 3
Constant	-887.43* (343.76)	-911.68* (354.60)	-1012.45* (364.37)
Area cultivated (acres)	134.95* (35.81)	123.37* (36.30)	112.64* (36.31)
BADC pilot area (0=no; 1=yes)	-616.47* (105.87)	-673.34* (112.84)	-704.24* (119.66)
Non-ag income (Tk)	0.025* (0.006)	0.024* (0.006)	0.024* (0.006)
Ag income/Total income (%)	1418.06* (343.32)	1376.96* (344.27)	1413.91* (348.95)
Veg sales/ Value of total agr.	900.81* (163.48)	937.63* (165.88)	928.49* (170.10)
Credit (0=no; 1=yes)	-50.79 (230.96)	-7.87 (231.87)	-85.75 (238.55)
Gender of respondent (0=male; 1=female)	318.47* (113.20)	208.38 (132.23)	311.79 (164.46)
Education (yrs)	—	8.43 (14.09)	4.94 (14.11)
Experience in agriculture (yrs)	—	5.05 (4.92)	3.68 (4.93)
Training (0=no;1=yes)	—	196.40 (135.72)	188.27 (135.52)
Rice damaged by disease (%)	—	—	23.83* (9.77)
Veg. damaged by disease (%)	—	—	3.89 (3.40)
Rice damaged by insects (%)	—	—	-8.62 (6.15)
Veg. damaged by insects (%)	—	—	1.66 (3.88)
R^2	0.21	0.22	0.24
N	400	400	400

Source: survey data

Note: * indicates significance at the 95% confidence level; standard errors are in parentheses.