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Bridging the Information Gap with Cost-Effective Dissemination Strategies: The Case of Integrated Pest Management in Bangladesh

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Cost-effective extension strategies are needed to promote widespread adoption of agricultural technologies in developing countries. Integrated pest management (IPM) practices, for example, can offer economic, health, and environmental benefits but remain largely underused. This study evaluates the current IPM dissemination program implemented by the Bangladesh Department of Agricultural Extension and uses a linear programming model to examine alternative strategies to improve IPM adoption. Results suggest that technology transfer programs may increase their impact by reallocating funding from intensive but costly interpersonal communication methods (i.e., farmer field schools) to less intensive methods (i.e., mass media and field days) that reach broader audiences.

Key Words: agricultural technologies, cost-effectiveness, dissemination, extension, IPM, linear programming

JEL Classifications: D83, Q16

Growing populations and rising incomes in developing countries place pressures on agricultural production to meet the increasing need for affordable food. Technologies that increase productivity can benefit producers and consumers; however, the high cost of many agricultural extension programs constrains their reach, thus making it difficult for millions of farmers in developing countries to access new information and innovations.

Integrated pest management (IPM) technologies enhance productivity while promoting safe and effective pest management (Norton, Rajotte, and Gapud, 1999). IPM integrates biological, cultural, and chemical controls, thus decreasing the need for intensive pesticide applications and offering a more sustainable solution for pest control (Greene et al., 1985). IPM researchers develop technology "packages," or sets of

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improved practices, based on agroecological principles that are adaptable to a wide range of agricultural situations (Thrupp and Altieri, 2001). Practices included in an IPM package are complementary in nature but differ in complexity and may require different types of training to be successfully implemented.

Farmers learn about IPM from many sources including public agricultural extension services, nongovernmental organizations (NGOs), private companies, and input suppliers. Additionally, information and knowledge can be transferred informally between neighboring farmers, friends, and family. Substantial research has investigated the effectiveness of alternative IPM dissemination strategies (Heong et al., 1998; Rola, Jamias, and Quizon, 2002; Feder, Murgai, and Quizon, 2004; Godtland et al., 2004; Mauceri et al., 2007; Ricker-Gilbert et al., 2008). Some researchers have promoted use of participatory techniques with individualized training, whereas others have called for less intensive and more widespread diffusion mechanisms. Recent research suggests that a combination of extension methods is needed to successfully promote IPM adoption (Mauceri et al., 2007; Ricker-Gilbert et al., 2008). Ricker-Gilbert et al. (2008) compared the cost-effectiveness of dissemination methods that are commonly used to promote adoption of "simple," "intermediate," and "complex" IPM technologies. Results suggested that the cost-effectiveness of extension programs may be improved by using low-intensity extension methods (e.g., field days) to diffuse information about "simple" technologies and using higher intensity methods (e.g., farmer field schools) for "complex" practices. Mauceri et al. (2007) found that farmer field schools can successfully promote adoption of IPM but that the high cost of field schools limits the number of farmers that can be reached, which creates a need for additional extension methods. Research is needed to identify a mix of extension methods that can cost-effectively promote adoption of IPM packages.

The ultimate goal of an IPM extension program is to diffuse information about available technologies and provide training to farmers to enhance IPM adoption. However, extension programs can be costly to implement, especially when private provision of information is limited and farmers must rely on public resources for knowledge. Building on the work of Ricker-Gilbert et al. (2008), the current study aims to identify the most cost-effective dissemination strategy for vegetable IPM technologies in Bangladesh, a country in which most IPM extension is provided by the government. This article differs from previous studies of IPM extension approaches by integrating several diffusion and training approaches that are designed to encourage adoption of IPM practices of varying complexity. An optimization (linear programming) model is used to maximize the total economic benefits from an IPM extension program for three vegetable crops with the benefits derived from economic impacts of various types of extension activities. Results suggest extension budget reallocations that would increase the impacts of extension programs by reaching more people and effectively motivating adoption.

Integrated Pest Management Dissemination in Bangladesh

Bangladesh, a South Asian country of approximately 155 million people, is characterized by a high population density, low per-capita income, and high poverty (FAO, 2013; The World Bank, 2013). Agriculture accounts for one-third of the country's gross domestic product and employs over half of the country's workforce (Bangladesh, Bureau of Statistics, 2008). Nearly half of the 28.7 million households in the country are agriculturally based with an average farm size of 0.5 hectares. Nearly two-thirds of the workforce depends on agriculture as an income source (including wages) or for subsistence farming. Every person in Bangladesh depends on agriculture for affordable food. Although agricultural production in the country is highly susceptible to flood damage, farmers have been able to increase food grain production significantly through improved irrigation, fertilizer use, and rural credit. Total food grain production in Bangladesh rose from 10 million tons in 1971 to over 31.3 million tons in 2006 (Bangladesh, Ministry of

Agriculture–Bangladesh Department of Agricultural Extension, 2013).

As a result of the high population density and scarce natural resources, it is important that farmers use IPM technologies to limit use of toxic chemicals with adverse effects on humans and the environment. Traditional extension programs, however, have not reached many of the 14.7 million farm households across the country, thus limiting the adoption of these technologies. Cost-effective provision of IPM information and training may facilitate more widespread adoption of IPM, leading to economic, environmental, and health benefits.

In Bangladesh, agricultural extension responsibilities are shared by the public and private sectors, but the public Department of Agricultural Extension (DAE) serves as the primary source for IPM information. The DAE is divided into two parts—the Agricultural Information Services (AIS) and the Agricultural Extension Component (AEC). The AIS manages mass media communication across Bangladesh, whereas the AEC focuses on more interpersonal types of extension such as field days, demonstrations, household visits, and farmer field schools.

Several NGOs also actively disseminate IPM and other agricultural information to farmers in their project areas. In the past, CARE, a large international NGO, had an active IPM program in Bangladesh. Currently, the Mennonite Central Committee (MCC) teaches farmers about IPM for vegetables and has helped establish local NGOs (e.g., Grameen Krishok Sohayak Sangstha) as suppliers of IPM inputs. Private companies such as Ispahani Biotech and Safe Agriculture Bangladesh Limited also spread IPM through input sales. These two companies began commercial production in 2009 and are developing marketing strategies to reach more farmers with information about two key technologies—sex pheromone traps and beneficial insects.

The IPM practices that the DAE and NGOs extend to farmers are developed primarily by the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Agricultural Research Institute (BARI) in collaboration with international partners such as the Integrated Pest Management Collaborative Research Support Program (IPM CRSP). Research and extension organizations work together to disseminate pest management information for rice and vegetables. This article focuses on the dissemination of vegetable IPM resulting from the availability of data. Research on disseminating rice IPM is needed because rice is a staple crop in Bangladesh and plays a major role in the economy.

Commonly promoted practices for vegetable production are soil amendments, sex pheromone traps, beneficial insects, and grafting. When applied to the seed bed, soil amendments (e.g., poultry refuse and mustard oil cake) help to improve soil quality while controlling for soilborne diseases such as bacterial wilt (BW) caused by the pathogen *Ralstonia solanacearum* and root-knot nematode (RKN) (*Meloidogyne* spp.). Tricho-compost, another soil amendment developed by the IPM CRSP, uses a type of fungi (*Trichoderma harzianum*) to control for these diseases. Pheromone traps function by using synthetic sex pheromone lures to attract insect pests to a plastic container where they are trapped in soapy water. Beneficial insects (biological controls) are the natural enemies of crop pests. Grafting involves attaching a high-yielding eggplant or tomato seedling to a rootstock that is resistant to BW and RKN. Each of these practices lowers the use of chemical pesticides, although pesticide applications are seldom eliminated completely. Assumptions made about pesticide use are discussed further in the "Methods and Data" section.

Farmers make adoption decisions based on perceptions about benefits and costs. Several features of the technology can directly affect how farmers perceive the expected benefits and must be considered in the diffusion process (Rogers, 1995). These attributes may include compatibility, complexity, observability, and trialability. Trialability refers to the degree to which a farmer can experiment with a technology before deciding whether to fully adopt it. The attributes may vary greatly across components of an IPM package. As a result, the heterogeneous nature of IPM practices can make dissemination difficult. Organizations use many tactics to disseminate information about IPM including mass media, field days, extension agent visits, and farmer field schools. Each tactic has its own benefits and drawbacks concerning cost, the number of farmers that can be reached, and the ability to influence adoption.

Methods Used to Disseminate Integrated Pest Management

Mass media includes paper media such as pamphlets, magazines, and newspapers and electronic media, including radio broadcasts, television programs, and the Internet. It is the cheapest form of information diffusion per person reached and has the potential to reach widespread, diverse audiences (Bentley et al., 2003). Research suggests that mass media can adequately convey simple messages about IPM and positively impact farmer perceptions, thus encouraging adoption (Heong et al., 1998). Its use, however, encounters some constraints including low literacy and limited access to media resources in some households and areas of Bangladesh. Mass media is also often inadequate when trying to disseminate complex technologies and frequently must be coupled with training.

The AIS uses paper media such as magazines, newspapers, pamphlets, and books. "Krishikatha" is an agricultural magazine with a circulation of 45,000 each month. Books and pamphlets are also produced periodically. Pamphlets are commonly distributed to farmers, whereas books are used as reference material for extension officers and educated community leaders.

Use of electronic media is increasing rapidly as more farmers have access to radios, televisions, and cell phones. Agricultural news is televised daily. Additionally, since 1978, the DAE has broadcast an agricultural TV program called *Mati O Manush*, directly translated as "Earth and Man." A new program airs each week at six different times and focuses on a particular issue faced by farmers. Between March and July 2010, IPM was the primary focus of 15 of the 53 episodes. Additionally, the National Agricultural Radio Program has broadcast agricultural news since its establishment in 1966. The radio stations are run by the Ministry of Information but are often staffed by DAE personnel.

Increased Internet access is changing extension delivery. Recently, AIS launched a new web site (www.ais.gov.bd) providing production and market information to farmers (Bangladesh, Ministry of Agriculture–Bangladesh Department of Agricultural Marketing, 2011). AIS has worked with the Danish Government on a project to establish Agricultural Information and Communication Centers (AICC) in rural areas of Bangladesh. An AICC consists of a television, phone, computer, fax machine, printer, and Internet modem. IPM clubs and other farmer organizations are targeted as recipients of these facilities.

Field days, extension agent visits, and farmer field schools (FFSs) are other strategies used to disseminate IPM information. Field days provide the AEC with an opportunity to reach many farmers and demonstrate successful agricultural technologies. This dissemination approach allows for relatively cost-effective diffusion of IPM information (Ricker-Gilbert et al., 2008), although the depth of training received in a field day can be limited. The AEC often holds field days in conjunction with the ceremonial graduation of each FFS group. Community officials and other farmers are invited to view the IPM plots established and maintained by the FFS.

Extension agents visit farmers individually and in groups to discuss IPM and other technologies. Currently, there are approximately 12,640 extension agents known as Sub Assistant Agricultural Officers (SAAO). One SAAO serves six to seven villages or approximately 900 farm households. Officers visit farmers directly and offer short courses to groups of leading farmers throughout the year. By selecting successful, influential farmers to participate in trainings, the AEC hopes that the trained farmers return to their villages and share the information they learn with others in a process of informal diffusion. SAAO officers collectively reach approximately 11 million farm households per year, although many of the farmers do not receive extensive or repeated consultation.

The most intensive method of teaching farmers about IPM is through a FFS. FFSs "help farmers develop their analytical skills, critical thinking, and creativity, and help them learn to make better decisions" (Feder, Murgai, and Quizon, 2004, p. 222). FFS can be led by agricultural officers or farmers who are leaders in the community. In 2009, the AEC conducted 4,625 FFSs. The FFS model in Bangladesh has evolved to include gender-specific trainings. Twenty-five households are represented in each FFS by one male and one female participant. Participants attend joint and gender-specific sessions throughout a growing season (8–12 weeks). Rice technologies are targeted toward men, whereas vegetable technologies are typically aimed at women. Although the basic curriculum is established by the AEC, each group has the opportunity to customize the FFS to address specific problems and needs of participants. FFSs cover a wide range of production topics. As a result of its importance in production, pest management comprises approximately 25% of the total FFS curriculum.

Compared with other dissemination methods, an FFS provides farmers with the most in-depth training on pest management, although the training comes at the relatively high cost of approximately $20 per farmer (author's own calculations subsequently). If FFS graduates share information with other farmers and encourage them to adopt IPM practices, the cost-effectiveness of FFS can be significantly improved. This continuing farmer-to-farmer information transfer is critical to cost-effectiveness of the FFS, but research in other countries has shown that although some informal diffusion occurs, it is often ineffective in conveying the intricacies of the IPM technology and does not reach large numbers of farmers (Rola, Jamias, and Quizon, 2002; Feder, Murgai, and Quizon, 2004).

In-depth training may build more knowledge than less intensive methods, but historically it has not successfully reached large numbers of farmers. For IPM technologies to spread, the research must be integrated into a broader diffusion process (Norton et al., 2005). Mass media has been proven to rapidly disseminate simple messages to a broad audience at a relatively low cost (Heong and Escalada, 1999). Other diffusion mechanisms, however, are needed to convey information associated with complex technologies. Establishing an effective and financially sustainable dissemination program is crucial to the success of IPM and the future productivity of farmers in Bangladesh and elsewhere.

Conceptual Framework

Increased productivity from adoption of IPM technologies results in an outward shift in the supply of targeted commodities and increased economic benefits to producers and consumers. Before farmers can implement these technologies, they must first be aware of the available practices; disseminating IPM information is the first step toward successful adoption. Investments in IPM extension programs generate economic benefits based on the level of technology adoption resulting from each dissemination activity within the overall program. In this study, a dissemination activity is defined as the active promotion of an IPM practice for a specific crop using one of five methods (paper media, electronic media, field days, extension agent visits, FFS). For example, one activity could be dissemination of the Tricho-compost technology for eggplant using field days.

Total economic benefits generated by an IPM extension program can be calculated by summing the economic surplus amounts resulting from technology adoption after participating in one or more dissemination activities. The magnitude of economic benefits from a single dissemination activity depends on the resources devoted to the activity, the number of farmers reached, the resulting level of adoption including spillovers—adopters who did not participate directly in the dissemination activity but changed their behavior by observing friends and neighbors who did—and economic benefits of the IPM technology (e.g., yield increase, input cost reductions, reduced consumer prices). Based on technology characteristics (compatibility, complexity, observability, and trialability), certain dissemination methods may be more effective in inducing adoption than others. In addition, some methods of information diffusion are more cost-effective than others as a result of differences in costs of the method per adopter.

Agricultural extension programs in Bangladesh currently rely heavily on participatory approaches. Although these efforts have encouraged hundreds of thousands of farmers to adopt IPM practices, there are millions of other farmers who could benefit from IPM but have not received information or training. By reallocating extension funding among various dissemination activities, program coordinators may be able to cost-effectively reach more farmers and increase the overall rate of IPM adoption.

Methods and Data

This study uses a linear programming (LP) model to identify a cost-effective strategy to disseminate IPM information in Bangladesh. The model focuses on dissemination of IPM information for three vegetable crops: eggplant, tomatoes, and cucurbits. Several steps were involved in collecting data and constructing the model. The first involved working with extension experts and program coordinators at the DAE to understand what IPM information is being transferred to farmers, the methods and costs of information dissemination, and how many farmers are being reached with the current budget. Scientists at BARI were also consulted to understand the IPM techniques available for each vegetable crop and their average yield and cost effects when applied at the farm level. The second step was to administer a questionnaire to IPM scientists and extension agents to project adoption rates for five IPM technologies depending on the method of dissemination. The data collected in the first two steps were then used to conduct economic surplus analyses to determine the economic benefits of each dissemination activity.

The economic benefits computed in the economic surplus analysis were used as coefficients on the decision-making variables (DMV) in the LP model. By maximizing total economic surplus, the model selected an optimal dissemination strategy by allocating funding among 60 possible dissemination activities. The 60 activities represent the dissemination of five IPM technologies (i.e., Tricho-compost application, other soil amendments, sex pheromone traps, beneficial insects, and grafting) using five dissemination methods (i.e., paper media, electronic media, field days, extension agent visits, and FFS) for three crops (i.e., eggplant, tomatoes, and cucurbits). Although Tricho-compost and other soil amendments can be applied to each of the three crops, sex pheromone traps and beneficial insects are typically applied to eggplant and cucurbit crops, whereas grafting is only effective for eggplant and tomatoes. Each of the IPM technologies is currently being disseminated by the five diffusion methods.

Calculating Dissemination Costs

The cost of disseminating IPM information to each farmer depends on the extension method. In general, the cost of transferring information to a farmer is lowest using mass media and increases as the method of dissemination becomes more personal; FFS and agent visits are usually considered the most individualized forms of agricultural extension. Table 1 provides a summary of the average extension costs for each method of information transfer and illustrates how average per-household dissemination costs were calculated. The DAE extends information about many agricultural technologies including, but not limited to, pest management. Row one presents the total DAE budget for all agricultural extension using five dissemination tactics. Estimates of the number of farmers currently being reached by each tactic are presented in row two. It was then possible to compute the average per-household dissemination cost for each extension method as presented in row three.

The number of IPM practices that are disseminated by a given extension method differs by method and affects the average per-household cost of disseminating a technology. The cost to disseminate a single technology is calculated based on the assumption that, on average, individual practices are disseminated in media campaigns, two practices are disseminated in a field day or extension agent visit, and four practices are disseminated during an FFS. This assumption was made based on information

Table 1. Summary of Annual Department of Agricultural Extension Dissemination Costs

	Dissemination Method				
	Paper Media[b]	Electronic Media[c]	Field Day	Extension Agent	Farmer Field School
All agricultural extension					
1. Total budget[a]	$114,819	$66,087	$355,254	$30,336,000	$2,258,877
2. Farm HH reached	325,000	2,026,250	462,500	11,376,000	115,625
3. Cost per household[d]	$0.35	$0.03	$0.77	$2.67	$19.54
4. IPM practices transferred[e]	1	1	2	2	4
5. Cost per IPM practice	$0.35	$0.03	$0.39	$1.34	$4.89
Vegetable IPM extension only					
6. Funding for IPM[f]	$19,261	$11,009	$23,980	$2,275,200	$152,474

[a] Based on Department of Agricultural Extension budget allocation in 2009 and 2010. Values are rounded to the nearest U.S. dollar based on an exchange rate of 69 taka to $1 U.S.
[b] Data on the cost and reach of paper media was only collected for IPM dissemination; therefore, the total budget includes the funding for paper materials regarding vegetable and rice IPM.
[c] Electronic media includes TV and the AIS web site. Data for radio broadcasts were unavailable.
[d] The cost per household is calculated by dividing the total budget by the number of households reached.
[e] It is assumed that, on average, individual practices are disseminated in media campaigns, two practices are disseminated in a field day or extension agent visit, and four practices are disseminated during an FFS.
[f] Funding for vegetable IPM only reflects the budget for three crops: eggplant, tomatoes, and cucurbits.
IPM, integrated pest management; AIS, Agricultural Information Services.

collected during DAE interviews. Table 1 presents the amount of DAE funding dedicated to dissemination of vegetable IPM. These estimates are based on information provided by the DAE from budget reports and other materials such as FFS syllabi and *Mati O Manush* broadcast schedules.

Projected Adoption Rates

Dissemination alone does not yield benefits; farmers who learn about a practice must decide to adopt it. Using the adoption questionnaire, the three scientists most knowledgeable about the target crops and IPM practices at BARI, and one extension expert at MCC, projected the average adoption rates for five IPM practices for each dissemination method. The expert opinion survey method took advantage of the rich local knowledge of IPM professionals working in Bangladesh, although potential bias from using responses based on their personal experience is recognized. Sensitivity analyses were used to address this concern. The average projected adoption rates were used in the preliminary economic surplus analysis and LP model, and two additional adoption levels were subsequently used in sensitivity analyses. The two levels were based on the highest and lowest projections indicated in the questionnaires. Copies of the questionnaire form are available from the authors.

The adoption rate for each practice is defined as the fraction of farmers who adopt the technology after receiving information through a specific dissemination method. The projected adoption rates for each of the five IPM practices differ depending on the dissemination method used to communicate the information to farmers.

Economic Surplus Analysis

Economic surplus analyses were used to calculate the benefits of investment in each dissemination activity for a particular crop, practice, and dissemination method. Data from several sources were used to calibrate the surplus model. The data pertaining to crop production and prices were obtained from the Ministry of Agriculture's Handbook of Agricultural Statistics, the Bangladesh Bureau of Statistics, and the Department of Agricultural Marketing (Bangladesh, Ministry of Agriculture, 2007; Bangladesh, Bureau of Statistics, 2009; Bangladesh, Ministry of Agriculture–Bangladesh Department of Agricultural Extension, 2011). Data on changes in yield and cost (the unit-cost reduction, or k-shift) per adopter were collected from BARI field trials and reports that indicate changes in productivity and profitability using the different IPM technologies. The analyses account for the fact that IPM adoption does not eliminate pesticide use but provides substitutes that allow for reduced use of insecticides and/or fungicides depending on the IPM practices.

Table 2 provides an example of how the surplus per dollar invested was calculated for each activity using the Tricho-compost technology with eggplant as an example. It is assumed that the budget for each dissemination method (Table 1, row 6) is divided equally among the five IPM practices. Furthermore, the budget for each practice is divided equally among the crops for which the practice is applicable. The number of farmers reached by the specific activity was estimated by dividing the budget for each activity by the cost of dissemination (per practice) presented in Table 1, row five. The number of adopting farmers was then computed by multiplying the number of farmers reached with a particular dissemination method by the projected adoption rates.

Total surplus was calculated using the closed economy (no trade) model presented by Alston, Norton, and Pardey (1998). The change in total economic surplus is calculated by adding the changes in consumer and producer surpluses. IPM technologies usually result in a change in productivity by increasing crop yields and/or altering input costs, thus shifting out the supply curve from its initial equilibrium with the demand curve, providing increased economic surplus. This proportional supply shift is called the unit cost reduction, k, and is a major determinant of the total benefits resulting from agricultural research and extension (Alston, Norton, and Pardey, 1998). The size of k depends on the proportionate changes in yield and input costs resulting from the new IPM technology and the rate of adoption.

The surplus per dollar invested is therefore the total surplus generated by the dissemination activity divided by the budget for that activity. This calculation was performed for each of the 60 activities at three rates of adoption (low, average, and high). The change-in-surplus estimates based on the average adoption rates were used in the base run of the LP model. Sensitivity analyses were then conducted by rerunning the model with change-in-surplus estimates calculated using the low and high adoption rates.

Table 2. Example of Calculating Economic Surplus for Tricho-Compost Technology Applied to Eggplant

Dissemination Method	Budget[a]	Farmers Reached[b]	Projected Adoption Rate[c]	Total Farmers Adopting[d]	Total Surplus[e]	Surplus Per Dollar Invested[f]
Paper media	$1,284	3,669	2.8%	103	$4,466	$3.48
Electronic media	$734	24,467	10.5%	2,569	$111,412	$151.79
FD	$1,599	4,100	38.8%	1,591	$68,992	$43.15
Agent visit	$151,680	113,194	22.5%	25,469	$1,106,839	$7.30
FFS	$10,165	2,079	33.8%	703	$30,483	$3.00

[a] The budget is based on information obtained from Department of Agricultural Extension interviews and budget data.
[b] Number of farmers reached is estimated based on information obtained in interviews with Department of Agricultural Extension personnel.
[c] Projected adoption rates obtained from questionnaires.
[d] Total farmers adopting = farmers reached * projected adoption rate.
[e] Total surplus is calculated using the economic surplus analysis method proposed by Alston, Norton, and Pardey (1998) using a closed economy model.
[f] Surplus per dollar invested in dissemination = total surplus/total cost.
FD, field day; FFS, farmer field school.

Modeling Integrated Pest Management Dissemination Strategies

The LP model is structured to maximize the economic benefits of the DAE's Integrated Pest Management extension program subject to a set of defined constraints. The extension program modeled in this study is limited to five IPM technologies for three vegetable crops using five dissemination methods. The annual total economic surplus change is calculated based on the optimal level of dissemination activities selected by the model. The difference between the economic surplus change resulting from the current IPM dissemination program and the result from the LP model optimization represents the expected economic benefits to be gained from implementing the proposed dissemination strategy.

A simplified structure of the LP model is displayed in Table 3. The structure follows that of the LP model used to examine agricultural research priorities in Zimbabwe (Mutangadura and Norton, 1999). Instead of allocating funding among research programs as in Mutangadura and Norton, our model allocates funds among dissemination activities.

Table 3. Structure of the Optimization (linear programming) Model

		Dissemination Activities							
		Activity 1[a]		Activity 2		. . .	Activity 60		
	Objective	Current[b]	High[b]	Current	High		Current	High	
(a) Equation description	x	c_{ijk1}	c_{ijk2}	c_{ijk1}	c_{ijk2}	. . .	c_{ijk1}	c_{ijk2}	RHS[d]
(b) Objective function	1								
(c) Surplus contributions to the objective[c]	−1	a_{ijk1}	a_{ijk2}	a_{ijk1}	a_{ijk2}	. . .	a_{ijk1}	a_{ijk2}	= 0
Subject to[e]:									
1. Total DAE IPM dissemination budget for vegetables (1)		1	1	1	1	. . .	1	1	<= R
2. Funding limit for each activity (120)	(i)	1							<= $R_{1,1}$
	(ii)	1	1						<= $R_{1,2}$
				1					<= $R_{2,1}$
				1	1				<= $R_{2,2}$
						. . .			. . .
							1		<= $R_{60,1}$
							1	1	<= $R_{60,2}$
3. Lower limit for each dissemination method (5)		A	A	A	A	. . .	A	A	>= R
4. Proportion of IPM practice funding to each crop (12)		±A	±A	±A	±A	. . .	±A	±A	<= 0
5. Proportion of dissemination method funding to each crop (15)		±A	±A	±A	±A	. . .	±A	±A	<= 0

[a] Each activity, or decision-making variable (DMV), is represented by c_{ijkl}, where "i" is the crop, "j" is the IPM practice, "k" is the dissemination method, and "l" is the level of funding.

[b] Each activity is represented by two DMVs. The first level ("Current") represents the current level of funding. Additional funding is allocated in the second level ("High") with a diminishing return of 75%.

[c] The coefficient for each DMV is represented by a_{ijkl}. The coefficient is the amount of economic surplus that is gained by a $1 investment in that activity.

[d] Each resource limit is represented by "R."

[e] Constraint coefficients differing from one are represented by positive or negative "A." The number of constraints contained in each category is noted in parentheses.

RHS, right-hand side, ; DAE, Department of Agricultural Extension; IPM, integrated pest management.

DMVs located across row "a" (Table 3) represent the amount of the total budget (in dollars) that will be invested in each activity (the decision variables). There are 120 DMVs representing the current and increased budget allocations for 60 different IPM extension activities. Each activity is a unique combination of a crop, IPM practice, and dissemination method. DMV coefficients located on row "c" (Table 3) indicate the return from a $1 U.S. investment in a particular dissemination activity. Calculation of these coefficients is explained in Table 2.

Diminishing marginal returns to extension activities may exist because of constraints within the extension program such as fixed costs, limited personnel, overhead costs, and so forth. To reflect the possibility of diminishing returns, two levels of dissemination are created for each activity. The first level reflects the current level of the dissemination budget for each activity and provides the full amount of surplus change calculated in the economic surplus analysis. The second level, called "high dissemination," allows additional money to be allocated to that activity at a lower level of marginal surplus gain (measured per dollar of the budget). For this analysis, it is assumed that additional funding in a particular activity provides an economic return that is 75% of the return from the original budget. Each activity may receive no funding, current funding, or current plus higher funding.

Sets of constraints are incorporated in the model to ensure that the budget is not exceeded. In Table 3, the AEC and AIS budgets are aggregated in row one, defining an overall budget constraint for the DAE. Currently, the annual IPM extension budget for eggplant, tomato, and cucurbit technologies is approximately U.S. $2.5 million, of which the AEC dissemination activities account for nearly 99%. Although AIS currently receives a small portion of the overall budget, the program may be able to expand its media activities to reach a large number of farmers if provided with additional funding.

Row two (Table 3) represents two constraints placed on each dissemination activity. The first constraint (i) constrains the "current" DMVs to their present level of funding. The second constraint (ii) ensures that funding to a particular activity does not exceed the amount that would be required to reach all the farm households by that particular method. This constraint is calculated by multiplying the per-household dissemination cost for each activity by 775,000, the estimated number of vegetable farm households in Bangladesh. Constraints depicted in row three (Table 3) ensure that each extension method is used to reach at least half of the number of farmers that currently receive information from that information channel. These constraints prevent drastic changes in the dissemination program in an effort to model a realistic strategy that could be feasibly implemented by the DAE.

Two additional sets of constraints are included to reflect how IPM is currently disseminated by the DAE. The constraints in row four (Table 3) ensure that of the total dissemination funding for a particular practice, at least 10% is dedicated to each of the applicable crops. Likewise, the constraints on row five require that at least 10% of the funding for each of the five dissemination methods is dedicated to each IPM practice. These constraints ensure that a minimum level of funding is provided to each crop for a particular practice and that each practice is disseminated by multiple methods. These constraints are necessary to respect the DAE's desire to disseminate the five IPM technologies using a mix of extension methods. For example, soil amendments can be applied to all three vegetable crops, but the dissemination of soil amendments provides the greatest surplus change when applied to cucurbits and disseminated through electronic media. Without these minimum funding-level constraints, the model would move toward a corner solution where almost the entire budget for soil amendments is allocated to cucurbits and electronic media, but in reality, the extension program teaches farmers about using soil amendments on all three crops using a variety of extension mechanisms. The purpose of the constraints in rows three, four, and five is to maintain a realistic optimization model with results that can lead to suggestions to improve extension in Bangladesh. The results of the unconstrained model are also presented because the corner solution suggests marginal changes in the extension strategy that would be most beneficial.

Results

Estimating Adoption of Integrated Pest Management Technologies

Before examining the results of the LP optimization model, it is important to identify factors that may influence adoption rates and to consider these factors when interpreting the results of the model. Among the extension tactics, it is estimated that farmers receiving IPM information at field days are the most likely to adopt IPM technologies. Paper media has the lowest projected adoption rate followed by electronic media. Considering the three interpersonal dissemination methods, single extension agent visits are estimated to have the lowest adoption rate.

Among the various IPM practices, sex pheromones and soil amendments have the highest average projected rates of adoption independent of the method of dissemination. Beneficial insects and grafting have considerably lower projected rates of adoption. Experts cite the "visibility" of pest reduction as a reason for the diverse adoption rates, noting that farmers are more likely to adopt practices when results are visible before harvest. For example, farmers remove dead insects from sex pheromone traps on a daily or weekly basis, which gives them confidence in the technology as opposed to using beneficial insects and not being certain if they are reducing the number of pests. Furthermore, practices for which results are clearly visible are more frequently noticed by neighboring farmers who may decide to try the IPM technology with their own crops.

Additionally, extension experts suggest that the availability of inputs and the severity of pest pressures directly affect adoption. Trichoderma-compost, beneficial insects, and grafted seedlings are not yet accessible across all of Bangladesh. Experts acknowledge that even if a farmer gains knowledge about the practices, he or she may not be able to purchase the inputs necessary to incorporate the technology into the production system, thus limiting adoption.

Optimizing the Dissemination of Integrated Pest Management Information

Before optimizing the constrained model, the model was run with only an overall budget constraint (row one in Table 3). This model moved toward a corner solution in which the extension budget was allocated to the dissemination of biological control practices for cucurbits through electronic media. This result indicates that allocating additional funding to this extension activity would likely result in the highest marginal return relative to the other extension options. Examining the corner solution is informative but does not lead us to a well-rounded extension strategy that could be implemented by the DAE. The addition of constraints on rows two through five provides more realistic solutions from which we can optimize the DAE extension strategy. The optimal allocation of funding among dissemination activities is assessed using the model presented in Table 3. The economic surplus resulting from the optimal dissemination strategy is nearly $111 million. This surplus is more than five times greater than the surplus resulting from the current dissemination strategy—approximately $21.5 million.

The current IPM extension strategy relies heavily on interpersonal dissemination methods. Almost $2.3 million—92% of the total IPM budget—is allocated to extension agent visits and $152,474 is apportioned to disseminating IPM through FFSs. Although these budgets are several orders of magnitude greater than the funds committed to media and field days, the methods fail to reach a significant portion of farmers as a result of high costs per participant that limit the number of farmers who can be reached. In addition, the projected adoption rates for most practices when conveyed to a farmer by an extension agent are lower than the adoption rates expected from field days (which include on-farm demonstrations). Shadow prices indicate that, at the margin, a budget reallocation from dissemination through extension agents to field days would provide $7.70–89.40 of additional economic surplus depending on the type of IPM practice and crop. As a result of high costs and low adoption impacts associated with extension visits, the optimized strategy moves away from the one-off personal visits while significantly increasing the electronic media and field day budgets. The current and optimal budget allocations by dissemination method are compared in Figure 1.

Some uncertainty is associated with optimization models as a result of assumptions made during parameter estimation. To assess the robustness and/or limitations of the results, a comprehensive sensitivity analysis is conducted to determine how sensitive the optimal dissemination strategy is to changes in constraints and parameters. The model is first run without the constraints on rows three, four, and five (Table 3). Without the additional constraints, none of the budget is allocated to extension agent visits and the paper media budget is lowered. The funding from these two dissemination methods is instead allocated to electronic media, field days, and FFS. The total surplus in this analysis increases to nearly $142 million; however, the mix of dissemination activities proposed in this model is unrealistic because it almost eliminates an important component of extension—IPM dissemination through extension agent visits. Such visits help maintain confidence in the research/extension complex and build credibility of other dissemination methods. This result suggests that widespread extension mechanisms are more cost-effective than interpersonal tactics.

As a result of uncertainty associated with the projected adoption rates, two sensitivity analyses are conducted to determine if the results change when the high and low adoption projections are assumed. The economic surplus is calculated for each activity using the low and high adoption rates, and the resulting surplus estimates (per dollar of dissemination) are used as the new DMV coefficients for two models: one with low adoption and another with high adoption. Table 4 compares the budget allocation resulting from these two models to the results from the original optimization model. Although the resulting economic surplus differs among the models, the allocation of the budget among dissemination methods is fairly robust to different assumptions about adoption rates.

Additional sensitivity analyses were conducted to test how the selected dissemination strategy may change depending on the following: 1) additional farmer-to-farmer diffusion after an FFS; 2) extending information to multiple farmers during an extension agent visit; 3) altering the level of adoption on specific disseminating methods while holding others constant; and 4) changing levels of diminishing returns. Research has indicated that after an FFS, participating farmers may share IPM information with an average of 11 additional farmers, thus significantly lowering the cost of IPM diffusion per household

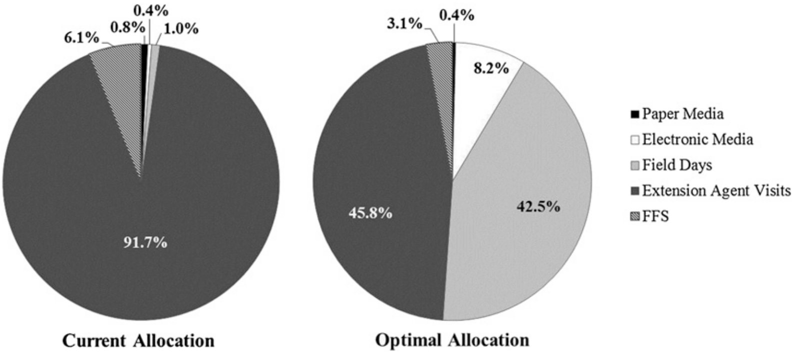

Figure 1. Department of Agricultural Extension Budget Allocation Among Dissemination Methods Using the Current Dissemination Strategy and the Optimized Strategy

Table 4. Comparing the Budget Allocation among Dissemination Methods Using Three Models with Different Levels of Adoption

	Original Model[a]		Low Adoption[b]		High Adoption[c]	
Dissemination Strategy	$ of Budget	Percent	$ of Budget	Percent	$ of Budget	Percent
Paper media	$9,630	0.4%	$9,630	0.4%	$9,630	0.4%
Electronic media	$203,316	8.2%	$176,939	7.1%	$228,593	9.2%
Field day	$1,055,140	42.5%	$1,081,517	43.6%	$1,029,863	41.5%
Extension visit	$1,137,600	45.8%	$1,137,600	45.8%	$1,137,600	45.8%
FFS	$76,237	3.1%	$76,237	3.1%	$76,237	3.1%
Total budget	$2,481,923	100.0%	$2,481,923	100.0%	$2,481,923	100.0%
Total surplus	$111,041,172		$69,159,156		$153,278,720	

[a] DMV coefficients were calculated from the economic surplus analysis using average adoption projections.
[b] DMV coefficients were calculated from the economic surplus analysis using low adoption projections.
[c] DMV coefficients were calculated from the economic surplus analysis using high adoption projections.
FFS, farmer field school; DMV, decision-making variable.

(Mauceri et al., 2007). If each FFS graduate teaches 11 other farmers about IPM, the model suggests increasing the FFS budget by $310,130 compared with the base model by reducing the field day budget by that amount. The analysis also suggests increasing the extension agent budget by $58,000 relative to the base model if agents are able to reach at least five households during a visit. This result suggests that extension agent visits may have more impact if they are able to target groups of farmers instead of focusing on individuals during farm visits.

The budget allocation also changes when the adoption rates are adjusted independently of one another. When the high adoption estimates are used for the agent visits and low adoption estimates are used for all other dissemination methods, the model increases the budget for extension agent visits to $1.22 million while lowering the electronic media and field day budgets to $176,939 and $997,479, respectively. If the low adoption estimates are used for field days whereas the average adoption estimates are used for all other extension methods, the model suggests lowering the field day budget to $1,005,686 while increasing the electronic media and extension agent budgets to $252,769 and $1,137,600, respectively. These results suggest that the model is sensitive to alternative adoption rates, but the selected mix of dissemination methods still favors increased use of field days and electronic media relative to the current budget allocation.

The assumption of having diminishing returns to extension was tested with two models. The first model eliminated diminishing returns for all dissemination activities and assumed that an increased budget would result in a proportional gain in economic surplus. The total economic surplus increased to $144 million, but the budget allocation remained unchanged. Another model assumed diminishing returns for dissemination using paper and electronic media, but not for funding dedicated to field days, agent visits, and FFS. Although these assumptions increased the maximized level of economic surplus to $134 million, the adjustments only slightly influenced the budget allocation by moving $1,000 of funding from electronic media to field days. Overall, the model was robust to changes in diminishing returns. The models used in this study and the full results are available from the corresponding author on request.

Conclusions and Recommendations

Limited funding for agricultural extension programs in Bangladesh creates the need for dissemination methods that can cost-effectively promote the adoption of improved agricultural technologies. This study identified a cost-effective IPM dissemination strategy that could be implemented by the DAE. Results suggest that increased use of electronic media and field days may lead to more widespread adoption of IPM technologies, thus providing greater economic benefit.

The information obtained from the adoption questionnaires and interviews with extension experts suggests that the differences in projected adoption rates among the dissemination methods is attributable, in part, to the degree to which the extension mechanism allows farmers to visualize the IPM technology in practice and observe the results. FFS and field days provide farmers with an opportunity to see the technology, whereas extension agent visits and paper media are rarely able to provide sufficient visual confirmation. TV programs also allow farmers to observe an IPM practice and may be able to change farmers' perceptions at a lower cost than other extension tactics. Future research is needed to quantitatively examine the connection between farmers' ability to visually confirm the success of IPM practices and the adoption rate resulting from various extension methods. The severity of pest pressure also influences farmers' perceptions and needs to adopt IPM technologies. Improving our knowledge of the type and severity of pest problems in different areas may help in targeting dissemination efforts. Geographic information systems (GIS) techniques might play a role in providing spatially explicit information regarding pest problems. More research is needed to explore how these factors affect adoption rates.

In this study, it is assumed that the benefits of IPM practices and dissemination methods are independent of one another and that their benefits are additive. In reality, farmers may learn about IPM practices from a number of different dissemination methods. Each exposure to IPM information may build on the farmers' perceptions and promote the sequential or simultaneous adoption of multiple technologies. It may be the case that mass media acts as a "primer" that encourages farmers to seek out more information about IPM from field days and more interpersonal methods. More research is needed to better understand how various communication channels can be used to influence farmer perceptions of agricultural practices and ultimately encourage technology adoption.

There is an urgent need for cost-effective and sustainable extension programs for IPM in Bangladesh. By increasing the proportion of resources devoted to widespread dissemination mechanisms, extension organizations can reach more farmers and encourage technology adoption within their limited budgets. Based on the findings of this study, the following recommendations to policymakers and program coordinators emerge for improved dissemination of IPM information:

- Mass media, especially electronic media, has the potential to reach large audiences at low cost, but potential benefits from media resources are not fully realized at the current funding level. With increasing availability of televisions, cell phones, and even computers, it should be possible to better use these methods in extension programs.
- It is difficult for extension agents to serve 900 farmers apiece if they are expected to use approaches that involve frequent one-on-one contact. Results of our model suggest that increasing the proportion of the budget dedicated to mass media and field days may help resolve this problem. These methods can be more cost-effective than individual extension agent visits. Extension agents can likely promote additional IPM adoption in a cost-effective manner by conducting field days and group demonstrations that create opportunities for follow-up visits in the future. Visits can also be used to reinforce mass media messages. More research on the complementarities among household visits, FFS, and field days may improve our understanding of the appropriate balance between these methods.
- Stakeholders noted that farmers will adopt IPM practices more readily if they can quickly observe positive results on their own or a neighboring farm. Focusing dissemination efforts on "visible" technologies, like pheromone traps, will likely result in more widespread adoption and greater economic benefits. Field days, FFS, and electronic media are examples of dissemination

methods that can capitalize on the visibility of technologies.

- Extension agents note that widespread adoption of some IPM technologies is constrained by their availability. Although research has demonstrated the effectiveness of technologies such as Tricho-compost, beneficial insects, and grafted seedlings, farmers may not be able to adopt the practices because appropriate inputs are not available. Recently, the Government of Bangladesh approved the import of pheromones and legalized their marketing. This new policy is increasing diffusion of pheromone traps by mobilizing private industry. In the last two years, private markets have also emerged for Tricho-compost and biological controls, creating new opportunities for their use.

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