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Agricultural diversification and integrated pest management in Bangladesh

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Abstract

We study factors associated with a shift toward diversified, high-valued vegetable crops and the incentives associated with the use of IPM methods for vegetable producers in Bangladesh. The primary objective is to measure how IPM technologies affect the crop and technology choices of low-income rice farmers. A three-season household optimisation model is used to study crop and technology choice under price and yield uncertainty. The model is parameterised using data from vegetable farms and experimental IPM trials conducted in Bangladesh. Simulation results show that access to IPM technology and IPM availability combined with access to credit increase household welfare and lead to higher rates of vegetable adoption. Off-farm employment opportunities work against vegetable cultivation and IPM use by risk-averse farmers. Implications for policy and extension efforts are highlighted.

JEL classification: D13; O13; O33; Q16

Keywords: IPM; Bangladesh; Vegetable production; Off-farm employment

1. Introduction

Bangladesh has recently attained self-sufficiency in food production (Government of Bangladesh, 2001). Nevertheless, the country's existing structure of agricultural production poses challenges for the future. In the absence of rice exports, and under conditions of low and falling income elasticities of demand for rice, domestic markets are unlikely to fuel rapid income growth (Dorosh, 2000; Timmer, 1988). Under an export regime, the outlook for rice is even less favourable. Economic returns for rice production, calculated at export parity prices, are much lower than for many alternative crops, including vegetables (Mahmud et al., 1994). This has sparked interest on the part of policy makers in promoting vegetable production among smallholders, both to serve domestic markets and to exploit growing opportunities in the export arena.

Despite upbeat forecasts for diversified farming strategies in Bangladesh, many observers regard widespread promotion of vegetable production in Bangladesh as misguided, in part due to concerns regarding the environmental and health effects of pesticide use. According to the Ministry of Agriculture, between 1982 and 1992 use of insecticides,

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herbicides and fungicides rose by 66, 260 and 1467%, albeit from a small base (Government of Bangladesh, 1995a). Several studies clearly document that, due to inadequate labelling and lack of farmer knowledge, pesticides are widely over- or misused in Bangladesh (Ramaswamy, 1992; Jackson, 1991). In some settings excessive application of pesticide may cause more harm than benefit (Antle and Pingali, 1994) and where farmer exposure is high—as it is in Bangladesh—the on-farm benefits from pesticide use can be completely offset by adverse impacts on farmer health and reduced worker productivity (Rola and Pingali, 1993). In Bangladesh, off-site effects are also important. For example, a recent study indicates 11% of tested water samples in Bangladesh contained pesticide residues at levels higher than WHO guidelines (Government of Bangladesh, 1995b).

As a result of these and similar findings, high rates of pesticide use in vegetable production have emerged as a policy concern in Bangladesh (Hossain et al., 1999). In response, a number of integrated pest management (IPM) strategies are being developed or adapted for use by smallholders in Bangladesh. While these IPM strategies often involve much more prudent use of pesticides than the methods they seek to replace, they remain unfamiliar, labour intensive and possibly prone to failure to protect fully against pest attacks. Under these conditions, rates of IPM adoption by smallholders remain uncertain, and potential barriers to IPM adoption remain unclear. In this paper we use data from recent experimental IPM trials and a survey of 400 peri-urban vegetable producers to study the potential impact of IPM availability on farmer's crop and technology choices. Our aim is to learn whether, under a set of stylised assumptions regarding farmer behaviours and constraints, IPM approaches would be attractive to farmers. We also examine the extent to which changes in variables broadly construed to be under the control of policy makers—including access to credit and employment outside agriculture—might lead to changes in cropping patterns, technology choices and smallholder income and welfare.

2. Model

To examine the potential value of IPM methods to smallholder vegetable farmers in Bangladesh we develop a model that focuses on the crop-technology choices of a representative farm household. We assume the household combines crops and technologies in each of three seasons (identified by the superscript s) to maximise expected utility, defined over n states of nature (indexed by j):

$$\mathrm{EU} = \sum_{s=1}^{3}\sum_{j=1}^{n}\pi_j u_j^s. \tag{1}$$

We assume for convenience that states are independent of season so that π_j and u_j^s represent probabilities and sub-utility functions in each state of nature. Utility is defined as a negative exponential function of consumption:

$$u_j^s = -\mathrm{e}^{-\rho c_j^s}, \quad \text{for } \rho > 1, \tag{2}$$

where ρ is the coefficient of constant absolute risk aversion and c_j^s represents consumption of a composite good (rice) in season s in state j. Consumption in each state is defined by rice directly consumed and cash income converted to a rice equivalent measure. We impose a transaction cost on rice purchases and accommodate cash requirements and the need for savings carryover by defining working income in each season as net revenue plus prior-season savings, minus savings carried forward. We allow savings to be used for consumption, input purchases or both. Farmers may obtain credit at a simple interest rate. Loans plus accrued interest must be repaid before the start of the next season. We do not discount outcomes.

We assume the household maximises expected utility subject to an initial endowment $\bar{E}$. Using t to denote a crop-technology index, the household also faces a constraint on the amount of land available for allocation among crop-technology packages in each season:

$$\sum_t A_t^s \le \bar{A}. \tag{3}$$

Available labour (household and hired) is utilised subject to fixed labour requirements across technologies and a constraint on available labour:

$$\sum_t A_t^s L_t^s \le L_{\mathrm{own}}^s + L_{\mathrm{hired}}^s, \quad L_{\mathrm{own}}^s + L_{\mathrm{sold}}^s \le \bar{L}. \tag{4}$$

We assume the household faces a seasonal cap on borrowing:

$$x^s \le \bar{x}, \tag{5}$$

Table 1
Characteristics of survey households, sample means (standard deviations)

Variable	Vegetable farms only	Vegetable and rice farms	All farms
Area cultivated (ha)	0.45 (0.65)	0.69 (0.60)	0.57 (0.65)
Income (=Taka)	26,264 (34,497)	51,604 (46,969)	40,327 (43,690)
Non-agricultural income (=Taka)	5,392 (11,620)	9,958 (15,887)	7,926 (14,313)
Agricultural income/total income (%)	0.84 (0.30)	0.83 (0.22)	0.83 (0.26)
Education of respondent (years)	2.2 (3.1)	4.6 (4.3)	3.5 (4.0)
Age of respondent (years)	36.8 (10.8)	41.8 (14.4)	39.6 (13.5)
Experience in agriculture (years)	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)
Gender of respondent (0 = female; 1 = male)	0.42 (0.49)	0.95 (0.21)	0.72 (0.45)
Utilised credit (0 = no; 1 = yes)	0.09 (0.29)	0.02 (0.13)	0.05 (0.22)
Number of households	178	222	400

Note: Means are statistically different at a 95% significance level for all variables except agricultural income/total income.

and we also impose a minimum consumption target:

$$c_j^s \geq c^{\min}, \tag{6}$$

where $c^{\min}$ represents a seasonal caloric minimum for the household in all states of nature.

Production is defined by a set of crop-technologies packages. We assume that the production requirement sets are fixed (Leontief) in form, and divisible.

3. Data

3.1. Production data

Production data used to implement our model come from surveys conducted between December 1998 and March 1999 among 400 households in four villages in Bangladesh.[2] Two of these villages fall within a pilot area of the Bangladesh Agricultural Development Corporation (BADC), an extension arm of the Bangladesh Department of Agriculture. As a result of this close proximity to BADC, as well as good transport and communication linkages to Dhaka, commercial cultivation of vegetables is quite common among farmers in the study area and more common than is typical in other areas of Bangladesh. Table 1 summarises the sample, which is described more fully in Mahmoud (2001). Approximately 45% of sample households specialised in vegetable production.[3] These households tended to be smaller and poorer than those growing both rice and vegetables.

Although vegetable production is ubiquitous in our sample, the use of IPM strategies is not. As a result, the household data summarised in Table 1 provide an opportunity to calibrate a model that captures the salient features of diversified smallholder production, whilst leaving open the possibility of studying the possible impact of IPM packages. To supplement our household survey data we use 1998 production data on rice from the Bangladesh Agricultural Yearbook (Government of Bangladesh, 1998) and detailed production data on vegetables from field experiments conducted by IPM CRSP researchers at the Bangladesh Agricultural Research Institute (BARI) in Gazipur. Complete field experiment data collected over four growing seasons were available for three popular vegetable crops: cucumber, eggplant and cabbage. In each case, data for the prevailing farmer practice and up to six different IPM treatments were available in four replications for each treatment. Experiment data are summarised in Table 2, in the form of sample means for the bottom quartile, middle second and third quartiles (combined), and upper quartile of the yield distributions.[4]

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[2] The villages are Enayetpur, Barenda-Nayapara, Joyertek and Ahaki.

[3] To distinguish between households growing both rice and vegetables and those specialising in vegetables only, the former are referred to as rice growers in the discussion.

[4] Data used to compile Table 2, as well as complete descriptions of all experimental treatments are available from the authors upon request. To conserve space, the tables report data only for experiment treatments that appear in simulation solutions.

Table 2
Yield data ('000 kg/ha)

Crop-technology combination	Bottom quartile	Middle quartile	Upper quartile
Season 1			
Aus			
Local	1.12	1.45	1.50
HYV	2.29	2.97	3.08
Cucumber			
Farmers' practice	16.96	21.20	25.44
IPM[a]	18.56	23.20	27.84
IPM[b]	22.08	27.60	33.12
IPM[c]	19.28	24.10	28.92
Season 2			
Aman			
Local	1.59	2.07	2.14
HYV	2.67	3.46	3.59
Eggplant			
Farmers' practice	10.22	12.78	15.33
IPM[a]	15.19	18.99	22.79
Season 3			
Boro			
HYV	3.15	4.10	4.25
Cabbage			
Farmers' practice	45.23	50.31	55.72
IPM[d]	49.28	56.35	58.73

[a] Pre-planting incorporation of poultry refuse.
[b] Pre-planting incorporation of sawdust and burned on field.
[c] Use of mustard oil cake as soil amendment at planting.
[d] Weed free cultivation using hand weeding.

These quartile cut-offs were used to compute state-dependent yields for the model. We assumed three yield states—high, medium and low—and computed state-dependent yields as follows. First, for each crop-technology combination three average yields were calculated for the ordered data corresponding to the bottom quartile, the middle two quartiles (combined), and the top quartile. In other words, we assume that the yield for the crop-technology combination of interest equals the mean of the bottom quartile with probability 0.25, the mean of the middle two quartiles with probability 0.50, and the mean of the top quartile with probability 0.25.

The input requirement set for each crop-technology package is independent of the yield state. Input requirements are presented in Table 3. Together, data in Tables 2 and 3 define production in the model. In general, IPM practices provide somewhat higher yields than farmer practices. Although cash input costs for the IPM practices tend to be lower than for farmer practices (primarily due to lower chemical costs), labour requirements for IPM practices are generally higher. As a result, the relative incentive to adopt an IPM technique hinges on labour availability and working capital constraints.

3.2. Price data

In the case of rice, the household survey provided prices received in each season (*Aus*, *Aman* and *Boro*). For vegetables, price data are taken from weekly price monitoring surveys that were conducted in conjunction with the household survey. For all crops, three states of nature for price were defined. In the case of rice, states were further distinguished by season. State-dependent prices were computed using a procedure similar to that for yields. First, for each crop the complete set of prices was sorted in ascending order and used to define quartiles for the data. Then three average prices were computed for the ordered data corresponding to the bottom quartile, the middle two quartiles (combined), and the top quartile. In other words, we again assume that the price for the crop of interest equals the mean of the bottom quartile with probability 0.25, the mean of the middle quartiles with probability 0.50, and the mean of the top quartile with probability 0.25. In all cases we assume that the distribution of prices is independent of the production technology. Prices used in the model are reported in Table 4.

3.3. Additional parameters of the model

Table 5 lists values for all remaining scalars used in the model. Data for wages per man-day, area available for cultivation, and initial endowments come from the household survey. The household's minimum consumption requirement is set at 2720 kg/season (120 days). This was computed assuming a five-member family and the WHO guideline of 1583 Kcal per capita per day. Remaining parameters were chosen based on survey data and reports of researchers and extension agents working in the study area. To complete the definition of states in the model we assume independence of prices and yields. The model contains nine

Table 3
Input requirements for crop-techniques

	Seed ('000 Taka/ha)	Fertiliser ('000 Taka/ha)	Pesticide ('000 Taka/ha)	Irrigation ('000 Taka/ha)	Miscellaneous ('000 Taka/ha)	Labour (man-days/ha)
Season 1						
Aus						
Local	1.058	0.932	0.0044	0	1.771	100
HYV	1.543	2.165	0.527	0.762	1.799	134
Cucumber						
Farmer practice	3	6.32	3.45	2.4	34.8	220
IPM[a]	3	6.32	0.75	2.4	35.8	220
IPM[b]	3	6.32	0.75	2.4	52.8	223
IPM[c]	3	6.32	0.75	2.4	37.8	228
Season 2						
Aman						
Local	1.567	1.098	0.105	0	1.905	112
HYV	1.799	2.326	0.37	0	1.986	128
Eggplant						
Farmer practice	6.4	4.63	2.7	6.3	4.8	322
IPM[a]	6.4	4.63	0	6.3	5.7	322
Season 3						
Boro						
HYV	1.989	3.374	0.523	5.17	2.08	153
Cabbage						
Farmer practice	20	4.206	3.15	7.5	8.8	293
IPM[d]	20	4.206	3.15	7.5	8.8	296

[a] Pre-planting incorporation of poultry refuse.

[b] Pre-planting incorporation of sawdust and burned on field.

[c] Use of mustard oil cake as soil amendment at planting.

[d] Weed free cultivation using hand weeding.

Table 4
Rice and vegetable prices (Taka/kg)

	Rice				Vegetables		
	Aus (local + HYV)	Aman local	Aman HYV	Boro HYV	Eggplant	Cucumber	Cabbage
State 1	7.00	7.45	7.39	7.00	7.38	6.30	3.82
State 2	7.31	8.49	7.57	7.31	9.05	9.06	8.77
State 3	8.93	12.36	10.22	8.93	12.83	14.87	9.37

Table 5
Values of the scalars in the model

Variables	
Labour endowment (man-days/season)	180
Wage (Taka/man-day)	70
Credit limit ('000 Taka/season)	10
Nominal interest rate (%)	25
Minimum consumption (rice gm/capita per day)	453
Transaction cost (Taka/kg of rice)	3
Endowment ('000 Taka)	6
Available land (ha/season)	0.58

states, corresponding to the joint-likelihood of prices and yields described above.[5]

4. Simulation results

We report results from three simulations conducted with the model. These simulations are de-

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[5] Available statistical evidence regarding the correlations between prices and yields for the crops examined here is mixed and generally weak (see Mahmoud, 2001).

Table 6
Simulation results

	Simulation			
	Base run	1 IPM	2 IPM + credit	3 IPM + credit + off-farm labour
(a) Risk-neutral household				
Area cultivated (ha/year)	1.74	1.49	1.74	1.74
Area in rice (ha/year)	0.58	0.0	0.0	0.0
Area in vegetables (ha/year)	1.16	1.49	1.74	1.74
Area in IPM (ha/year)	0.00	1.49	1.74	1.74
Total cost ('000 Taka/year)	46.1	57.7	80.9	80.9
Amount borrowed ('000 Taka/year)	23.9	30	69.2	69.2
Family labour (man-days/year)	428	425	482	540
Hired labour (man-days/year)	7.0	7.0	7.0	7.0
Income ('000 Taka/year)	253.6	369.3	423.4	427.5
Consumption ('000 kg/year)	22.6	31.7	38.5	38.9
(b) Risk-averse household				
Area cultivated (ha/year)	1.42	1.32	1.74	1.74
Area in rice (ha/year)	0.71	0.3	0.1	0.2
Area in vegetables (ha/year)	0.71	1.0	1.67	1.5
Area in IPM (ha/year)	0.00	1.0	1.67	1.5
Total cost ('000 Taka/year)	29.0	41.9	79.8	87.8
Amount borrowed ('000 Taka/year)	20.0	30.0	68.1	75.5
Family labour (man-days/year)	316	334	478	540
Hired labour (man-days/year)	0.0	0.0	0.0	187
Income ('000 Taka/year)	130.8	232.7	413.9	343.9
Consumption ('000 kg/year)	12.8	21.3	37.7	31.8

signed to measure the potential impact of plausible policy changes on smallholder vegetable growers in Bangladesh. Simulation 1 examines the impact of making IPM packages available within the existing structure of farming. Simulation 2 adds to Simulation 1 an expansion in credit availability. Simulation 3 studies the combination of IPM and credit expansion in the context of increased off-farm opportunities. Each simulation is conducted for risk-neutral and risk-averse decision makers. In the latter case we use a value of $\rho = 3$. Table 6 reports results for risk-neutral household in panel a and for risk-averse households in panel b. Reported outcomes have been aggregated across three seasons. For seasonally disaggregated results see Mahmoud (2001).

4.1. Simulation 1 (access to IPM)

Compared with results in the base run of the model, introducing IPM leads to increases in area planted to vegetables for risk-neutral and risk-averse households. For both households IPM emerges as the dominant technology strategy for vegetable production. With IPM, vegetable production increases substantially at the expense of rice cultivation; the risk-neutral household shifts completely from rice to vegetables and the area for vegetable increases by almost 28% compared with the base run. As vegetables are more input intensive, this leads to an increase in production cost of 25%. Higher levels of borrowing finance the increase in production cost. Credit constraints are binding for all seasons at 10,000 Taka and the household is forced to keep 14% of its land fallow. The net result of IPM adoption is an increase in household welfare. Income and consumption increase by 46 and 40%, respectively for the risk-neutral household in Simulation 1 compared with the no IPM situation.

Patterns for the risk-averse decision maker are consistent with those in the risk-neutral case. However, because vegetable production generates greater income risk than rice production, the risk-averse household maintains a larger share of land in rice. Nevertheless, the availability of IPM does provide a powerful incentive for vegetable production and leads to a 58% drop in rice area planted to rice. Income and consumption increase by 78 and 67%, respectively.

4.2. Simulation 2 (expanded credit)

Simulation 2 lifts the cap on borrowing from 10,000 to 30,000 Taka/season. As a result, vegetable production rises for both the risk-neutral and risk-averse decision makers. For both, land previously kept fallow is brought under production. For the risk-neutral household, the lifting of the borrowing cap leads the household to plant vegetables on all remaining land (an increase in vegetable area over the Simulation 1 level of about 17%). For the risk-averse household, vegetable area increases by 67% compared with Simulation 1. Borrowing increases by 130% for the risk-neutral household and by 127% for the risk-averse household. Additional credit increases household welfare: income rises by 15 and 78% and consumption rises by 22 and 77% for the risk-neutral and risk-averse households, respectively. Hence, the expansion in credit provides a substantially greater return to the risk-averse household.

For both the risk-neutral and risk-averse household the expanded borrowing constraint binds only during the first season in Simulation 2. For seasons two and three the risk neutral household borrows 13,800 and 25,320 Taka, respectively. The risk-averse household uses credit in the amounts 12,780 and 25,320 Taka/season. The shadow value of the borrowing constraint indicates that, for the risk neutral household, a one Taka increase in the borrowing limit translates into a 6 Taka increase in income.

4.3. Simulation 3 (access to off-farm employment)

Simulation 3 provides the option of off-farm employment in addition to access to IPM and expanded credit. For the risk-neutral household access to wage income has no bearing on land allocation decisions beyond the incentives provided by access to IPM and additional credit. For the risk-averse household, however, the option of off-farm unemployment leads to a reduction in vegetable area. Annual area planted to vegetables drops by 10%, to 1.5 ha, as the household shifts area to rice cultivation, which is less labour intensive than vegetable production. Although income and consumption fall (by 17 and 16%, respectively), and production costs increase, the shift from vegetable production to off-farm employment and rice production reduces income uncertainty and thereby generates a utility gain. Expanded labour market opportunities work against vegetable production.

5. Discussion and policy implications

Our aim in this paper was to examine factors that may contribute to production diversification away from rice toward high-value crops such as vegetables, as well as the use of IPM methods for vegetable producers. We analysed three factors via a series of simulations: (1) access to IPM technologies, (2) expanded access to credit, and (3) access to off-farm employment. We studied potential impacts using a three-season household optimisation model. The model incorporated multiple crops, multiple technologies and price and yield uncertainty. The most important assumptions made in setting up the model were that production was Leontief in form, prices and yields were independent (with discrete probability distributions) and cultivable area was fixed.

Three simulations were conducted with the model under assumptions of risk-neutrality and risk-aversion. Results show that access to IPM can play an important role in shifting production towards vegetables. We found that access to credit led to an increase vegetable production, primarily because access to credit relaxes binding constraints on working capital for vegetable production. Somewhat unexpectedly, access to off-farm employment appears to work against vegetable cultivation and IPM use, at least within the context of the stylised model presented here. The increase in working capital provided by wages is insufficient to compensate for the loss in labour resulting from off-farm work. In addition, the opportunity to reduce the uncertainty associated with income and consumption leads risk-averse households to sell labour off-farm, which reduces consumption risk. This shift necessitates the use of less labour-intensive crops such as rice. This suggests that farmers depending only on farming are more likely to adopt vegetable production than those with higher opportunity costs of labour, and could mean that extension efforts should target vegetable production and IPM practices to areas in which off-farm intensive market opportunities remain absent or weak.

Results clearly indicate that, provided they perform as well in farmers' fields as in the experimental situations upon which this research was based, IPM methods should dominate traditional methods used for vegetable production. This reflects the fact that, while somewhat more labour-intensive, IPM practices tend to generate higher yields and hence higher net returns per hectare. Results suggest that IPM technologies have the potential to provide farmers with sufficient economic returns as to increase vegetable production. Although lack of labour and credit constitute barriers to expansion of vegetables production and uptake of IPM practices, our analysis shows that returns to borrowing are high. The Government of Bangladesh may therefore wish to consider initiatives to enhance financial deepening and broaden farmers' access to credit, especially near urban markets. This need not imply credit subsidisation, since our analysis shows that borrowing is advantageous even at prevailing interest rates. However, access to credit for smallholders remains problematic in Bangladesh, suggesting a continued role for credit targeting, perhaps in conjunction with dissemination of IPM packages.

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