Journal of Agricultural and Applied Economics, 39,3(December 2007):765–780

Effectiveness of Integrated Pest Management Dissemination Techniques: A Case Study of Potato Farmers in Carchi, Ecuador

Maria Mauceri, Jeffrey Alwang*, George Norton, and Victor Barrera

Potato farmers in Ecuador rely on chemical inputs to manage pests and optimize yields. Integrated pest management techniques lower production costs, reduce pesticide exposure, and improve long-term agricultural sustainability. Public extension does not, however, exist in Ecuador, and cost-effective means of communicating complex messages to producers are needed. We analyze cost-effectiveness of alternative dissemination methods, including farmer field schools (FFS), field days, pamphlets, and word-of-mouth transmission. Field days and pamphlets have strong impacts on adoption, especially considering their low costs. FFS are effective, but expensive. Evidence also indicates significant diffusion from FFS to non-FFS farmers, indicating high complementarity across methods.

Key Words: Ecuador, farmer field schools, integrated pest management, technology adoption, technology dissemination

JEL Classifications: Q01, Q16

Agricultural development is essential for improved well-being in rural Ecuador, as approximately 40% of the population relies on agriculture as its primary source of income. In the highlands, potatoes are a major staple, and more than 90,000 producers grow them on about 60,000 hectares of land. Potato production is associated with heavy use of chemical inputs—pesticides and fertilizers—to manage pests and optimize profits. Concerns have emerged about the sustainability of Ecuador's potato crop as rising input costs are lowering competitiveness and about adverse consequences related to overuse of pesticides. These consequences include short- and long-term human health problems, water and soil contamination, buildup of resistance in pest populations, and loss of beneficial insects. Besides negative health and environmental impacts, pesticide expenditures signify significant costs for potato, typically between 12% and 20% of total production cost (Barrera et al.).

Carchi Province in the northern highlands[1] currently produces more potatoes than any

* Contact author: Jeffrey Alwang, 215I Hutcheson Hall, Virginia Tech, Blacksburg, VA 24061, USA. Telephone: 540-231-6517, fax: 540-231-7417, e-mail: alwangj@vt.edu.

Maria Mauceri, Jeffrey Alwang, and George W. Norton are former graduate student and professors, respectively, Department of Agricultural and Applied Economics, Virginia Tech, Blacksburg, VA. Victor Barrera is researcher, Assessment Division, INIAP, Santa Catalina Experiment Station, Quito, Ecuador.

The research was supported by the IPM CRSP, with funding provided by USAID under Agreement No. LAG-4196-G-00-5001-00 to Virginia Tech, but does not necessarily reflect the views of that agency.

[1] Carchi province is located on the northern border with Colombia. The province is characterized by steep slopes at high elevations—potatoes are produced between 2,800 and 3,500 m above sea level. Average temperatures in the region are about 12°C, with highs of 25°C and extremely rare freezes. Rainfall averages 1,000 ml per year and is spread rather evenly throughout the year. The population is primarily meztizo, and average holding sizes are about 5 ha per family.

other region of the country. Yields in Carchi are relatively high, averaging between 15 and 20 tons per hectare, compared to average yields for all Ecuador of around 7 tons per hectare (Barrera et al.). Of all cultivated crops in Carchi, potatoes use the most pesticides and fertilizers. Producers need feasible alternative pest management approaches that are economically sustainable and effective at controlling pests.

Integrated pest management (IPM) is an approach that can help lower production costs, reduce exposure to pesticides, and improve long-term sustainability of the agricultural system. Scientists at the national agricultural research institution in Ecuador (INIAP), with partial support from the USAID-funded Integrated Pest Management Collaborative Support Program (IPM CRSP) and the International Potato Center, have developed several IPM technologies to manage potato pests. Information about these technologies is diffused through various mechanisms, including farmer field schools (FFS), field days, exposure to other farmers, and written media (e.g., pamphlets). Since the public agricultural extension service was effectively dismantled during the 1990s, decision makers have increasingly sought cost-effective alternatives for information dissemination, especially for complex messages like IPM.

The main objective of this study is to compare the cost-effectiveness of FFS compared to other information-dissemination methods. In order to achieve this objective we also (1) analyze the extent of IPM use in Carchi and identify determinants and constraints to IPM adoption and (2) evaluate how IPM technologies are spread among potato farmers. FFS are a relatively new approach for disseminating complex information, and there is conflicting evidence in the literature about their cost-effectiveness. Davis summarizes the evidence relative to FFS cost-effectiveness, noting that while some studies find FFS participants have increased farmer knowledge (Feder, Murgai, and Quizon 2004a; Godtland et al.; Rola, Jamias, and Quizon), there is less evidence that FFS participants effectively spread knowledge to others (Feder, Murgai, and Quizon 2004b; Rola, Jamias, and Quizon). This paper contributes to this literature by combining evidence on participation, diffusion, and costs associated with FFS and by comparing these factors with other dissemination measures. While the literature on agricultural technology adoption is quite rich (see Brown; Feder and Slade; Griliches; and the summary of literature by Feder, Just, and Zilberman), there is considerably less information on adoption of IPM. IPM is different from many agricultural technologies in that it involves a continuum of practices of varying complexity. Thus, impacts of variables on adoption are likely to be different, and adoption can no longer be represented as a discrete choice. The literature on IPM adoption is thinner than that for agricultural technologies (see Barrera et al.; Bonabana-Wabbi; Caviglia-Harris; Van de Fliert, Jonson, and Asmunati).

Background: Pest Problems and IPM Solutions

Potato Pests in Carchi, Ecuador

Three main pests significantly impact potato production in Ecuador. In order of economic significance, they are late blight (*Phytophthora infestans*), Andean Potato Weevil (*Premnotrypes vorax*), and the Central American tuber moth (*Tecia solanivora*). Studies in the late 1990s in northern Ecuador reported that nearly 100% of farmers are reportedly affected by late blight, 80% by Andean Weevil, and 6% by tuber moth (Barrera, Norton, and Ortiz). INIAP conducted original research (complementing existing research) and developed strategies for effective management of these pests.

Late blight is a fungal disease affecting potatoes around the world. Yield losses depend on the virulence of the fungal strain and whether farmers have the resources to use available fungicides. Studies on lower-virulence strains estimate losses at 15%–30% of the crop (Lang). Without chemical intervention, more-lethal strains put farmers at great risk of losing much of their crop. The prime means of control for late blight is fungicide application, and overspraying is common: potato farmers in Carchi spray their fields as many as 11 times in a crop cycle, and the modal number of applications is six (Barrera et al.; Crissman et al.). Because late blight is difficult to control once the disease has become established, farmers spray as a preventative strategy. IPM CRSP recommendations for control of late blight include use of resistant varieties, improved field sanitation, crop rotation, monitoring insect populations to guide spray applications, and alternating fungicides to manage pest resistance.

The Andean Weevil causes significant damage without proper management. Up to 80% crop damage has been estimated in infested fields in Ecuador (Muñoz and Cruz). Farmers typically use three strategies against the Andean Weevil: insecticides targeted at the larval stage of the insect, namely Carbofuran and Methamidofos (both of which are restricted in the United States because of high toxicity); crop rotations; and use of undamaged seed. The main mistake in the conventional approach to controlling the weevil is targeting the larval stage of the insect. Insecticidal sprays are more effective when targeting adult populations. The IPM CRSP recommends the use of traps to monitor and target adult Andean Weevil populations. Traps consist of foliage from potato plants baited with Acefato, a relatively low-toxicity insecticide. If pest populations reach a threshold, farmers are advised to spray at the base of plants, since adult weevils tend to remain at soil level. At harvest, all tubers should be removed from the field. Farmers are advised to wait 30 days before replanting, causing larva to die before the next crop is established.

The tuber moth is not yet a major problem for farmers in Ecuador (Barrera, Norton, and Ortiz); however, it has an affinity for temperate valleys like those found in Carchi. It can cause damage to preharvested tubers and in stored potatoes. In either case, current methods of control use highly toxic insecticides (Carbofuran and Carbosulfan). In the field, IPM techniques for control of the tuber moth include pheromone traps to monitor and track adult populations and spraying low doses of Profenos when populations reach a threshold. In terms of storage, farmers are advised to use baculovirus to kill insects and to keep harvested potatoes covered. Other recommendations include earlier planting and harvest to avoid the dry season; hilling up of soil around plants; crop rotations; and disinfecting seed with low-toxicity pesticides such as Carbaryl and Malathion.

Ecuadorian authorities recognize problems related to pesticide overuse in the region. Several laws, promulgated in the early to mid-1990s, regulate the formulation, production, and importation of pesticides, but weak enforcement and poor information on the part of producers contribute to continued overuse.[2] Government also supported a major national program that was designed to increase the productivity and profitability of potato production and to reduce use of pesticides (Crissman et al.).

IPM Solutions: Are They Profitable?

From 1998 to 2003, with funding from Food and Agricultural Organization of the United Nations (FAO) and later the IPM CRSP, 18 FFS were set up in the Carchi region. The main purpose of the field schools was to educate participants in IPM techniques. In three FFS field trials, cost–benefit analysis was used to compare conventional pest control methods to IPM. In all cases, input costs were significantly lower on IPM plots, and yields were at least equal. Taking into account costs and benefits, net profits were higher in all cases for the FFS/IPM plots. IPM-related increased profits ranged from about $270 to more than $560 per hectare, and in all cases differences between profits on the IPM and on conventional fields were statistically significant (Barrera et al.). IPM is thus a cost-effective choice for potato farmers and requires no additional capital. Extra labor only appears to be necessary in minor amounts to monitor insect populations. Inputs such as pesticides and fertilizers are used less in IPM plots and offset

[2] See www.sica.gov.ec/agro/insumos/SESA.pdf

the increase in costs due to greater labor use and purchase of improved seed.

Access to IPM Information

IPM techniques are relatively complex and therefore require sufficient knowledge acquisition for successful implementation. Complexity of the IPM message affects which method of information diffusion will have the greatest impact. More complex messages include knowledge of the pest life cycle, understanding of trap use and pest population monitoring, use of systemic versus protectant pesticides, and use of different active ingredients to manage resistance in pests. Other messages can be understood with minimum explanation, such as early harvests, crop rotations, and use of resistant varieties.

FFS are a relatively recent approach in the education of developing-world farmers. This program was created in response to deficiencies in other agriculture education and extension programs (see Nelson et al.; Pontius, Dilts, and Bartlett). Field schools attempt to improve upon previous methods of educating farmers by using a participatory, rather than a top-down, approach and by teaching farmers how to think critically about pest and production problems. This system allows farmers to evaluate their farm situations and to use technologies according to their needs. In Ecuador, participants met once a week for approximately 3 hours for an entire 6-month potato-growing season. Participants engage in hands-on learning activities and are taught how to teach others. They are not compensated for their time; however, they are fed a meal and they share in the output of FFS fields.

Because of their high program costs (approximately $30/farmer in Ecuador), FFS rely on farmer networks to facilitate the spread of information and adoption to increase the cost-effectiveness of the program. Field days are used to give pest management information to large groups of farmers at one time for a fraction of the cost ($1.50/farmer). However, a field day participant will not receive as much information as a graduate of the FFS program, and the method of instruction is top down. Pamphlets are the least expensive ($.50/farmer), but their use assumes farmer literacy, and pamphlets are less effective for transmission of complex messages.

Selection of participants for potato-producer FFS in Carchi is based on four factors: (1) interest in the program, (2) that potatoes are the principal crop on the farmer's land, (3) desire to share/diffuse information with other farmers, and (4) creativity and ability to innovate. The selection criteria raise questions about an inherent bias in the FFS approach that causes researchers to overestimate the impact of FFS on adoption of IPM (Feder, Murgai, and Quizon 2004b) FFS may simply be educating only those farmers who would adopt the IPM technology, regardless of the information source and those already striving to use alternative strategies. Without controlling for endogenous program participation, estimates of the impact of the program on IPM adoption may be biased. Our study controls for this endogeneity.

Several studies have evaluated the effectiveness of FFS in extending complex messages to resource-poor farmers. These studies can roughly be divided into those that do not control for endogenous program participation and those that do. The first group of studies generally finds that FFS participation increases farmer understanding of pest control methods (e.g., Rola, Jamias, and Quizon; Van de Fliert, Jonson, and Asmunati), with some finding increased yields and lower pesticide usage among participating households. The second group includes studies by Feder, Murgai, and Quizon (2004b) and Godtland et al. The Feder, Murgai, and Quizon (2004b) study showed little evidence that the impact of FFS participation affected farmer knowledge in Indonesia once endogenous participation had been controlled for. Godtland et al., in contrast, found that FFS participation increased IPM knowledge among potato farmers in the Peruvian Andes. Our study adds to this literature by examining knowledge changes and the impact of these changes on pest control practices. We do so while controlling for endogenous participation of the farmers, and we extend the analysis to examine the cost-effectiveness of FFS compared to other dissemination efforts.

Methods

The analysis in this paper involves four steps: (1) determination of spread of information and sources of information by IPM adoption level and knowledge; (2) analysis of the determinants of participation in FFS using a probit model; (3) analysis of determinants of adoption of IPM using an instrumental variables (IV) regression; and (4) use of the econometric results and information on program costs to examine cost-effectiveness of alternative diffusion mechanisms.

A comprehensive survey was conducted of 109 potato farmers in Carchi during September–October 2003. Respondents included 30 FFS participants, 28 farmers who had been exposed to FFS participants, and 51 randomly selected farmers. The survey collected information on demographic and socioeconomic conditions, potato production, pesticide usage and handling, IPM knowledge and implemented techniques, and farmer knowledge about the three most significant potato pests. The survey information was combined in our analysis with budgets and costs from the FFS and with expert opinion.

To address the spread of information, farmers were asked a series of questions during the survey to determine knowledge of IPM and degree of IPM adoption. Using descriptive statistics and differences in means, we analyze the relationships between access to information, IPM knowledge, and adoption and word-of-mouth diffusion of IPM techniques to neighboring farmers. We model the decision to participate in a FFS using a probit model. The independent variables include three categories of potential determinants of participation in an FFS, including farmer characteristics, economic factors, and institutional factors.

The instrumental variables regression used to obtain estimates of the determinants of the intensity of IPM adoption included variables representing farmer characteristics and economic and institutional factors together with dummy variables representing access to sources of information (participation in FFS, field days, etc.). Because of endogeneity of participation in FFS, this variable was instrumented. Using the IV results, marginal impacts of significant variables were calculated to compare the impacts of the significant independent variables on the percentage of IPM techniques adopted. Information on these impacts was compared to per-farmer costs for FFS, field days, and pamphlets to estimate relative cost-effectiveness of these information-diffusion mechanisms.

Model of Technology Adoption

The IPM technology adoption model used here is based on the theory that farmers make adoption decisions to maximize their expected utility or benefits (see Adesina et al.; Ersado, Amacher, and Alwang; and Feder and Slade for details on the theory of adoption). Benefits may include increased profitability, health, food security, lower risk, and environmental sustainability. Farmers adopt technologies when their expected utility from the new technology exceeds that of the current or other available technologies. Many factors affect farmers' expectations and should be included as determinants of adoption.

Farmer characteristics often considered in adoption models include age, human capital (formal or informal education), and household size. Age is typically found to be negatively correlated with adoption (Adesina and Zinnah), likely as a result of an increase in risk aversion and decreased interest in investment in the farm as farmers age. Younger farmers are typically less risk-averse and more willing to try new technologies.

Formal education increases the farmer's ability to understand and respond to information concerning new technologies (Feder and Slade; Rahm and Huffman). Studies show that farmers with more formal education tend to adopt more agricultural technologies (Feder, Just, and Zilberman; Strauss et al.). Household size is another determinant of adoption. When we hold other factors constant, larger households adopt new technologies more often than smaller households (Bonabana-Wabbi; De Souza Filho, Young, and Burton). Households containing members able to participate in on-farm activities enable farmers to adopt labor-intensive technologies (Feder, Just, and Zilberman).

Economic barriers may discourage or prevent adoption; these barriers include wealth (farm size, income), access to credit, and labor availability. In general, populations with higher incomes exhibit a willingness to accept more risk and to adopt complex technologies (Batz, Peters, and Janssen). Farmers with access to more land are wealthier, invest more in information acquisition, and accumulate knowledge that leads to adoption (Feder and Slade). Wealth and income can lead to use of more pesticides because they lower barriers to acquisition of capital items. Studies indicate that wealthier farmers prefer capital-intensive over labor-intensive technologies, often because of the transaction costs associated with monitoring labor (Goodell, Andrews, and López). Distance to a market can affect the profitability of IPM by lowering the farm–gate prices of outputs, raising the prices of inputs, and making information acquisition more costly.

Access to information affects farmers' perceptions of risk. Having sufficient knowledge about the technology enables farmers to optimize these decision-making processes (Feder, Murgai, and Quizon 2004a). Feder, Murgai, and Quizon (2004a) found that farmers consider other farmers to be the most important source of agriculture information, but they prefer more specifically trained sources as the complexity of the message increases. The acquisition of knowledge may lead to a change in farmer perceptions about risk and profitability associated with a technology package. Thus, farmers who are knowledgeable about profit-enhancing technologies will choose to adopt (Negatu and Parikh).

Access to information through FFS and other means can promote adoption by providing improved understanding of IPM technology benefits and costs. We consider exposure to several sources of information: FFS, field days, exposure to other farmers who attended and did not attend FFS, and pamphlets; all these factors can enhance information and promote adoption.

The Empirical Model

The model we employ examines decisions to participate in FFS and the impacts of FFS participation and other variables on adoption of IPM techniques. Let Y_P represent the decision to participate in the FFS (a binary decision) and Y_{IPM} represent the decision to adopt IPM techniques. While Y_{IPM} could be considered to be a binary decision, in practice IPM adoption is a continuum, and we model Y_{IPM} as the percentage of technologies adopted, a continuous variable. In this way, we retain more information about the adoption decision. The relationships can be expressed as

$$(1) \quad Y_{Pi} = X_{Pi}\beta_P + \varepsilon_{Pi}$$

$$(2) \quad Y_{IPMi} = X_{IPMi}\beta_{IPM} + \alpha Y_{Pi} + \varepsilon_{IPMi},$$

where X_i is a vector of determinants of participation in FFS (for X_P) and determinants of adoption of IPM (for X_{IPM}) for the ith farmer and β_P and β_{IPM} are vectors of parameters for the determinants of participation in field schools and IPM adoption, respectively. The vector X_{IPM} contains all the previously mentioned factors. The expected increase in adoption associated with participation in the FFS is determined by the parameter α. The ε_{Pi} and ε_{IPMi} are random error terms. Participation in the FFS cannot, however, be treated as exogenous if $\text{Cov}(\varepsilon_{Pi}, \varepsilon_{IPMi}) \neq 0$, that is, if unobserved factors affect both the participation and the adoption decision. If this endogeneity is ignored and Equation 2 is estimated using ordinary least squares (OLS), the resulting parameters will be biased and inconsistent. One such solution to this problem is the use of IV techniques using the predicted value of the endogenous variable in the second-stage regression (Heckman; Robinson). To ensure identification, an instrument is used that is correlated with FFS

Table 1. Percent Adoption of Integrated Pest Management (IPM) by Technique and Farmer Group, Carchi Potato Farmers, 2003

IPM Technique	FFS (%)	Exposed (%)	Random (%)	Total (%)	χ^2
Use recommended storage	23.3	7.1	2.0	9.2	0.005
Use traps (baited) for Andean Weevil	30.0	3.6	3.9	11.0	0.000
Use fungicides with different active ingredients	26.7	7.1	7.8	12.8	0.029
Use traps (mobile)	50.0	14.3	3.9	19.3	0.000
Use pheromone traps (tuber moth)	33.3	35.7	9.8	22.9	0.009
Use yellow traps	56.7	21.4	9.8	25.7	0.000
Use recommended hilling methods	60.0	53.6	2.0	31.2	0.000
Use irrigation	43.3	17.9	31. 4	31.2	0.112
Use resistant varieties	50.0	14.3	37.3	34.9	0.015
Use pest stage in control strategy	83.3	57.1	3.9	39.4	0.000
Use quality seed	56.7	46.4	33.3	43.1	0.113
Use insecticides according to recommendations	70.0	53.6	33.3	48.6	0.005
Dispose of residues in the field	70.0	60.7	33.3	50.5	0.003
Disinfect seed with insecticides	70.0	75.0	39.2	56.9	0.002
Use early harvest to control tuber moth	73.3	85.7	33.3	57.8	0.000
Use crop rotations	83.3	75.0	35.3	58.7	0.000
Use traps	80.0	75.0	52.9	66.1	0.023

Note: $n = 109$; *FFS* indicates that the farmer attended farmer field school (FFS); *Exposed* indicates farmer with some exposure to an FFS participant; *Random* indicates no apparent contact with FFS participants.

participation but that only affects adoption through its impact on participation. We use the variable distance from the extension office (in kilometers) as such an instrument.[3]

Participation in FFS can be modeled as a binary (e.g., probit, logit) decision. Adoption of IPM may also be modeled as a binary, but farmers often manage risk through diversification, and a diversification strategy may be reflected in partial adoption of technologies (Ersado, Amacher, and Alwang). In this study, we look not only at whether adoption occurs but also at the intensity of adoption. We use as a dependent variable (Y_{IPM}) the percentage (out of 17) of IPM techniques that are adopted on potato fields by the responding farmer.

[3] We tested the validity of this instrument using the relevance test, the over-identification test, and the Durban-Hausman-Wu test. See Ersado, Amacher, and Alwang for details on these tests. Based on these tests, the *variable distance from the extension office* was determined to be an acceptable instrument.

Results

Descriptive Analysis of IPM Knowledge and Use

For the descriptive analysis, farmers were divided into three populations: (1) FFS participants (FFS), (2) farmers exposed to FFS graduates (Exposed), and (3) random farmers with no apparent relationship to FFS or FFS participants (Random). Adoption of IPM varied across these categories (Table 1). Adoption of IPM varies significantly according to the type of technology in question. More than half of farmers used some form of insect traps, crop rotations, disinfection of seed with insecticides, removal of crop residues from fields, and early harvest to control tuber moth. The least popular practices were use of recommended storage bins, traps for Andean Weevil, and use of fungicides with different active ingredients.

Although adoption intensity was significantly different across farmer groups, the *pattern* of adoption was similar (i.e., least-adopted and most-adopted technologies were consistent across groups). The least-adopted practices were recommended storage practices, use of fungicides with different active ingredients, baited traps for Andean Weevil, irrigation, quality seed, and resistant varieties. These practices are relatively complex and are perceived to be most risky and capital-intensive. Among the most-adopted technologies are use of traps (in general), residue disposal, crop rotations, early harvest, disinfection of seeds, and use of insecticides as recommended. These technologies tend to be lower risk, of low to moderate complexity, and are not capital-intensive. Using pest stage as a control strategy was widely adopted by FFS farmers, moderately adopted by Exposed farmers, and hardly adopted at all by Random farmers. These results reflect the high information requirement associated with this more-complex technology.

An index of farmer knowledge about IPM was created by computing the percentage of IPM-related questions correctly answered. FFS participants had the highest IPM knowledge scores (Table 2), but field days and pamphlets also contributed to knowledge. Farmer-to-farmer diffusion (FEXP2 and FEXP3) has some impact on knowledge, but knowledge scores for farmers who received the bulk of their IPM information from other farmers are not as high as those obtained when other media (field days, pamphlets) are used.

Adoption of IPM varies depending on the information source. Around 42% of all farmers had moderately high to high adoption (Categories IV and V), 37% had low to moderate adoption (Categories II and III), and 20% did not adopt any IPM (Category I) (Table 3). FFS were associated with the highest levels of IPM adoption—Category V adoption was mainly observed among FFS participants. Category IV adoption was observed with FFS farmers, those who attended field days, and those who read pamphlets (partially attributed to correspondingly high knowledge scores). Farmer-to-farmer diffusion (FEXP2 and FEXP3) seemed to be less effective, as both knowledge scores and adoption rates were lower. The lowest rates

Table 2. Depth of Knowledge About Integrated Pest Management (IPM) by Information Source, Carchi Potato Farmers, 2003

IPM Knowledge by Category	FFS	FEXP2 (Other Farmers—FFS)	FEXP3 (Other Farmers—Non-FFS)	FEXP4 (Field Days)	FEXP5 (Pamphlets)	FEXP0 (Have Not Heard)
Category I (0%)	0.0	5.9	16.7	5.9	14.3	44.4
Category II (1–25%)	0.0	35.3	41.7	11.8	28.6	27.8
Category III (26–50%)	3.3	41.2	33.3	35.3	21.4	22.2
Category IV (51–75%)	23.3	11.8	0.0	41.2	21.4	5.6
Category V (76–100%)	73.3	5.9	8.3	5.9	14.3	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

Note: A Pearson χ^2 test showed significant differences between information sources at the 1% level; knowledge category was determined by the percentage of IPM questions answered correctly by farmers. FFS is farmer field school.

Table 3. Percent Adoption of Integrated Pest Management (IPM) by Information Source, Carchi Potato Farmers, 2003

IPM Use by Category	FFS	FEXP2 (Other Farmers—FFS)	FEXP3 (Other Farmers—Non-FFS)	FEXP4 (Field Days)	FEXP5 (Pamphlets)	FEXP0 (No Info.)	Total
Category I (0%)	3.3	11.8	33.3	5.9	21.4	61.1	20.2
Category II (1–25%)	6.7	29.4	33.3	17.6	21.4	11.1	17.4
Category III (26–50%)	20.0	29.4	16.7	23.5	21.4	5.6	20.2
Category IV (51–75%)	43.3	23.5	8.3	47.1	35.7	22.2	32.1
Category V (76–100%)	26.7	5.9	8.3	5.9	0.0	0.0	10.1
Total (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Note: A Pearson χ^2 test showed significant differences between information sources at the 1% level; knowledge category was determined by the percentage of IPM questions answered correctly by farmers. FFS is farmer field school.

of adoption were observed in the farmers who had heard of IPM from non-FFS farmers (FEXP3) or who claimed they had not received information on IPM (FEXP0). Non-FFS farmers may lack the expertise to transfer IPM knowledge effectively. Recipient farmers may also show a preference for more-experienced individuals when learning IPM technologies.

FFS encourage information diffusion from participants to nonparticipants. FFS participants claimed to have shared information with 11 additional farmers, on average (Table 4). More than 220 farmers in Carchi were trained in FFS between 1998 and 2003. If we assume there is no overlap in these interactions, approximately 2,500 farmers were exposed to IPM as a result of interactions with FFS participants, representing more than one third of potato farmers in Carchi. Exposed farmers also spread information to other farmers, but at much lower rates than did the FFS participants, while Random farmers hardly shared any information with other farmers. FFS participants' willingness to share information can be a significant benefit of the FFS approach, as Exposed farmers had higher knowledge scores and were more likely to seek further information, either through field days or written pamphlets. This evidence of willingness of FFS participants to spread information is consistent with the FFS selection criteria described above.

Multivariate Analysis: Determinants of Participation in FFS

In order to assess the impacts of FFS attendance on the intensity of adoption of IPM, it is first necessary to examine the determinants of participation in a FFS. A probit model was run with the dependent variable being participation (=1 if farmer participated; =0 otherwise). Independent variables are summarized in Table 5. Farmers were predominantly male with a primary school education; only 12% had secondary school education. Ages ranged from 18 to 86 years, with nearly half of farmers between 31 and 50 years of age, and mean farming

Table 4. Farmer-to-Farmer Spread of Integrated Pest Management (IPM) Information, Carchi Potato Farmers, 2003

	FFS	Exposed	Random	Total
Number of farmers who spread IPM information to other farmers	28/30	25/28	4/51	57/109
Total number of farmers to whom information was spread	332	61	14	407
Average number of farmers each farmer spoke to about IPM	11	2.17	0.27	3.73

Note: FFS is farmer field school.

experience was 25.9 years. The average household size was 4.9 members. Farmer characteristics from this survey were comparable to those of other surveys conducted in Carchi in recent years (see Barrera et al.).

The probit participation equation has a reasonable fit, with plausible results (Table 6). The estimates show that younger people, females, and those from larger households are significantly more likely to attend field schools. The gender impact is quite strong and reflects a conscious effort on the part of FFS to include women in the training process. Education of the participant is not a significant determinant of participation. Wealth has mixed impacts on FFS participation. Owners of larger farms (wealthier farmers) are more likely to attend field schools, but income is not related in a significant way to participation. Farmers who had been made sick in the past from pesticide poisoning (Health) are more likely to participate, while those who are more distant from the extension office (Distxoff) also are more likely to participate. The latter result may seem counterintuitive, but it is consistent with desires of the FFS planners. Field school planners wanted field schools to reach into otherwise-remote areas and made a conscious decision to locate them relatively far from the district center (Barrera et al.).

Information Sources and Adoption of IPM

The results in Table 6 indicate that participation in FFS is not a random event, opening the possibility that unobserved factors affecting FFS participation may also affect IPM adoption. Under such circumstances, including FFS participation as a regressor in the adoption equation (Equation 2) will lead to biased and inconsistent parameter estimates. For this reason, we use predicted participation as an instrument in an instrumental variables estimation procedure (the Distxoff is used to identify the effect of participation; it affects FFS participation directly but only affects adoption of IPM through its impact on participation). Three separate sets of estimates are presented in Table 7; the first represent the regression of adoption intensity (Pctuse, or the percentage of the 17 IPM techniques that the farmer uses) on its determinants, not controlling for the endogeneity of FFS participation (model 1); the second is an instrumental variables estimate of the same regression in which FFS participation is instrumented (model 2); and model 3 includes other variables representing sources of information, such as field days, pamphlets, etc.

Not controlling for endogeneity, FFS participation has a strong, statistically significant effect on adoption. In fact, FFS participants adopt, on average, 26%-point higher proportions of IPM practices, when holding all other factors constant.[4] When endogeneity of participation is controlled for in the instrumental variables regression (model 2 estimates in Table 7), the statistical significance of FFS participation is reduced, but the magnitude of participation's effect on adoption percentage is increased. Lower significance of an instrumented endogenous variable is a typical finding with IV regressions; the

[4] The regression coefficients in Table 7 represent the marginal impact of the independent variable on the proportion of IPM techniques adopted. In the case of model 1, nonparticipants would have a value of zero and participants would have a value of one, and the increment to this proportion due to participation would be .26, or 26 percentage points.

Table 5. Description of Variables and Summary Statistics

Variable	Type	Description	Mean (n = 109)	SD	Min	Max
Dependent Variables						
FFS	Binary	Attend FFS	0.28	0.45	0	1
Pctuse	Continuous	Proportion of IPM practices (out of 17 total) adopted	0.36	0.28	0	17
Characteristics of Farmer						
Fage	Continuous	Farmer age	43.50	14.62	18	86
Male	Binary	Gender of household head	0.94	0.25	0	1
Education	Binary	Household head attended secondary school	0.12	0.33	0	1
HHsize	Discrete	Household size	4.94	1.82	1	9
Economic Factors						
Land	Continuous	Land holdings per family member (hectares)	0.24	0.43	0	1
Income	Continuous	Income ($U.S.) per family member	467	375	0	1800
Health	Binary	Farmer has been sick from pesticides	0.24	0.43	0	1
Institutional/Exposure Factors						
Distxoff	Continuous	Travel time in minutes to nearest extension office	30.9	18.1	0	80
Distmark	Continuous	Travel time in minutes to nearest potato market	92.2	97.6	0	480
FEXP2	Binary	Heard of IPM from FFS farmers	0.16	0.36	0	1
FEXP3	Binary	Heard of IPM from non-FFS farmers	0.11	0.31	0	1
FEXP4	Binary	Heard of IPM from a field day	0.16	0.36	0	1
FEXP5	Binary	Heard of IPM from pamphlets	0.13	0.34	0	1

Note: SD is standard deviation; Min is minimum; Max is maximum; FFS is farmer field school; IPM is integrated pest management.

Table 6. Determinants of Attendance in Farmer Field School (FFS). Probit model: Dependent Variable (FFS) = 1 if Attended, =0 Otherwise

Variable	Coefficient	Significance (p-Value)	Marginal Effect
Intercept	−.577	.495	
Fage	−.017	.120	−.005
Male	−.799	0	−.631
HHsize	.183	.041	.056
Educ	−.034	.944	−.010
Land	.243	.017	.074
Income[a]	.003	.43	.001
Health	.659	.044	.221
Distxoff	.025	.003	.076
Pseudo R^2		.192	
Percent correct prediction		74.3	
N		109	

[a] Income coefficient is multiplied by 10. Fage is farmer age; HHsize is household size; Educ is education.

reason the magnitude of the effect grows in the properly specified IV regressions (models 2 and 3) is that household size is positively correlated with FFS participation and negatively correlated with adoption. Holding FFS participation constant, as in model 1, the indirect impact of household size on participation is absorbed into the FFS participation effect, leading to an underestimate of the influence of participation on adoption.

Focusing on models 2 and 3, we see that when holding all else constant, households with more members adopt fewer IPM techniques. Households farther from markets

Table 7. Determinants of Intensity of Adoption of Integrated Pest Management (IPM) Techniques (Dependent Variable = Pctuse)

	Model 1		Model 2		Model 3	
Variable	Coef.	t	Coef.	t	Coef.	t
Intercept	0.646	4.76	0.197	2.88	0.295	1.38
Fage	−0.001	−0.37	−0.000	−0.02	0.001	0.38
Male	−0.094	1.61	−0.025	0.20	−0.030	0.22
HHsize	−0.038	−2.41	−0.044	−2.55	−0.045	−2.51
Educ	−0.072	−1.16	−0.062	−0.86	−0.082	−1.13
Land	0.026	0.98	0.018	0.57	0.009	0.29
Income[a]	−0.001	−1.28	−0.001	−1.36	0.000	−0.45
Health	0.062	1.21	0.039	0.69	0.053	0.94
Distmark	−0.001	−2.70	−0.001	−2.70	−0.000	−1.76
FFS[b]	0.261	4.76	0.394	1.89	0.564	1.73
FEXP2					0.245	1.20
FEXP3					0.170	0.91
FEXP4					0.383	1.95
FEXP5					0.278	1.22
R^2	0.348		0.310		0.405	
N	109		109		109	

[a] Income coefficient is multiplied by 10. Coef. is coefficient; Fage is farmer age; HHsize is household size; Educ is education; FEXP2 indicates heard of IPM from FFS farmers; FEXP3 indicates heard of IPM from non-FFS farmers; FEXP4 indicates heard of IPM from a field day; FEXP5 indicates heard of IPM from pamphlets.

[b] FFS (participation in farmer field school) is endogenous in models 2 and 3.

(Distmark) also adopt significantly fewer techniques. The latter finding is consistent with expectations, indicating that remoteness lowers the profitability of IPM and, hence, slows its adoption. The former result is counterintuitive. One explanation is that children may compete with other activities for the farm manager's time; because cultivated land per person is relatively small, the added impact of additional labor on the propensity to adopt IPM might be small. In model 2, endogenous participation in the FFS was significant at the 10% level, indicating that when holding all other factors constant while allowing their decision to participate to vary, FFS participants adopted, on average, 39% more IPM techniques compared to nonparticipants. No other variables had a statistically significant impact on IPM adoption.

When FFS attendance is compared with other means of being exposed to IPM techniques (model 3), we see that only FFS participation and attendance at a field day (FEXP4) were significant determinants of IPM adoption. Both had positive impacts on the percentage of IPM techniques adopted. Endogenous participation in a FFS is associated with a 56% age point increase in the intensity of IPM adoption, while participation in field days raises adoption by 38% age points. Having heard of IPM from other farmers and exposure to pamphlets did not significantly increase the proportion of IPM techniques that the farmer adopted, raising doubt about the informal diffusion of IPM. Household size and distance were still negatively and significantly associated with IPM adoption.

Using the marginal impact on adoption intensity of all techniques (FFS, field days, and pamphlets) and cost data we can evaluate the relative cost-effectiveness of information dissemination methods. Estimated costs are $30/farmer for FFS, $1.50/farmer for field days, and $.50/farmer for a pamphlet (Barrera et al.). Although FFS are 20 times the cost of field days per participant, they have only about 1.71 times the impact on adoption intensities, assuming that all adopting farmers used the IPM techniques appropriately and retained the information (Table 8). We can

Table 8. Cost-Effectiveness of Information Dissemination Methods

	FEXP1 (Attend FFS)	FEXP4 (Field Days)	FEXP5 (Pamphlets)	Cost Ratios FFS/Field Days	Cost Ratios FFS/ Pamphlets
Implementation costs (per attendee)	$30	$1.50	$0.50	20:01	60:01:00
Farmer-to-farmer diffusion (No. of other farmers with whom they shared IPM information)	11	2.7	0.33		
Marginal effects on adoption taking diffusion into account	0.564	0.383	0.277		
Cost/total number of farmers reached	$2.50[a]	$0.40[a]	$0.38[a]	6.25:1	6.58:1
Total effect on adoption (=marginal effect + contacts × marginal effect)	3.26	0.84	0.33	3.88:1	9.88:1

[a] $2.50 = ($30/12); $0.40 = $1.50/3.7; $0.38 = $0.50/1.33. FFS is farmer field school; IPM is integrated pest management.

compare the relative cost-effectiveness of pamphlets and FFS in a similar manner and find again that pamphlets have a greater effect, considering their low cost (a cost ratio of 60:1 with an adoption intensity ratio of only 2.04:1).

Taking into account diffusion among farmers, the cost differential between FFS, field days, and pamphlets is reduced, since FFS participants spread information to more farmers than those who learned of IPM from alternative means.[5] The cost per person reached for FFS participation is about 6.25 times the cost per person reached through field days and 6.58 times the cost per person reached through pamphlets. We can combine the diffusion data presented in Table 4 with the information on marginal effects of the information source on participants and people who they contacted (the parameter estimates from model 3 in Table 7). For instance, we can add the marginal impact of participation in a FFS (.564) to 11 (the number of contacts) times the marginal impact of word-of-mouth spread from an FFS participant (.245) and get a total effect of 3.26. When we compare this effect with the total marginal impact including word-of-mouth spread from field day participation and pamphlets, we see that FFS participants (both directly and indirectly through their impact on diffusion) are associated with a 3.88:1 increment in adoption intensity compared to field days and a 9.88:1 increment compared to pamphlets. These adoption intensity increments do not, however, even begin to cover the difference in costs (20:1 and 60:1) between FFS and field days and FFS and pamphlets, respectively. Thus, on a cost per person reached and impact on adoption basis, FFS are not as good as the other methods.

[5] Since informal diffusion was not a statistically significant determinant of IPM adoption, controlling for other factors, this calculation overstates the impacts of FFS.

Conclusions

IPM technologies for control of potato pests in Carchi, Ecuador, are clearly profitable, showing increased profits per hectare of between $270 and $560. However, adoption of IPM is not widespread because the public extension system was dismantled in the early 1990s and because of the complexity of IPM practices. This paper examined the cost-effectiveness of different alternative diffusion methods.

We find that FFS and field days are effective mechanisms for transferring IPM information to potato farmers in Carchi and for promoting more intense adoption of IPM practices. Field days are relatively inexpensive and positively impact farmer knowledge and IPM adoption. Pamphlets alone were not shown to have a statistically significant impact on IPM adoption. FFS are expensive but have some distinct benefits, including the following: they provide the most complete IPM knowledge; participants share information readily; and they provide hands-on experience. Farmers exposed to FFS participants often go on to learn more about IPM through other dissemination methods. Each of these dissemination mechanisms has a role to play in increasing farmer knowledge and promoting adoption. An approach that integrates diffusion mechanisms is recommended.

There are two main concerns with the FFS approach. The first concern is program costs. Feder, Murgai, and Quizon (2004a,b) suggest that FFS can lower program costs by (1) limiting the number of sessions, (2) using better-quality trainers, and (3) focusing on the most significant IPM messages. However, because IPM for potatoes is complex, one must be careful not to oversimplify the message. It is possible that added profitability from adoption of IPM would enable farmers to contribute financially to FFS programs (Thiele et al.). In addition, participants could be trained to facilitate field days and to improve the flow of information from FFS to non-FFS farmers. Agricultural development can be enhanced if policy makers recognize the complementarity between field schools and other forms of information dissemination. Field schools provide depth in knowledge that allows participants to become leaders among agriculturalists in their communities, but they are expensive.

The other concern with FFS is that there is a bias toward certain farmers, especially those with larger land holdings. In fact, landholding was positively associated with participation in FFS in our model. Less-motivated and illiterate farmers may continue to know very little about IPM, while motivated and literate farmers will learn and adopt these technologies. Because of the obvious profitability of the IPM package, differential adoption rates may exacerbate existing inequalities in income and wealth. In addition, Feder, Murgai, and Quizon (2004a) found that the quality of FFS tended to diminish with large-scale implementation. Consequently, it is important to have other means of transferring information to farmers who are not likely to attend these schools. Information dissemination mechanisms can supplement each other to reach a larger and more diverse population of farmers. FFS should be strategically dispersed throughout the region. Analysis needs to be done to identify communities that have not been exposed to IPM and to evaluate the best approach for that area. Site-specific studies are necessary in order to understand particular circumstances, including crop characteristics, severity of pest problems, current use of pesticides, flexibility and adequacy of IPM packages, and the availability of labor and capital.

[Received May 2006; Accepted January 2007.]

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