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SUMMARY

Farmers' perception of the environmental impacts of modern agricultural technology diffusion and factors determining such awareness were examined using survey data from 21 villages in three agro-ecological regions of Bangladesh. Results reveal that farmers are well aware of the adverse environmental impacts of modern agricultural technology, although their awareness remains confined within visible impacts such as soil fertility, fish catches, and health effects. Their perception of intangible impacts such as, toxicity in water and soils is weak. Level and duration of modern agricultural technology adoption directly influence awareness of its adverse effects. Education and extension contacts also play an important role in raising awareness. Awareness is higher among farmers in developed regions, fertile locations and those with access to off-farm income sources. Promotion of education and strengthening extension services will boost farmers' environmental awareness. Infrastructure development and measures to replenish depleting soil fertility will also play a positive role in raising awareness.

Key Words: Bangladesh, environmental impacts, 'Green Revolution', multivariate analysis.

Running title: Environmental impacts of modern agricultural technology

INTRODUCTION

Agriculture constitutes the major source of livelihood in Bangladesh accounting for more than 50% of national income and employs two-third of the labour force. Crop production dominates Bangladesh agriculture accounting for more than 60% of agricultural value added (BBS, 1996). Being one of the most densely populated nations of the world the land-man ratio is highly unfavourable resulting in lack of food security and widespread hunger (Ahmed and Sampath, 1992). As such continued agricultural growth is deemed pivotal in alleviating poverty and raising standard of living of the population. Consequently, over the past four decades, the major thrust for national policies was directed towards transforming agriculture through rapid technological progress to keep up with the increasing population. This led to widespread diffusion of 'Green Revolution' technology with corresponding support in the provision of modern inputs, such as, chemical fertilizers, pesticides, irrigation equipment, institutional credit, product procurement, storage and marketing facilities. As a result food production grew at an estimated annual rate of about 3.3% during the period 1968/69 – 1993/94 with corresponding increase in area under irrigation and modern rice varieties, and use rates of fertilizers and pesticides per unit of land (Rahman, 2002).

Delayed consequences of 'Green Revolution' technology on the environment and the question of sustainability of agricultural growth received priority only recently (Singh, 2000; Shiva, 1991; Alauddin and Tisdell, 1991; and Redclift, 1989). Singh (2000) identified widespread adoption of 'Green Revolution' technologies as a cause of significant soil degradation in Haryana state of India. Shiva (1991) in her analysis of agricultural transformation in Indian Punjab concluded that the 'Green Revolution' produced scarcity and not abundance by reducing the availability of fertile land and genetic diversity of crops. Redclift (1989) examining the issues of environmental degradation in rural areas of Latin America noted that it is closely related to agricultural modernization. Similarly, in Bangladesh, historical analysis revealed that the productivity from the 'Green Revolution' is declining and these technologies now pose a threat to sustainability of economic development (Alauddin and Tisdell, 1991). The adoption rate of modern rice varieties seemed to be stagnated around 60% (BBS, 2001) and there are claims that the ceiling level of adoption has been already reached (Bera and Kelly, 1990). Such stagnation in the diffusion of modern rice varieties is attributed primarily to slower expansion of modern irrigation facilities, susceptibility to pest and disease attack, and the requirement of heavy capital investment (Rahman and Thapa, 1999). Also, it is believed that the soil fertility level, which is the key to keeping up land productivity, seems to be declining in Bangladesh, as evident from actual soil test results of 460 soil samples from 43 profiles from the same locations between 1967 and 1995 (Ali et al., 1997).

Given this backdrop, the present paper examines one of the least touched upon issues related to diffusion of modern agricultural technology, specifically examination of farmers' perception or awareness of the environmental impacts associated with this technology and identification of socio-economic factors determining such awareness. The importance arises since perception is viewed to contain goals including those achieved and those yet to be achieved and, hence, is looked upon as a guiding concept of behaviour and/or decision-making (Gengaje, 1996). And sustainability of agricultural production depends largely on actions of the farmers and their ability to make decisions given the level of knowledge and information available to them. The hypothesis is that the 'level' and 'duration' of adoption of this modern agricultural technology would positively influence farmers' awareness of its environmental consequences in addition to other farm and farmer specific socio-economic factors. The next section describes the methodology and data. Section three provides the results and the final section concludes.

METHODOLOGY

Theoretical framework

Economic analysis of farmers' technology adoption decision is deeply rooted on the assumption of utility maximization (e.g., Baidu-Forson, 1999; Adesina and Baidu-Forson, 1995; and Adesina and Zinnah, 1993). The underlying utility function, which ranks the preference of individual farmers of a given technology, is not observable. What is observed is a set of farm and farmer specific socio-economic characteristics that influence farmers' decision to adopt a given technology, which is assumed to provide him/her with a certain level of perceived utility. In addition to socio-economic factors determining adoption, farmers' perception of the modern technology also has significant influence on adoption decisions (Negatu and Parikh, 1999; and Adesina and Zinnah, 1993). Following this adoption – perception paradigm, we postulate that, at the post adoption stage, an observable set of technology attributes and farm specific socio-economic characteristics will similarly influence farmers' awareness of the adverse environmental impacts associated with the adopted technology. This is because a farmer's perception (in this case environmental awareness) may be determined by his/her experience of growing the new variety, extension visits, his/her knowledge about the modern variety and other conditions (Negatu and Parikh, 1999).

The econometric model

Among the limited dependent variable models widely used to analyse farmers' decision making processes, Tobit analysis has gained importance since it uses all observations, both those are at the limit, usually zero (e.g., non-adopters), and those above the limit (e.g., adopters), to estimate a regression line, as opposed to other techniques that uses observations which are only above the limit value (McDonald and Moffit, 1980). In our case, farmers could be unaware of any environmental impacts of modern agricultural technology even after adoption. Therefore, there are a number of farmers with zero environmental awareness at the limit. In such case, the application of Tobit analysis is most suited because of the censored nature of the data. The stochastic model underlying Tobit may be expressed as follows (McDonald and Moffit, 1980):

$$
\begin{aligned}
y_i \quad &= X_i\beta + u_i \qquad && if\ X_i\beta + u_i > 0 \\
&= 0 && if\ X_i\beta + u_i \leq 0, \\
& && i = 1,2,......n, \qquad (1)
\end{aligned}
$$

where n is the number of observations, y_i is the dependent variable (farmers' environmental awareness), X_i is a vector of independent variables representing technology attributes and farm and farmer specific socio-economic characteristics, β is a vector of parameters to be estimated, and u_i is an independently distributed error term assumed to be normal with zero mean and constant variance σ^2. The model assumes that there is an underlying stochastic index equal to ($X_i\beta$ + u_i) which is observed when it is positive, and hence qualifies as an unobserved latent variable. The relationship between the expected value of all observations, E_y and the expected conditional value above the limit E_y* is given by:

$$E_y = F(z)\, E_y*$$

where F(z) is the cumulative density normal distribution function and $z = X\beta/\sigma$. Following the framework of McDonald and Moffit (1980), the effect of the *k*th variable of X on y led to decomposition as follows:

$$\delta E_y / \delta X_k = F(z)(\delta E_y * / \delta X_k) + E_y * (\delta F(z) / \delta X_k) \quad (2)$$

Equation (2) suggests that the total change in elasticity of y can be disaggregated into: (a) a change in the elasticity of intensity of awareness (change in awareness) for farmers who already are aware; and (b) change in the elasticity of awareness (change in the probability of becoming aware).

Study regions and the data

The study is based on farm-level cross section data for crop year 1996 collected from three agro-ecological regions of Bangladesh. The survey was conducted from February to April 1997. The specific selected regions were Jamalpur (representing wet agroecology), Jessore (representing dry agroecology), and Comilla (representing both wet agroecology and an agriculturally developed area). A multistage random sampling technique was employed to locate the districts, then the *thana* (subdistricts), and then the villages in each of the three subdistricts and finally the sample households. A total of 406 households from 21 villages (175 households from eight villages of Jamalpur Sadar *thana*, 105 households from six villages of Manirampur *thana* and 126 households from seven villages of Matlab *thana*) form the sample for the study.

Detailed crop input-output data were collected for 10 groups of crops[1]. The dataset also includes information on level of soil fertility[2] determined from soil samples collected from representative locations and information on level of infrastructure[3] development in the study villages.

The empirical model

The estimated empirical model uses a set of technological attributes, farm-specific socio-economic characteristics and regional characteristics as explanatory variables that are assumed to influence farmers' environmental awareness. Choice of the explanatory variables is based on the adoption – perception literature with similar justification thereof. Table 1 presents the description, measure, hypothesized direction of the relationship between explanatory variables with the dependent variable (environmental awareness index) and summary statistics.

The dependent variable: farmers' environmental awareness index[4]

Figure 1 summarizes the construction procedure of the farmers' environmental awareness index. Farmers' perception on the environmental impacts of technological change is elicited in two steps. First, a set of 12 specific environmental impacts was read to the respondents who were asked to reveal their opinion on each of these impacts (E_j). A value of 1 is assigned for each of the impact indicators where the farmer recognises the impact, and 0 otherwise. Selection of the list of indicators was based on the Focus Group Discussions (FGD) with the farmers during a pre-testing stage prior to the administration of the structured questionnaire. In the next step, farmers were then asked to reveal the relative importance of each impact indicator on a five-point scale (R_m). A score of 1 is assigned for least importance and 5 for very high importance. These ranks are then converted into weighted scores (W_q). A weight of 0.2 is assigned for lowest rank of 1 and a weight of 1 is assigned for the highest rank of 5. A zero weight is assigned for indicators where the farmer does not recognise the impact. Then the overall environmental awareness index (EAI) for each farmer is computed by summing up the weighted scores of each impact indicator and then dividing by total number of impacts (Figure 1).

[INSERT FIGURE 1 HERE]

The explanatory variables

Two principal technology attributes, the 'level' and 'duration' of modern technology adoption, are hypothesized as the major determinants in raising farmers' environmental awareness since perception comes from experience of adoption (Negatu and Parikh, 1999). The variable 'area under modern varieties of rice and/or wheat' reflects the level and extent of modern agricultural technology adoption by these farmers[5] and 'years of actually growing modern varieties of rice' reflects duration of involvement with this technology and are expected to insist the farmer to identify reasons for variation in output level and/or declining productivity over time, if any. Access to modern irrigation facilities is an important pre-requisite for growing modern rice varieties, particularly, for the HYV *Boro* rice grown in dry season. Lack of access to modern irrigation facilities has been identified as one of the principal reasons for stagnation in the expansion of modern rice which currently accounts for a little over 50% of total rice area (Rahman and Thapa, 1999; Hossain, et al., 1990, and Hossain, 1989). Nevertheless, farmers choose to grow modern varieties of rice during the main monsoon season (*Aman* season) with heavy reliance on monsoon rain as it still yields twice that of traditional rice varieties if managed with proper supplementary irrigation and water control. Hence, the irrigation variable is incorporated to account for its influence in raising awareness.

Use of age and education level of farmer as explanatory variables in adoption – perception studies is fairly common (e.g., Neupane et al., 2002; Mbaga-Semgalawe and Folmer, 2000; Baidu-Forson, 1999; Adesina and Baidu-Forson, 1995; and Adesina and Zinnah, 1993). These variables, acting as a group or separately, are expected to have an influence in raising environmental awareness for the following reasons. The education variable is used as a surrogate for a number of factors. At the technical level, access to information as well as capacity to understand the technical aspects related to the modern technology may influence crop production decisions. Age of the farmer is incorporated to account for the maturity of the farmer in his/her decision-making ability.

Agricultural extension can be singled out as one of the important sources of information dissemination directly relevant to agricultural production practices, particularly in nations like Bangladesh where farmers has very limited access to information. This is reinforced by the fact that many studies found a significant influence of extension education on adoption of land-improving technologies (e.g., Baidu-Forson, 1999; and Adesina and Zinnah, 1993). Therefore, this variable is incorporated to account for its influence as well as to make a case for strengthening extension services and networks if proved useful.

According to Chayanovian theory of the peasant economy, higher subsistence pressure increases the tendency to adopt new technology and this has been found to be consistent with the Bangladesh case (Hossain, et al., 1990; and Hossain, 1989). The subsistence pressure variable, measured by family size per farm household was incorporated to account for its influence in raising awareness, if any.

In Bangladesh, land ownership serves as a surrogate for a large number of factors as it is a major source of wealth and influences crop production. The impact of tenancy on the extent of modern technology adoption is varied (Hossain, et al., 1990). Although there is no significant difference in adoption rate between owner-operators and tenants, the owner-operators were found to be relatively cost-efficient in producing modern rice (Coelli, et al., 2002). The tenancy variable is incorporated to test whether there is any difference in the level of perception between landowners and tenant farmers. A positive coefficient for this variable implies that landowners are relatively more aware than the tenants.

The percentage of income earned off-farm was included to reflect the relative importance of non-agricultural work in these farm households. Mbaga-Semgalawe and Folmer (2000) used off-farm income as a proxy for measuring investment potential soil conservation measure.

Infrastructure affects agricultural production indirectly through prices, diffusion of technology and use of inputs and has profound impact on the incomes of the poor (Ahmed and

Hossain, 1990). The state of infrastructure implies improved access to markets and institutions, which in turn can improve access to information and hence raise farmers' awareness. This effect is captured by the index of underdevelopment of infrastructure. Higher soil fertility status implies favourable physical conditions for agricultural production. This in turn would influence crop production decisions including adoption of modern agricultural technology.

[INSERT TABLE 1 HERE]

RESULTS

Environmental impacts of technological change in agriculture: farmers' perceptions

'Decline in soil fertility' featured at the top of the list of perceived adverse environmental impacts of modern agricultural technology diffusion, followed by 'health effects', 'decline in fish catch', 'increase in crop disease', 'soil compaction', 'increase in insect/pest attack', 'soil erosion' and 'soil salinity' (Table 2). The perception of the adverse impact of modern technology on water resources is, however, very weak, as evident from the sharp decline in index values. This implies that though farmers are aware of the adverse environmental impacts of modern agricultural technology, their awareness of the extent remains confined to the visible impacts evident from farm fields and crop production on which their livelihoods depend. The awareness of indirect impacts such as 'contamination of soil and water bodies' is poor as indicated by low index values. This may well be due primarily to high levels of illiteracy amongst the farmers (see Table 1) and poor exposure to messages on health and hygiene. All relative rankings of impacts across regions are significantly ($p<0.01$) and positively related, with the value of rank-correlation coefficient varying within a range of 0.70 to 0.99 (see lower section of Table 2).

[INSERT TABLE 2 HERE]

Determinants of farmers' environmental awareness: a multivariate analysis

Since the overall environmental awareness index (EAI) is a composite index formed by taking into account 12 impact indicators, we subdivided this list into four sub-categories of impacts and constructed sub-indices using same method. The intent was to examine consistency of the effects of the chosen explanatory variables on these sub-categories of impacts. These sub-indices are: (a) Soil related impacts (EAI_S) – includes 'reduces soil fertility', 'compacts/hardens soil', 'increases soil erosion', 'increases soil salinity', and 'increases toxicity in soil'; (b) Water related impacts (EAI_W) – includes 'contaminates water source', 'creates water logging', and 'increases toxicity in water'; (c) Impact on crops (EAI_C) – includes 'increases insect/pest attack' and 'increases disease in crops'; and (d) Impact on human (EAI_H) – includes 'human health' impacts (see Table 2 for list of impacts).

Table 3 presents the parameter estimates of all the five models applying the Tobit regression procedure[6]. Except for the age and family size variables, the coefficients for the remaining nine variables representing farmers' socio-economic characteristics and production circumstances were significantly different from zero at 10% level at least indicating that inclusion of these variables were correctly justified in explaining farmers' overall environmental awareness (see last column of Table 3). The Likelihood Ratio test results, presented at the bottom of Table 3, further statistically validates that these variables contribute significantly as a group to the explanation of the environmental awareness level of the farmers. The direction of the effect of each variable in these models is same when it is significantly different from zero, thereby confirming that these variables are robust in explaining farmers' environmental awareness. Decomposition of Tobit total elasticity estimates into elasticity of awareness and elasticity of intensity of awareness using parameters of EAI model is presented in the last two columns of Table 3. Results show that, except for the soil fertility variable, any marginal changes in the chosen explanatory variable increases the probability of becoming environmentally aware more than it increases the intensity of awareness.

'Level' and 'duration' of involvement with modern technology are the two most important determinants, which directly influences farmers' awareness of its ill effects thereby, supporting the maintained hypotheses. The total elasticity values of 'level' and 'duration' of involvement are 0.57 and 0.61, which are divided into 0.34 and 0.35 for the elasticity of becoming aware and 0.23 and 0.26 for the elasticity of awareness intensity, respectively. This suggests that either a 10% change in the expansion of area under modern technology or change in duration of growing modern varieties is expected to result in about 4% increase in the awareness probability and 2 – 3% increase in awareness intensity. Lack of access to modern irrigation also raises awareness. Lack of this important input, which is a pre-requisite, results in poor yield performance and perhaps higher incidence of pest and disease infestations, thereby, enabling farmers to realize the ill effects of modern technology. The elasticity estimates show that a 10% reduction in irrigated area is expected to result in about 3% increase in the awareness probability and 1% increase in its intensity.

Both education and extension contact significantly increase awareness, as expected. The total elasticity values are 0.55 and 0.52 for education and extension, implying that a 10% increase either in education level or extension contact is expected to result in about 3% increase in the awareness probability and 2% increase in its intensity, respectively. These findings conform to the results of other adoption – perception studies (e.g., Neupane et al.; 2002; Mbaga-Semgalawe, 2000; Baidu-Forson, 1999; and Hossain et al., 1990). Next, owner operators, who are presumably relatively large farmers as well, are relatively more aware than the tenants. One of the pathways to trigger awareness among owner operators might be through receipt of lesser amount of earning in the form of land rent wherein the popular arrangement (also set by law) is 33% of the total produce with selective sharing of input costs. Those who earn their livelihood substantially from off-farm sources are also more aware. Probably, these are the households who eventually turned towards off-farm activities, provided opportunities exist, after realizing that modern agricultural technologies are not paying off over time.

Farmers in developed regions[7] are more aware as it is probably endowed with better access to information and opportunities to exchange information. Negatu and Parikh (1999) concluded that proximity to town (a proxy of developed infrastructure) is an important explanatory variable affecting perception (of marketability of modern variety). Also, awareness is significantly higher in areas with relatively better soil fertility status. The total elasticity value is highest estimated at 0.91 indicating that 10% improvement in soil fertility level is expected to raise probability of awareness by 2% and its intensity by 7%.

[INSERT TABLE 3 HERE]

DISCUSSION AND POLICY IMPLICATIONS

The study deals with one of the least touched upon issues associated with the diffusion of modern agricultural technology, specifically its impact on the environment, through exploring farmers' perceptions and their determinants, since sustainability of agricultural production depends largely on the action of the farmers. Results reveal that farmers are well aware of the adverse environmental impacts of modern agricultural technology. However, their awareness level remains confined within the visible impacts that are most closely related to their local experience. This is reflected in their ranking of the environmental impacts (Table 2). Review of secondary evidences, the soil test results and time-trend analyses of relevant indicators also rendered support and validated farmers' environmental awareness (for details, see Rahman and Thapa, 1999).

All three technology attributes, the 'level' and 'duration' of modern agricultural technology adoption and 'lack of modern irrigation facilities' directly influence farmers' awareness of its ill effects. This has profound implications for agricultural sustainability because perception and/or awareness significantly condition adoption behaviour (Negatu and Parikh, 1999; Adesina and Baidu-Forson, 1995; and Adesina and Zinnah, 1993) and perhaps partly explains stagnation of modern rice expansion after four decades of major thrust in its diffusion. Morris et al., (1996) reported that locations where facilities for mechanical irrigation are uncertain, farmers opt to choose modern wheat and is one of the principal reasons for expansion in wheat acreage in recent years, although in financial terms, production of modern *Boro* rice is far more profitable (Rahman, 1998). Also, such awareness may influence adoption of conservation measures, a proposition worth exploring. Mbaga-Semgalawe and Folmer (2000), found partial support in their empirical findings that perception of a soil-erosion problem as a first stage in the sequential household decision making process leads to adoption of conservation measures and finally to effort devoted to conservation.

Among the socio-economic factors, education and extension contacts play an important role in raising awareness. This clearly provides an opportunity to design and strategise information dissemination process through existing educational institutions and agricultural extension system. Several studies highlighted use of extension education to promote conservation (e.g., Neupane et al., 2002; Mbaga-Semgalawe and Folmer, 2000; and Baidu-Forson, 1999).

Regional characteristics (state of infrastructure and soil fertility status) also influence environmental awareness. This may very well justify improvement in rural infrastructure, as it seems to facilitate access to resources vis-à-vis improved information. Poor rural infrastructure has been identified as one of the major impediments to agricultural development in Bangladesh (Ahmed and Hossain, 1990). Promotion of soil fertility status, however, would require considerable effort in disseminating important conservation information as well as crop production practices and crop-mixes to suit specific agro-ecological niches. In this context, it may be mentioned that the Soil Resources Development Institute (SRDI) in collaboration with five other institutes[8] launched a project to prepare 'Land and Soil Resource Use Guide' (in Bangla) for each of the 460 sub-districts of the country in early 1980s. The manual consists of physical and chemical test result of soil for each soil series, a soil map drawn on 1:50,000 scale for each sub-district, plus fertilizer recommendation guide for major and minor crops. These manuals are then distributed to Block Supervisors, the lowest unit of agricultural extension officials. However, considerable delay (about 15 years since the project started to collect soil samples) in publishing the complete set of manuals reduced its current effectiveness in planning. Nevertheless, these manuals can still serve as a basis to identify suitable crops for each soil series complemented with updated fertilizer recommendation guide as well as extension services. In fact, areas that are fertile are also home to relatively higher levels of modern wheat acreage as well as legume crops (that fix soil nitrogen), particularly, the survey villages in Jessore region (Rahman, 1998).

The policy implications are clear. Promotion of education and strengthening extension services both in terms of its quality and coverage would boost farmers' environmental awareness. Also, development of rural infrastructure and measures to replenish depleting soil fertility will play a positive role in raising awareness. It is hoped that results of this study could be used to develop a comprehensive agricultural development strategy conducive to maintaining or even increasing agricultural production without affecting environmental quality.

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Notes

1. The crop groups are: traditional rice varieties (Aus – pre-monsoon, Aman – monsoon, and Boro – dry seasons), modern/high yielding rice varieties (Aus, Aman, and Boro seasons), modern/high yielding wheat varieties, jute, potato, pulses, spices, oilseeds, vegetables, and cotton. Pulses in turn include lentil, mungbean, and gram. Spices include onion, garlic, chilly, ginger, and turmeric. Oilseeds include sesame, mustard, and groundnut. Vegetables include eggplant, cauliflower, cabbage, arum, beans, gourds, radish, and leafy vegetables.

2. Information on physical and chemical properties of soil from the selected farmers' fields was collected to evaluate the general fertility status of the soil and to examine inter-regional differences (if any) between the study areas. Ten soil-fertility parameters were tested. These were: (1) soil pH, (2) available nitrogen, (3) available potassium, (4) available phosphorus, (5) available sulphur, (6) available zinc, (7) soil texture, (8) cation exchange capacity (CEC) of soil, (9) soil organic matter content, and (10) electrical conductivity of soil. The soil fertility index was constructed from test results of these soil samples. High index value refers to better soil fertility.

3. The index of infrastructure was constructed using the cost of access approach. A total of 13 elements were considered for its construction. These are, (1) primary market, (2) secondary market, (3) storage facility, (4) rice mill, (5) paved road, (6) bus stop, (7) bank, (8) union office, (9) agricultural extension office, (10) high school, (11) college, (12) thana (sub-

district) headquarter, and (13) post office. High index value refers to high under developed infrastructure (for details of construction procedure, see Ahmed and Hossain, 1990).

4. Construction procedure of the farmers' environmental awareness index and secondary evidence confirming validity of such awareness has been reported in Rahman and Thapa (1999). However, for the ease of exposition, the construction procedure of the index is reproduced in this paper with permission.

5. In cross-section data, this is a standard proxy for specifying a technology variable, particularly in Bangladesh (see Ahmed and Hossain, 1990, Hossain et al., 1990, and Hossain, 1989).

6. LIMDEP Version 7 (1997) was used for the analyses.

7. The index reflects the underdevelopment of infrastructure, and therefore, a negative sign indicates positive effect on the dependent variable.

8. The collaborating institutes are Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh Agricultural Research Council (BARC), and Department of Agricultural Extension, respectively.

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Table 1. Description, summary statistics and hypothesized direction of influence of the variables specified.

Description	Measurement	Hypothesized direction of influence	Mean	Standard deviation
Technology characteristics				
Level or extent of involvement with modern agricultural technology (defined as the amount of cultivated land allocated to modern rice and wheat varieties).	Hectare	+	0.74	0.79
Duration of involvement with modern agricultural technology (defined as years of growing modern varieties of rice)	Years	+	9.71	5.71
Irrigation index (defined as proportion of total cultivated land under modern irrigation facilities)	Percent	±	0.62	0.30
Socio-economic characteristics				
Education level of the farmer	Completed years of schooling	+	3.74	4.26

Description	Measurement	Hypothesized direction of influence	Mean	Standard deviation
Age of the farmer	Years	+	46.88	14.46
Subsistence pressure (defined as family size)	Persons per household	±	6.02	2.53
Tenurial status	Value is 1 if owner operator, 0 otherwise	±	0.58	0.49
Extension contact	Value is 1 if had extension contact in the past one year, 0 otherwise	+	0.13	0.33
Off-farm income share in the household	Percent	±	0.22	0.31
Regional characteristics				
Infrastructure	Number	+	33.32	14.95
Soil fertility level	Number	+	1.68	0.19

Note: ± means that the direction of influence is indeterminate, and + means positive influence.

Table 2. Ranking of farmers' perception on environmental impacts of modern agricultural technology.

Sl. no.	Environmental impacts of modern agricultural technology	Index weighted by rank of responses[a]											
		Jamalpur region			Jessore region			Comilla region			All region		
		Agree (%)	Index	Rank	Agree (%)	Index	Rank	Agree (%)	Index	Rank	Agree (%)	Index	Rank
1	Reduces soil fertility	85	0.82	1	98	0.94	1	76	0.63	1	86	0.79	1
2	Affects human health	74	0.60	2	87	0.79	2	70	0.45	4	76	0.60	2
3	Reduces fish catch	65	0.55	3	65	0.59	4	91	0.57	2	73	0.56	3
4	Increases disease in crops	66	0.51	4	74	0.61	3	66	0.45	3	68	0.52	4
5	Compacts/ hardens soil	51	0.36	7	71	0.57	6	49	0.37	5	56	0.42	5
6	Increases insect/ pest attack	53	0.43	5	68	0.58	5	21	0.12	9	47	0.37	6
7	Increases soil erosion	53	0.39	6	67	0.49	7	18	0.11	10	46	0.33	7
8	Increases soil salinity	41	0.28	8	56	0.43	8	36	0.24	6	43	0.30	8
9	Contaminates water source	35	0.26	9	34	0.24	9	16	0.08	11	29	0.20	9
10	Increases toxicity in soil	22	0.14	11	20	0.16	11	21	0.13	7	21	0.15	10
11	Creates water logging	22	0.14	10	22	0.18	10	6	0.05	12	17	0.13	11

Sl. no.	Environmental impacts of modern agricultural technology	Index weighted by rank of responses[a]											
		Jamalpur region			Jessore region			Comilla region			All region		
		Agree (%)	Index	Rank	Agree (%)	Index	Rank	Agree (%)	Index	Rank	Agree (%)	Index	Rank
12	Increases toxicity in water	17	0.12	12	10	0.07	12	20	0.13	8	16	0.11	12
	All impacts	49	0.38[b]	2	56	0.47[b]	1	41	0.28[b]	3	48	0.37	
		Rank correlation among regions (Spearman rank correlation coefficient r_s)											
	Jamalpur region	1.00											
	Jessore region	0.99***			1.00								
	Comilla region	0.70***			0.73***			1.00					
	All region	0.97***			0.98***			0.80***			1.00		

Note: The higher the index the stronger the perception.

[a] Ranking done by weighting individual responses by their ranks.

[b] Ranking done across 3 regions.

*** Significant at 1% level ($p<0.01$).

Source: After Rahman and Thapa (1999).

Table 3. Estimated Tobit models for factors influencing farmers' environmental awareness.

Variables	**Dependent variables**					**Elasticity of**[a]	
	Index of soil related impacts	**Index of water related impacts**	**Index of impact on crops**	**Index of impact on human health**	**Environmental awareness index**	**awareness (probability of becoming aware)**	**intensity of awareness (change in awareness)**
	$\mathbf{EAI_S}$	$\mathbf{EAI_W}$	$\mathbf{EAI_C}$	$\mathbf{EAI_H}$	**EAI**		
Constant	-0.0298	-0.1372	-0.0861	0.5436	0.1316		
	(-0.254)	(-0.595)	(-0.297)	(1.177)	(1.548)		
Technology characteristics							
Extent of technology adoption	0.0227	0.0679	0.0786	0.1455	0.0351	0.3391	0.2277
	(1.437)	(2.204)**	(1.974)**	(2.231)**	(3.055)***		
Duration of adoption	0.0049	0.0082	0.0080	0.0180	0.0045	0.3487	0.2622
	(2.481)***	(2.115)**	(1.649)*	(2.226)**	(3.131)***		
Irrigation facilities	-0.0159	-0.1982	-0.2408	0.0381	-0.0497	-0.2857	-0.1361
	(-0.430)	(-2.660)***	(-2.618)***	(0.262)	(-1.858)*		

Variables	**Dependent variables**					**Elasticity of**[a]	
	Index of soil related impacts	**Index of water related impacts**	**Index of impact on crops**	**Index of impact on human health**	**Environmental awareness index**	**awareness (probability of becoming aware)**	**intensity of awareness (change in awareness)**
Socio-economic characteristics							
Education of farmer	0.0068	0.0066	-0.0007	-0.0003	0.0050	0.3337	0.2133
	(2.317)**	(1.177)	(-0.095)	(-0.023)	(2.381)**		
Age of farmer	0.0005	-0.0014	0.0010	-0.0032	0.0002	0.3281	0.2004
	(0.633)	(-0.857)	(0.520)	(-1.014)	(0.414)		
Subsistence pressure	0.0015	-0.0137	-0.0166	-0.0028	-0.0023	-0.3041	-0.1593
	(0.333)	(-1.478)	(-1.475)	(-0.152)	(-0.690)		
Owner operator	0.0507	0.0579	0.0379	-0.0103	0.0297	0.3331	0.2117
	(2.196)**	(1.258)	(0.665)	(-0.112)	(1.773)*		
Extension contact	0.0452	0.0793	0.1472	0.3250	0.0481	0.3236	0.1914
	(1.322)	(1.194)	(1.731)*	(2.254)**	(1.939)*		
Off-farm income share	0.0571	0.1585	0.1024	0.1177	0.0544	0.3285	0.2014

Variables	**Dependent variables**					**Elasticity of**[a]	
	Index of soil related impacts	**Index of water related impacts**	**Index of impact on crops**	**Index of impact on human health**	**Environmental awareness index**	**awareness (probability of becoming aware)**	**intensity of awareness (change in awareness)**
	(1.578)	(2.201)**	(1.136)	(0.824)	(2.072)**		
Regional characteristics							
Infrastructure	-0.0016	-0.0017	-0.0037	-0.0112	-0.0017	0.2519	0.1029
	(-2.088)**	(-1.095)	(-2.009)**	(-3.718)***	(-3.179)***		
Soil fertility	0.1879	0.1161	0.3599	0.1798	0.1233	0.2438	0.6684
	(3.205)***	(1.013)	(2.481)***	(0.772)	(2.900)***		
Likelihood Ratio test ($\chi^2_{11,0.95}$)	57.46***	41.99***	42.77***	31.63***	78.09***		

Note: Elasticities are computed using the parameter estimates from the Overall Environmental Awareness Index (EAI) model.

Figures in parentheses are asymptotic t-ratios.

Likelihood ratio (LR) test is used to test the null hypothesis that there is no relationship between the farmers' environmental awareness level and the set of independent variables included in the model (i.e., H_0: $\beta_1 = \beta_2 = ... = \beta_{11} = 0$).

*** Significant at 1% level (p<0.01);

** Significant at 5% level ($p<0.05$);

* Significant at 10% level ($p<0.10$).

Figure 1. Construction of the environmental awareness index.

Opinion on the *j*th impact	Disagree	Agree				
Impact value (E_j)	0	1				
Rank of the importance of *j*th impact on a five-point scale (R_m)	0	1	2	3	4	5
Rank interpretation	None	Very low	Low	Medium	High	Very high
Weights (W_q)	0	0.2	0.4	0.6	0.8	1.0
Aggregate awareness index of the *i*th farmer (AAI_i)	$\sum_{j=1}^{12}\sum_{m=0}^{5}\sum_{q=0}^{1} ERW_{jmq}, \quad \forall\ j=1,2,...,12;\ m=0,1,.....,5; q=0,0.2,...1.$ (1)					
Overall environmental awareness index of the *i*th farmer (EAI_i)	$\frac{AAI_i}{N}, \ \textit{where}\ N=12\,(\textit{total number of impacts}).$ (2)					