JAE Journal of Agricultural Economics

Journal of Agricultural Economics
doi: 10.1111/1477-9552.12140

Does IPM Have Staying Power? Revisiting a Potato-producing Area Years After Formal Training Ended

Vanessa Carrión Yaguana, Jeffrey Alwang, George Norton and Victor Barrera[1]

(Original submitted August 2014, revision received February 2015, accepted July 2015.)

Abstract

Integrated pest management (IPM) potentially reduces pesticide use and costs of agricultural production. However, IPM is knowledge intensive and its spread may dissipate over time due to knowledge required for its effective implementation and to competing messages about pest control. We examine IPM spread and adoption several years after formal intensive IPM outreach efforts ceased in a potato-producing region in Ecuador. We describe adoption patterns and sources of IPM knowledge in 2012 and compare them with patterns that existed when outreach ceased in 2003. Results show that IPM adoption continues in the area but with a lower proportion of farmers fully adopting all practices and a higher proportion adopting low to moderate levels as compared to 2003. Almost all potato farmers in the area use some IPM practices, reflecting a major increase in IPM use. Farmer-to-farmer spread has supplanted formal training and outreach mechanisms. IPM adoption significantly lowers pesticide use and saves production costs for adopters.

Keywords: *Adoption persistence; Ecuador; integrated pest management; potato farming; technology adoption; technology dissemination.*

JEL classifications: *Q16, O33.*

---

[1] Vanessa Carrión Yaguana is a PhD candidate in Agricultural and Applied Economics, Virginia Tech, Blacksburg, VA, USA. E-mail: vcarrion@vt.edu for correspondence. Jeffrey Alwang and George Norton are Professors at Virginia Tech, Blacksburg, VA, USA. Victor Barrera is with the National Autonomous Institute of Agricultural and Livestock Research's (INIAP), Quito, Ecuador. The authors thank the Editor and two anonymous referees for valuable comments and suggestions. Bradford Mills, Catherine Larochelle and Susan Richter also provided insightful comments. All errors are our own. This material is based upon work supported by the United States Agency for International Development under the Cooperative Agreement No: EPP-A-00-0400016-00.

1. Introduction

Pesticide use in agriculture has increased worldwide over time. This increase has helped farmers meet a growing global demand for food, but several well-known problems are associated with pesticide use. Pesticides are costly, and their over-use can reduce farm profits and incomes. Pesticide exposure is associated with negative human health effects ranging from dermatitis and asthma to severe problems such as obstructive pulmonary disease and cancer (Sanborn *et al.*, 2002). Pesticide use is also associated with environmental problems such as soil and water contamination and off-farm damages such as poisoning of wildlife. Indiscriminate pesticide use increases pest resistance and reduces populations of beneficial insects, which can push farmers into a cycle of increasing use of and dependence on new pesticides.

To mitigate the harmful effects of pesticides and better manage pest problems, alternative management methods have been sought. Although basic tactics of integrated pest management (IPM) have been used to reduce pest-related crop losses since the late 19th century, it was not until the early 1970s that IPM became widely accepted by the scientific community (Kogan, 1998). IPM is a systematic approach to pest and disease control using chemical, biological and cultural controls, and steps to increase host-plant resistance (Koul *et al.*, 2004). IPM seeks to reduce pest populations to economically tolerable levels while minimising pesticide use, particularly of more toxic pesticides.

Integrated pest management practices have been identified and tested in various farming systems in developed and developing countries. However, IPM adoption remains relatively low in most of the developing world (World Bank, 2005). In most developing-country commercialised farming systems, aggressive pesticide use still predominates.

The spread of IPM in less-developed areas is constrained by many factors. Effective use of IPM involves understanding complex interrelationships among crops and diseases, and formal training in IPM techniques often includes detailed information on the life-cycle of pests. This training is costly and time intensive and may not be accessible to many producers. Pest pressures evolve, sometimes rapidly, and IPM practices often have to be adapted to this evolution. Farmers receive mixed and often conflicting messages from researchers and chemical vendors. Pesticides are viewed by many farmers as the least risky way of reducing crop losses, while a culture of pesticide use and dependence is difficult to overcome.

A goal of IPM research programmes is to ensure that IPM techniques are widely adopted. Over time, alternative mechanisms for IPM training have been used. For example, farmer field schools (FFS) are an intensive participatory training programme involving weekly training sessions during a full crop season (Godtland *et al.*, 2004). Field days are daylong events in which researchers demonstrate specific, often multiple, IPM practices to participants. Observation visits involve groups of farmers visiting other communities to gain exposure to IPM practices. Extension agent visits involve direct provision of information to farmers. Mass media methods include pamphlets, newspapers and radio (Mauceri *et al.*, 2007).

Several studies have examined the effect of IPM training methods on adoption and IPM knowledge. Godtland *et al.* (2004) evaluated the impact of FFS on IPM knowledge in potato production in Peru using propensity score matching (PSM). They found that FFS participation significantly enhances knowledge in subjects relevant to IPM adoption such as pest dynamics, fungicide rotations, and use of resistant varieties. However, since FFS participants are purposively selected based on their dynamism and willingness to spread practices to others, the underlying assumption of PSM of selection only on observables is likely to have been violated. When selection is on unobservables, the matched sample may not represent the appropriate counterfactual and this violation is likely to have introduced bias into their estimates. Ricker-Gilbert *et al.* (2008) evaluated the cost-effectiveness of IPM extension methods in Bangladesh, using an instrumental variables model to allow for selection on unobservables. They determined that FFS, field days and extension agent visits had positive impacts on farmers' adoption. FFS participants were more likely to adopt intermediate and complex IPM practices while field day participants were more likely to adopt simple ones. Because of high costs of the FFS, field days and extension agent visits were found to be the most cost-effective sources of IPM information.

Most previous studies assess IPM adoption and knowledge shortly after participation in IPM training, capturing short-term adoption and knowledge acquisition that may not last. If IPM knowledge degrades over time or becomes less effective as pest pressures evolve, adoption rates may fall. Alternatively, falling rates might be due to competing messages from chemical vendors or other information sources. This raises the question of whether IPM has staying power. Do farmers continue to use IPM without on-going training? We address this question by examining IPM spread and adoption long after formal IPM outreach efforts ceased in a potato-producing area of Ecuador. We examine adoption patterns and sources of IPM knowledge in 2012 and compare them with patterns that existed when outreach ceased in the area in 2003. Factors affecting current IPM adoption are identified and the effect of IPM adoption on current pesticide expenditures is estimated.

The article is organised as follows. Section 2 discusses the study site and the technology offered to farmers. Section 3 describes how farmers obtain information on IPM and their knowledge levels. Section 4 compares IPM spread and adoption in 2003 and 2012. In section 5, the methods used to measure the economic impact of IPM adoption are presented. Results are shown in section 6, and section 7 concludes.

2. Study Site and IPM Programme

Carchi Province in northern Ecuador is the most important potato-growing area in the country, with 28% of national potato production on only 13% of the total potato area (SINAGAP, 2012). Average yield is significantly higher (17.9 tons/hectare) than the national average (8.3 tons/hectare). Farms in Carchi tend to be larger; the average area planted to potatoes in Ecuador is 0.57 hectares while in Carchi the average is 1.48 hectares (SINAGAP, 2012). Agro-ecological conditions make Carchi an ideal location for potatoes: soils are deep, loamy and high in organic content. The province receives rainfall throughout the year and potatoes can be produced year-round.

Potato farmers in Carchi face many pest problems. Of particular concern are late blight (*Phytophthora infestans*), the Andean potato weevil (*Premnotrypes vorax*), and the Central American tuber moth (*Tecia solanivora*). Under conventional production practices, these pests are managed with intensive applications of toxic chemicals (Sherwood *et al.*, 2005), and studies have shown that potato farmers in Carchi had become heavily dependent on pesticides (Yanggen *et al.*, 2004). By the late 1990s and early 2000s, this dependency generated high input expenditures, lower profit margins, and evidence of negative health and environmental impacts (Crissman *et al.*, 1998). As a response, Ecuador's agriculture ministry, together with national and international research[2] and development organisations, designed, tested, and conducted outreach on a package of IPM practices for potato producers.

The collaborative research and outreach programme in Carchi was coordinated by the Ministry of Agriculture's long-running Fortipapa programme and consisted of multiple components. Between 1999 and 2003, 18 FFS were run, many field days and a number of workshops were held. Participants in FFS were selected based on their interest in participating and their willingness to share their knowledge and experiences with other farmers.[3] In the FFS, farmers and researchers met once per week during the 6 month potato growing season. Each session lasted approximately 3 hours and combined practice- and theory-based learning. Non-FFS farmers were invited to participate in field days. During these day-long events, participants were taught low-intermediate complexity IPM practices using demonstrations, short lectures, and poster-based educational materials. Farmers in Carchi were also exposed to IPM through mass-media dissemination efforts including pamphlets, newspaper articles and radio messages.

The preferred IPM package for potatoes combined cultural, mechanical and chemical pest management. Cultural controls include: (i) use of certified and resistant seeds, (ii) use of high-hilling methods to create a barrier between insect pests and the tuber, (iii) improved crop rotations, (iv) early harvesting to avoid damage by tuber moth, (v) disposal of residues to keep fields clean and to prevent propagation of pests, and (vi) irrigation during the dry season to manage insect pest populations. Mechanical controls, intended to kill a pest directly, include: (i) yellow sticky mobile and fixed traps for monitoring and mass trapping of leafminer insects (*Bedellia somnulentella*), and (ii) cardboard traps to target adult Andean weevil populations. Finally, IPM chemical control includes use of low-toxicity pesticides when other options are not available. IPM chemical controls include: (i) seed disinfection with pesticides, (ii) directed-spray pesticide application to specific parts of the plant, and (iii) rotating use of fungicides (mainly against late blight) with different active ingredients using low-toxicity pesticides.

An evaluation of training methods conducted in 2003 showed that IPM practices commonly adopted by potato growers included: (i) improved crop rotations (58.7% of farmers adopted), (ii) early harvesting (57.8%), (iii) disposal of plant residues (50.5%), and (iv) directed-spray pesticide application (48.6%) (Mauceri *et al.*, 2007).

Formal IPM training and outreach in Carchi stopped in 2003. While the National Autonomous Institute of Agricultural and Livestock Research's (INIAP) office remains open, few outreach events have been held and no organised formal IPM training has occurred. The decision to abandon IPM training in the area was based on resource constraints but could have important implications for continued spread and use of IPM. In the past decade, potato price variability has become a serious problem for area farmers. This phenomenon is attributed in part to variable potato imports from Colombia and Peru. For many years, farmers acted as though they were playing

---

[2] The Integrated Pest Management Innovation Laboratory, funded by the United States Agency for International Development was an important research partner in this effort.

[3] Farmers are purposively selected for participation in FFS. FFS are intended to provide intensive training to a few farmers, with the idea that this knowledge will spread due to the dynamism of the participants (Feder *et al.*, 2004).

the lottery, investing in continual production while betting on high prices at harvest to recover their investment (Sherwood *et al.*, 2005). Recently, farmers in Carchi have decreased their land dedicated to potato production. In 2003, 8,644 hectares in the Province were planted with potatoes. Nine years later this amount had almost halved to 4,555 hectares (SINAGAP, 2012).

We use data from farm-household surveys collected in 2003 and 2012. During September–October 2003, an adoption survey was conducted of 109 potato farmers from Tulcan, Montufar and Espejo municipalities, which account for 90% of total production in Carchi. Randomly selected respondents included 30 FFS participants, 28 farmers who had been exposed to FFS participants, and 51 non-participant and non-exposed farmers (Mauceri *et al.*, 2007). In May–July 2012, a random sample of 404 potato farmers from the same three municipalities was selected from a list provided by the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP). This sample consisted of 74 FFS participants, 302 farmers exposed to other sources of IPM information and 28 IPM-unexposed farmers. Both simple random samples were designed to be representative of the potato-producing population in the Province.

The 2003 and 2012 questionnaires were similar, but not identical. Both included modules on demographic and socio-economic conditions, potato production, pesticide usage and handling, and IPM knowledge and adoption. The 2012 survey contained additional information on potato production such as cultivated area, input costs and yields; main source of IPM information; and household assets. Although the surveys were similar, they do not cover an identical group of farmers mainly because the 2003 survey was not conceived of as a panel. There are several advantages associated with panel data, but these come at a cost. Given the small sample size of the 2003 survey and subsequent attrition since that survey, no attempt was made to construct a panel in 2012. Our analysis thus compares two similarly representative cross sections.[4]

To assess the spread and adoption of IPM long after formal outreach efforts ceased in Carchi, the 2003 and 2012 datasets are used to examine changes in patterns of IPM adoption. To examine sources of IPM information and depth of knowledge (section 3) and for the analysis of determinants of adoption and pesticide expenditures (section 5), the 2012 dataset alone is used because the 2003 survey did not contain the requisite information on pesticide expenditures.

3. Sources of IPM Information and Depth of Knowledge

Knowledge and skills are associated with agricultural technology adoption (Caviglia and Kahn, 2001). However, the value of training does not stop with knowledge creation among participants. As training budgets tighten, technology spread depends on active farmer to farmer diffusion of information. Trained farmers are expected to retain the skills and knowledge acquired and transmit knowledge to neighbours, friends and relatives. Farmer-to-farmer knowledge transfer is, in fact, a cornerstone of the FFS approach; progressive farmers are selected for the schools with the hope

---

[4] Obviously, the 2012 survey, given its larger size, allows more precise estimates of key parameters. The 2003 survey has less power to detect differences, so discussion of it focuses on statistically significant differences and does not highlight non-significance.

that their neighbours will follow their lead and IPM will spread. A key objective of the 2012 survey was to understand how farmers obtained and retained information about IPM.

Respondents were asked to identify their primary source of IPM information. Potential sources included: direct participation in FFS, field days, other farmers, observation visits, extension agent visits, family members, local government activities, and mass media sources. Nine years after the intervention in Carchi ended, 'other farmers' constitute the main source of IPM information. Almost 36% of respondents in 2012 reported having heard about IPM from other farmers, while about the same percentage of farmers reported receiving formal training (Figure 1). An important question is whether the quality of IPM knowledge is high and whether knowledge varies by source.

IPM knowledge may be defined (Feder *et al.*, 2004) as 'the possession of analytical skills, critical thinking, ability to make better decisions, familiarity with specific agricultural practices, and understanding of interactions within the agro-ecological system' (p. 225). To measure knowledge in 2012, respondents were asked 20 questions about pest management and IPM. The questions tested knowledge of the three major pests in the area, criteria (when and where) for applying pesticides, and pesticide handling and storage practices. Respondents were also asked about the meaning of warning labels on pesticide containers, and what precautions they take in applying and storing pesticides. Farmers were grouped into three categories: low, medium and high IPM knowledge.[5]

In 2012, FFS participation was associated with the most (lasting) high knowledge scores, followed by field days; differences in knowledge by main source of information are significant at the 5% level (Table 1). Farmers who never participated in formal IPM training do not have high knowledge levels. Knowledge retention varies by information source and it increases with training intensity. Former participants in FFS and field days are more knowledgeable about IPM than other farmers, so it is no surprise that they retain more IPM knowledge over time.

Some types of IPM knowledge may be more important than others. Limited knowledge of pesticide exposure hazards has been associated with unsafe application practices in the Carchi area (Sherwood *et al.*, 2005). It is thus important that farmers are able to read labels and understand their meaning. In Ecuador, as in most countries, pesticide labels have colour coding to reflect product toxicity (red, yellow, blue and green). The meaning of the colour coding scheme was not understood by 42.3% of respondents in 2012. Only 1.5% was able to identify correctly the meaning of the four standard colours; 12.4% recognized three, and 26.7% correctly identified two. Few farmers use protective equipment while spraying (See Table S1, Appendix A in the supplementary materials to this paper, available online). Most (81.5%) are aware of risks associated with spraying pesticides while performing other tasks, such as eating or drinking water, but few take simple safety precautions. This evidence shows that knowledge about potential damages from pesticide mis-handling is low, and handling and safety procedures are not widely used in the region despite widespread use of pesticides.

---

[5] Scores were transformed to a 100-point scale and categorised as follows: no IPM knowledge = 0 points; low = $0 < z \leq 25$; medium = $25 < z \leq 50$; high = $50 < z \leq 75$; and full = $75 < z \leq 100$. No farmer fell into the zero knowledge or the full knowledge category.

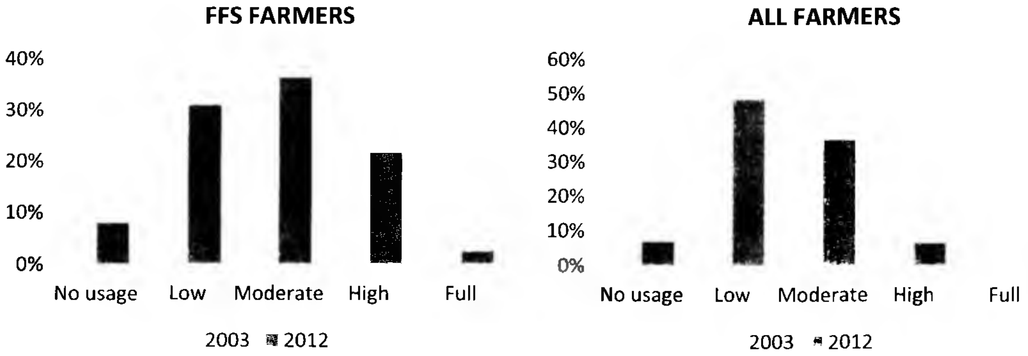

Figure 1. Integrated pest management adoption over time, Carchi, Ecuador, 2003 and 2012
Source: M. Mauceri (Unpublished raw data) V. Carrion (Unpublished raw data);
n = 109 and 404, respectively.

Table 1

Main sources of integrated pest management (IPM) information and knowledge levels by source, Carchi, Ecuador, 2012

Main source of IPM information		Knowledge level by source		
Source	%	Low (%)	Moderate (%)	High (%)
No formal IPM training	7	29	71	0
FFS	18	10	85	5
Field days	17	15	82	3
Other farmers	35	27	72	1
Other sources	23	35	63	2

Note: Any training using FFS or field days occurred prior to 2003; Pearson $\chi^2(12) = 22.13$, $P = 1.005$. ***Source***: V. Carrion (Unpublished raw data).

4. IPM Adoption Over Time

IPM packages taught prior to 2003 consisted of a set of farming practices to enhance pest control; farmers ultimately decide whether or not to adopt them. They may adopt the complete package of innovations, adopt nothing, or pick subsets or bundles of practices. Here, IPM adoption is defined as the degree of use of the technology, recognising that all IPM practices are not equally important. Each IPM practice was assigned a weight based on advice provided by a team of local agricultural scientists. Weights were assigned based on level of complexity and knowledge necessary to successfully implement the practice. Detailed information is provided in Table S2 of the supplementary material to this paper, available online. Adoption intensity was calculated by summing practice-specific scores for each respondent. Based on these scores, respondents were classified as non-, low-, moderate-, high- or full-IPM adopter.[6] This procedure was conducted for both surveys. Because the studies differ slightly in the

---

[6] Each respondent was given a maximum score of 8 based on use of weighted IPM practices (Table S1 of the supplementary materials to this paper (available online). These grades were transformed to a 100-point scale. For the descriptive analysis, the following categories were employed: non-adopters = 0 practices; low = $0 < z \leq 25$; medium = $25 < z \leq 50$; high = $50 < z \leq 75$; and full = $75 < z < 100$.

IPM practices included (see Appendix A of the supplementary materials to this paper, available online), adoption was computed based on 11 IPM practices common to both studies.

The proportion of farmers in non- and low-adoption categories changed substantially between 2003 and 2012 (Figure 1). The proportion of farmers not adopting any IPM practice fell from 30% to less than 10%, while the proportion reporting low levels of IPM adoption grew from 15% to nearly 50%. Percentages in the high- and full-adoption categories declined over time, but the magnitudes of these changes were not as large as for the non- and low-adoption categories. The proportion of FFS participants in the non-, high- and full-adoption categories fell over time. A corresponding increase in the proportions adopting at low and moderate levels is observed for those who received their IPM information from FFSs. In Carchi, IPM use has become more widespread, but even intensively trained farmers are now using relatively fewer IPM techniques.

Many farmers with no formal training in IPM had adopted multiple practices in 2012. Nevertheless, adoption rates for most practices were below rates for those with formal IPM training. Former FFS participants had the highest rates of adoption of practices requiring more knowledge or that are more labour intensive such as traps for Andean weevil, and fixed and mobile yellow insect traps (Table S4 of the supplementary materials to this paper, available online).

Many factors influence the diffusion of a new technology. For example, when an agricultural innovation is first introduced, potential adopters may be uncertain about its benefits. Over time, own experiences and information gathered from different sources contribute to reduce this uncertainty, and adoption is expected to grow (Pannell, 2003). While some IPM practices such as rotating use of fungicides with different low-toxicity active ingredients and improved crop rotations have become widely used, other practices, such as insect traps and disposal of plant residues to keep fields clean, have been abandoned by prior adopters. Farmers have experimented with IPM practices in their own context and continue to use effective and profitable practices and abandoned others.

To gain insights into abandonment of IPM practices, farmers were asked in 2012 whether they were using and had used a particular IPM technique and (if applicable) why they stopped using that practice. In Table 2, 2003 and 2012 adoption rates are compared for all IPM practices. For most practices, early adoption rates, based on the 2003 survey, were relatively high and decreased by the time of the 2012 survey. Some practices were tried and discarded for different reasons. Primary reasons for abandonment of IPM practices are presented in Table S5 of the supplementary materials to this paper (available online). High abandonment occurred for labour intensive practices, especially, insect traps, with time constraints cited as the main reason for their decision to abandon the practice. Farmers also adjust their farming strategies in response to evolving pest pressures; many farmers reported abandoning IPM practices because they are no longer needed. In fact, subsequent IPM research has shown that leafminer traps are rarely needed in an IPM regime where reduced spraying allows beneficial insect populations to grow. Discontinued use of yellow traps might be expected in areas where IPM practices are relatively widespread. Limited effectiveness of some practices was mentioned several times by respondents, indicating that some may not be suited for farm-specific conditions. Other common reasons for abandonment of IPM practices are inclement weather and lack of interest. Overall, farmers use practices they are comfortable with and are perceived as being cost-effective. Practices

Table 2

Percentage adopting integrated pest management (IPM) practices, Carchi, Ecuador, 2003 and 2012

IPM practices	2003 %	2012 %
Cardboard traps for adult Andean weevil populations	11.0	11.9
Directed-spray pesticide application to specific parts of the plant	48.6	31.9
Irrigation during dry season to manage insect pest populations	31.2	14.1
Yellow mobile sticky trap for leafminer insects	19.3	5.7
Rotating use of low toxicity fungicides with different active ingredients	12.8	68.1
Use of potato seed storehouse	9.2	5.5
Use of high-hilling methods to create barrier for insect pests	31.2	25.0
Disposal of plant residues to keep fields clean	50.5	37.1
Improved crop rotations	58.7	68.1
Yellow fixed traps for leafminer insects	25.7	6.7
Early harvesting to avoid damage by tuber moth	57.8	34.4
Number of observations	109	404

Source: M. Mauceri (Unpublished raw data); Carrión (Unpublished raw data).

perceived to require complex, costly and time-consuming activities, such as trapping and irrigation, have low rates of use and high rates of abandonment.

5. Econometric Analysis

The information presented above suggests that IPM has become relatively well-entrenched in the Carchi area and farmers are now learning from one another and from their own experience. Further information is needed on: (i) factors determining current decisions about IPM adoption, and (ii) the effects of IPM adoption on pesticide expenditures.

Integrated pest management adoption is assumed to result from expected utility maximisation by farmers. Benefits considered may include health, lower risk and increased profitability. Let adoption of IPM be specified as:

$$Y_{IPMi} = X_{IPMi}\beta_{IPM} + INF_{IPMi}\delta_{IPMi} + \varepsilon_{IPMi} \tag{1}$$

where Y_{IPM} is a continuous variable representing the degree of IPM adoption,[7] X_{IPMi} is a vector of observable control covariates (e.g. education, experience, wealth, etc.) INF_{IPMi} is the vector of primary information source each farmer was exposed to – FFS, field days, other farmers and others – and ε_{IPMi} is a random error term.

Pesticide expenditures are modeled as follows:

$$lnY_{EXPi} = X_{EXPi}\beta_{EXP} + \alpha Y_{IPMi} + \varepsilon_{EXPi} \tag{2}$$

---

[7] To facilitate the interpretation of estimated coefficients in our regression model, we transform our 0–8 practice-weighted IPM adoption variable to a 0–100 scale.

where lnY_{EXP} is the natural logarithm of per hectare pesticide expenditures.[8] The vector X_{IPMi} contains exogenous explanatory household-level variables. As discussed above Y_{IPMi} is the IPM adoption variable, and ε_{EXP_i} is the unobserved random error term.

An endogeneity problem arises if unobserved factors in ε_{IPMi} and ε_{EXP_i} make these error terms correlated. In the context of this study, unobserved variables such as managerial ability or awareness of dangers of pesticides could affect both the decision to adopt IPM and pesticide expenditure. When endogeneity is present and it is ignored, the parameter estimates from an ordinary least squares (OLS) regression of equation (2) are inconsistent and biased. To account for the endogeneity of IPM adoption, we use an instrumental-variable two-stage least squares (IV TSLS) approach. Potato IPM adoption is instrumented by the four information sources farmers reported being exposed to (FFSs, field days, other farmers, and other diffusion methods). These variables are not ideal candidates as instruments. They are highly correlated with adoption and their effect on pesticide expenditures is likely to be only through their effect on IPM adoption. However, missing variables, such as eagerness to undertake IPM or concern about the environment are likely to affect both. We conduct diagnostic tests to evaluate their appropriateness as instruments, but, as is well-known, these tests do not address the fundamental question of instrument validity. We experimented with alternative instruments and compared the estimates of equation (2) with a more parsimonious specification to build confidence in our findings, but recognise that the identification of the effect of Y_{IPMi} is compromised.

Control covariates X_{IPMi} used in estimating equation (1) include education, experience, having been made sick due to pesticide use, land size, wealth and household size. These variables are consistently found to be key determinants of IPM and agricultural technology adoption in the literature (D'Souza *et al.*, 1993; Yorobe *et al.*, 2011; Teklewold *et al.*, 2013). Education is expected to be positively related to adoption since more educated farmers understand and respond better to new technologies (Lin, 1991). The effect of experience is anticipated to be positive because more experienced farmers are more likely to know how inputs interact. More experienced farmers may also be better able to assess new technologies. We expect a positive effect of household size because large families have more labour available to perform on-farm activities, enabling farmers to adopt labour-intensive technologies (Feder and Umali, 1993). Having fallen sick due to exposure to pesticides may encourage farmers to adopt IPM. Hence, a positive effect is expected. Wealth is anticipated to have a positive effect on adoption because wealthier farmers can withstand the losses resulting from the adoption of new and potentially risky technologies (Ellis, 1988).

In equation (2) the equation describing pesticide expenditure, vector X_{EXP_i} contains the same explanatory variable as in X_{IPMi} except for household size, since we do not believe household size explains pesticide expenditure. We expect that education and experience will negatively affect pesticide expenditure. Wealth may lead to use of more pesticides because wealthier farmers can afford the cost of these inputs or it may enable them to overcome credit constraints.

---

[8] Due to the high degree of commercialisation of pest production in the area and the ubiquitous presence of pests and diseases, all farmers use some pesticides.

6. Estimation Results

Descriptive statistics are presented in Table 3. On average, farmers spend US$ 272 per hectare per potato crop cycle on pesticides. The average IPM score is 25 out of 100. Twenty eight percent of farmers had been sick in the year prior to the survey due to pesticide usage. The average area planted with potatoes by potato-producing households is 1.89 hectares.[9] Estimates from equation (1) are reported in Table 4. Signs for most coefficients are consistent with expectations and the overall fit (adjusted R^2 of 0.13) is acceptable given the nature of the data. Having attended a FFS raises the potato IPM adoption score by 22 points compared to farmers who did not receive any training. An increment of this size is equivalent to adopting three more medium complexity IPM practices (weight of 0.6) or two high-complexity practices (one with a weight of 1 and one with a weight of 0.8). Having learned IPM from field days and from other farmers increases the adoption score by 12 and 13 points, respectively, again compared with untrained farmers.

The effect of method of learning on adoption score follows expectations. FFS attendance has the largest effect on the probability of adopting higher levels of IPM, but other methods are significant and their magnitudes are large. A one unit increase in the wealth index was associated with an increase of 1.6 points in IPM adoption. Education and wealth are significant at the 5% and 1% level, respectively. Farming experience, plot size and farmer reporting being sick due to pesticides use are not significantly associated with adoption of IPM.

Instrumental variable analysis suffers from certain limitations that should be acknowledged. One challenge in using the information sources farmers were exposed to as instruments is that they may be correlated with other unobservable factors, such as environmental concerns and motivation that in turn are correlated with the unobserved confounders that impact pesticides expenditures. To rule out any direct effect of the instrument on the dependent variable we estimate a parsimonious model with just IPM adoption involved. Results of the OLS and IV TSLS full-model (equation (2)) and parsimonious-model estimates are presented in Table 5. The IPM adoption coefficient obtained from the multiple regression is similar to that obtained from the simple regression, implying that omitted variable bias may not be a huge concern. To further validate the extent to which the set of instruments fits the IV assumptions, we employ a standard over-identification statistical test, which is a partial test of the extent to which instruments are truly excludable from the pesticide expenditure function. We fail to reject the null hypothesis ($P = 0.201$), which provides some evidence that the instruments are valid.

The IPM adoption coefficient estimated via IV 2SLS is substantially larger than the corresponding OLS coefficient.[10] A potential explanation for the large difference is that the IPM adoption variable contains random measurement errors. Hence, its OLS coefficient is biased toward zero with the magnitude a function of the noise to signal ratio (Behrman *et al.*, 1995). This problem is usually mitigated using an IV approach

---

[9] This number differs from the province average of 1.48 hectare because the household survey is representative of the three main commercial potato producing municipalities. These account for 90% of the total potato production in Carchi and in these municipalities, potato production is extensive compared to the rest of the province.

[10] The OLS robust standard error of the coefficient on IPM adoption is 0.0017, much smaller than the IV robust standard error of 0.0053. This result is typical in IV approaches.

Table 3

Summary statistics for variables in econometric model

Variable	Mean	Std. dev.
Pesticide expenditure per hectare per crop cycle (US dollars)	272.4	160.1
Integrated pest management (IPM) adoption (0–100)	25.2	16.7
Farmer's age	46.6	13.1
Farmer secondary education (yes = 1)	0.2	0.4
Farming years of experience	26.1	13.1
Farmer has been sick due to pesticide use (yes = 1)	0.3	0.5
Area planted with potatoes	1.9	2.5
Wealth index	0.0	1.6
Household size	4.2	1.7
Information sources (set of dummies)		
IPM-untrained farmers	0.1	0.3
FFS	0.2	0.4
Field days	0.2	0.4
Other farmers	0.4	0.5
Other sources of IPM information	0.2	0.4
Number of observations	404	

Source: V. Carrión (Unpublished raw data).

(Gujarati, 2003). A second potential explanation is the strength of the instrumental variables used in our 2SLS estimation. Instruments are generally considered to be weak if they have a joint F-statistic in the equation of less than 10. In our analysis the F-statistic is 12.17; hence it is unlikely that the large coefficient difference is due to weak instruments. Finally, we tested the exogeneity of the IPM adoption variable in equation (2) using the Wu-Hausman test, the null hypothesis that IPM adoption is exogenous was rejected at the 1% level. While these tests do not eliminate concern about the appropriateness of the instruments, they do not indicate that they are not good.

As mentioned above, IPM adoption is a continuous variable measured on a 0–100 scale. A point increase in the IPM adoption score decreases pesticide expenditures by 1.5%, showing a relatively high elasticity. The coefficient of the log of plot size is negative and significant suggesting economies of scale. The wealth index coefficient is positive and significant, meaning that wealthier farmers, as expected, are more likely to spend more on pesticides. The variables education, experience and farmer being sick due to pesticide use are not significant. Overall, farmers that adopted more than 50% of the IPM practices had average pesticide expenditures of US$ 142 per crop season, while their counterparts who did not adopt any IPM practices spent US$ 361. A relatively modest increase in IPM adoption, say 10 points (equivalent to a practice with a weight of 0.8), would be consistent with a reduction of pesticide expenditures of 15%. Compared with those of a previous study, our results show an overall decrease in pesticides expenditures in the area. Barrera *et al.* (2004) found, without controlling for endogeneity of IPM adoption, that farmers who adopted IPM had average pesticide expenditures of US$ 353 per hectare, while those who produced using the conventional approach spent US$ 667.[11]

---

[11] Values expressed in 2012 US dollars.

Table 4

Determinants of Integrated pest management (IPM) adoption

Independent variable: IPM adoption (0–100)	
Explanatory variable	Coefficient
Farmer secondary education	4.03**
	(2.03)
Farming years of experience	0.29
	(0.24)
Farming years of experience squared	−0.01
	(0.00)
Farmer has been sick due to pesticides	−2.53
	(1.75)
Plot size (natural logarithm)	−0.15
	(0.96)
Wealth index	1.62***
	(0.52)
Household size	0.21
	(0.46)
FFS	22.25***
	(3.48)
Field days	12.23***
	(3.53)
Other farmers	12.56***
	(3.29)
Other sources of IPM information	11.20***
	(3.38)
_cons	8.10
	(5.01)
Adjusted R^2	0.13
Number of observations	404

Note: Significance levels: *10%, **5%, ***1%. Robust standard errors in parentheses.

7. Conclusions and Policy Implications

National governments and research and development organisations invest resources in IPM programmes to evaluate and promote adoption of IPM practices. Since these programmes increasingly face resource constraints, an important concern is whether programme interventions have a long-lasting impact. Few studies have examined whether IPM adoption is durable, and whether IPM will continue to spread after formal training has ended. Using field data from a survey of 404 potato farmers in Carchi, Ecuador, we find that 9 years after an intensive intervention ended, IPM knowledge is still spreading and having an impact in the area. While adoption continues, relatively few farmers fully adopt all practices, but many adopt a variety of relatively less-complex practices compared to 2003. Farmer-to-farmer spread supplanted the formal training and outreach mechanisms that ended in the area in 2003, strongly suggesting that training leading farmers has been effective in disseminating IPM practices.

Important benefits are generated by adoption of potato IPM in Carchi. IPM adoption has significantly lowered pesticide use and saved production costs for adopting

Table 5

Determinants of pesticide expenditures for potato production

Independent variable: natural logarithm pesticide expenditure per hectare

	OLS		IV 2SLS	
Explanatory variable	(1)	(2)	(3)	(4)
Integrated pest management adoption (endogenous variable) (0–100)	−0.00 (0.00)	−0.00 (0.00)	−0.01** (0.01)	−0.02*** (0.01)
Farmer has secondary education		−0.01 (0.07)		0.05 (0.08)
Farming experience		0.01 (0.01)		0.02 (0.01)
Farming experience squared		0.00* (0.00)		−0.00** (0.00)
Farmer had been sick due to pesticides		0.07 (0.06)		0.04 (0.06)
Plot size (natural logarithm)		−0.16*** (0.04)		−0.17*** (0.04)
Wealth index (quartiles)		0.02 (0.02)		0.04* (0.02)
_cons		5.42*** (0.13)		5.73*** (0.18)
R^2	0.00	0.07		
Number of observations	404	404	404	404

Note: Significance levels: *10%, **5%, ***1%; Robust standard errors in parentheses.

farmers. Farmers experiment with different IPM practices, and continue to use some while abandoning others, but IPM adoption is clearly associated with lower pesticide expenditures. As the IPM programme recommended use of lower-toxicity pesticides, this finding suggests broad and persistent declines in pesticide applications in the region.

The study provides justification for continued public investments in IPM outreach in areas where such outreach has not existed in the past. IPM messages have to compete against those from private pesticide dealers who are able to provide new products to combat emerging problems. Intensive training in IPM, although relatively costly (Godtland *et al.*, 2004; Mauceri *et al.*, 2007), seems to be effective in making durable changes in how farmers think about pest management. Earlier concerns in the literature that IPM may not spread to farmers who are not intensively trained appear to be alleviated, at least in the Ecuador case.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. IPM practices drop from the list of practices used to measure adoption.

Table S2. IPM practices and weights.

Table S3. Use of protective equipment, Carchi, Ecuador, 2012.

Table S4. Percentage of respondents adopting each IPM practice by main source of IPM information, 2012.

Table S5. Disadoption of IPM practices and causes (Carchi, 2012).

References

Barrera, V., Escudero, L., Norton, G. and Alwang, J. *Encontrando salidas para reducir los costos y la exposición a plaguicidas en los productores de papa: Experiencia de la intervención en la provincia del Carchi, Ecuador* (Quito, Ecuador: INIAP, IPM-CRPS, CROPLIFE, FAO, 2004).

Behrman, J. R., Pollak, R. A. and Taubman, P. *From Parent To Child: Intrahousehold Allocations and Intergenerational Relations in the United States* (Chicago: University of Chicago Press, 1995).

Caviglia, J. L. and Kahn, J. R. 'Diffusion of sustainable agriculture in the Brazilian tropical rain forest: A discrete choice analysis', *Economic Development and Cultural Change*, Vol. 49, (2001) pp. 311–333.

Crissman, C. C., Antle, J. M. and Capalbo, S. M. *Economic, Environmental, and Health Tradeoffs in Agriculture: Pesticides and the Sustainability of Andean Potato Production*, International Potato Center (1998).

D'Souza, G., Cyphers, D. and Phipps, T. 'Factors affecting the adoption of sustainable agricultural practices', *Agricultural and Resource Economics Review*, Vol. 22, (1993) pp. 159–165.

Ellis, F. *Peasant Economics: Farm Households and Agrarian Development* (Cambridge, UK; New York: Cambridge University Press, 1988).

Feder, G. and Umali, D. L. 'The adoption of agricultural innovations: A review', *Technological Forecasting and Social Change*, Vol. 43, (1993) pp. 215–239.

Feder, G., Murgai, R. and Quizon, J. B. 'The acquisition and diffusion of knowledge: The case of pest management training in farmer field schools, Indonesia', *Journal of Agricultural Economics*, Vol. 55, (2004) pp. 221–243.

Gujarati, D. Econometría (Mexico: McGraw Hill, 2003).

Godtland, E. M., Sadoulet, E., Janvry, A., Murgai, R. and Ortiz, O. 'The impact of farmer field schools on knowledge and productivity: A study of potato farmers in the Peruvian Andes', *Economic Development and Cultural Change*, Vol. 53, (2004) pp. 63–92.

Kogan, M. 'Integrated pest management: Historical perspectives and contemporary developments', *Annual Review of Entomology*, Vol. 43, (1998) pp. 243–270.

Koul, O., Dhaliwal, G. S. and Cuperus, G. W. *Integrated Pest Management: Potential, Constraints and Challenges* (Cambridge, MA: CABI Publishing, 2004).

Lin, J. Y. 'Education and innovation adoption in agriculture: Evidence from hybrid rice in China', *American Journal of Agricultural Economics*, Vol. 73, (1991) pp. 713–723.

Mauceri, M., Alwang, J., Norton, G. and Barrera, V. 'Effectiveness of integrated pest management dissemination techniques: A case study of potato farmers in Carchi, Ecuador', *Journal of Agricultural and Applied Economics*, Vol. 39, (2007) pp. 765–780.

National Information System of Agriculture, *Livestock, Aquaculture and Fisheries of Ecuador (SINAGAP). Area, production and yields of potato in Ecuador 2012 (Data file)*. Retrieved from http://sinagap.agricultura.gob.ec/papa-2.

Pannell, D. J. 'Uncertainty and adoption of sustainable farming systems', in: B. A. Babcock, R. W. Fraser and J. N. Lekakis (eds.), *Risk Management and the Environment: Agriculture in Perspective*. (Netherlands: Springer, 2003).

Ricker-Gilbert, J., Norton, G. W., Alwang, J., Miah, M. and Feder, G. 'Cost-effectiveness of alternative integrated pest management extension methods: An example from Bangladesh', *Review of Agricultural Economics*, Vol. 30, (2008) pp. 252–269.

Sanborn, M., Cole, D., Abelsohn, A. and Weir, E. 'Identifying and managing adverse environmental health effects: 4. Pesticides', *Canadian Medical Association journal*, Vol. 166, (2002) pp. 1431–1436.

Sherwood, S., Cole, D., Crissman, C. and Paredes, M. *From Pesticides to People: Improving Ecosystem Health in the Northern Andes* (London: Earthscan Publications Ltd., 2005).

Teklewold, H., Kassie, M. and Shiferaw, B. 'Adoption of multiple sustainable agricultural practices in rural Ethiopia', *Journal of Agricultural Economics*, Vol. 64, (2013) pp. 597–623.

World Bank *The World Bank Annual Report 2005* (Washington, DC: The World Bank, 2005).

Yanggen, D., Cole, D. C., Crissman, C. and Sherwood, S. 'Pesticide use in commercial potato production: Reflections on research and intervention efforts towards greater ecosystems health in northern Ecuador', *EcoHealth*, Vol. 1, (2004) pp. SU72–SU83.

Yorobe, J. M. Jr, Rejesus, R. M. and Hammig, M. D. 'Insecticide use impacts of Integrated Pest Management (IPM) Farmer Field Schools: Evidence from onion farmers in the Philippines', *Agricultural Systems*, Vol. 104, (2011) pp. 580–587.