Chapter 10
IPM Technologies for Potato Producers in Highland Ecuador

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Abstract This chapter describes a research and outreach effort to develop and diffuse IPM packages for potatoes in highland Ecuador. Potato production in Carchi is essential for livelihoods of small-scale producers and these producers face growing pest problems. The research project identified key pest constraints, worked with farmers and local scientists to develop and test appropriate IPM technologies, and created packages tailored to farmer needs. The research was especially relevant because farmers in the area were using large quantities of highly toxic chemicals as a part of their pest-control regimes and human and environmental health were suffering as a result. The partnership with an ongoing research-outreach effort, ability to leverage prior research findings, and participatory engagement of local stakeholders all contributed to the project's success. Emergence of new pests and changing potato market conditions are the main threats to long-term viability of the IPM packages, but they have spread into many potato farming communities in Carchi Province.

Keywords Ecuador • INIAP • Potatoes • Late blight • Andean potato weevil • Central American tuber moth

Introduction

Potatoes have been produced in Carchi Province in northern Ecuador for centuries. The province is the most important potato-growing area in the country, with 28 % of national production from plantings on only 13 % of total national potato area (SINAGAP 2012). Average yield in Carchi is significantly higher (17.9 tons/ha)

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than the national average (8.3 tons/ha). Agro-ecological conditions make Carchi an ideal location for potato production: soils are deep, loamy and high in organic content. The province receives regular rainfall and potato production is possible throughout the year. Supplemental irrigation is available for farmers when natural conditions fail.

In spite of the favorable conditions for producing potatoes, pests are severe constraints to potato production in Ecuador's highlands. Late blight (*Phytophthora infestans*), the Andean potato weevil (*Premnotrypes vorax*), and the Central American tuber moth (*Tecia solanivora*) have been prominent in Carchi since at least the mid-1980s. By the late 1990s, nearly 100 % of potato farmers in Carchi were affected by late blight, 80 % by the Andean weevil, and 6 % by the Central American tuber moth (Barrera et al. 1998). Farmers employ intensive applications of toxic chemicals to manage pests (Sherwood et al. 2005), and studies indicate that potato farmers in Carchi have become heavily dependent on pesticides (Yanggen et al. 2004). By the late 1990s, this dependency manifested itself in high input expenditures,[1] low profit margins, and evidence of negative health and environmental impacts (Crissman et al. 1998). Because of pesticide overuse and the potential human health and environmental costs of this overuse, a unique collaboration between national and international research[2] organizations, designed, tested, and conducted outreach on a package of IPM practices for potato producers.

The research and outreach program in Carchi, coordinated by the Ministry of Agriculture's (MAGAP) long-running Fortipapa[3] program, consisted of several components. A participatory appraisal, conducted in 1998 (Barrera et al. 1998), identified the major pests faced by Carchi potato farmers. This appraisal helped gauge farmer perceptions of potato pests, and use of control methods; outputs from the appraisal were used to prioritize research. The IPM CRSP program was able to build on prior research conducted by CIP and INIAP, and prioritized pest management technologies were tested on-station and in farmer fields. Randomized experiments were set up with an approved statistical design and farmer field trials ran for a minimum of 2 years to ensure that the results were not sensitive to weather or short-term anomalies.

Tested components included the following:

- Late Blight – use of certified and resistant seeds, field sanitation, crop rotation, and alternating low-toxicity fungicides to reduce resistance build up in the fungus

[1] In 2003, it was estimated that pesticide expenditures represented between 12 % and 20 % of potato production costs in Carchi (Barrera et al. 2004)

[2] The Integrated Pest Management Collaborative Research Support Program (IPM-CRSP), funded by the United States Agency for International Development (USAID), was an important research partner in this effort.

[3] Fortipapa (*Fortalecimiento de la investigación y producción de semilla de papa en Ecuador*) began in 1992 with funding from the Swiss Development Agency (COSUDE). This project was a long-standing collaboration between MAGAP, Ecuador's National Institute of Agricultural Research (INIAP) and the International Potato Center (CIP).

- Andean potato weevil – monitoring and control using cardboard traps; use of bait plants; chemical control using low toxicity pesticides; alternative spraying practices to increase effectiveness and reduce use of chemicals, removal of all tubers at harvest, 30 day wait (host-free period) before replanting
- Tuber moth – monitoring insect populations, earlier planting, high hilling around plants, crop rotation, controls with low toxicity pesticides, seed solarization and application of low-toxicity and biological products prior to seed storage

Yellow fixed and mobile sticky traps were also investigated for control of a minor (in terms of damage) insect pest – the leaf miner (*Liriomyza huidobrensis*). Testing for the effectiveness of these components occurred primarily prior to 2003, when IPM CRSP potato research in Carchi ended. The Fortipapa program also ended around 2004 and most potato-related research activities conducted by INIAP in Carchi were suspended. Since then, Rhizoctonia (*Rhizoctonia solani*) appeared in the area and researchers have conducted a limited number of experiments to examine the effectiveness of seed disinfection and low-toxicity chemicals to control the disease (Travis 2015).

Development of IPM Packages: Field Trials and Experimentation

The preferred IPM package for potatoes combined cultural, mechanical, and chemical pest management methods. Recommended components were developed for each pest and disease, and development followed a standard protocol. Cultural controls help reduce the incidence of diseases and insect pests in the field. Examples include the use of certified and resistant seeds, high-hilling methods to create a barrier between insect pests and the tuber, and improved crop rotations. Mechanical controls are intended to kill a pest directly and include traps for monitoring and mass trapping of leafminer adults, and traps to target adult Andean potato weevil populations. IPM-related chemical control includes use of low-toxicity pesticides when other options are not available. Potato IPM chemical control practices include seed disinfection, directed-spray pesticide application to specific parts of the plant, and rotating use of fungicides with different active ingredients using low-toxicity pesticides.

Statistical evidence of the cost/benefit of the components and packages was obtained through field experiments. In some cases, individual practices were compared to a control and in others, components with known effectiveness were combined into a package and the package was compared to a control. The control was frequently the current farmer practice. Chemical alternatives were always compared face-to-face with alternatives that are more toxic; this was done to comply with the PERSUAP requirement associated with USAID funding.[4] Other components, like hilling during cultivation for control of the tuber moth were tested in combination with other practices, such as solarization of potato seeds and use of limited irrigation.

While several IPM packages built on earlier work conducted by Fortipapa, others were completely new. The fungicide rotation and resistant variety for late blight control were originally introduced to farmers by INIAP and CIP under Fortipapa; the IPM CRSP conducted final trials to ensure acceptability of the variety and refine the fungicide regime. The IPM CRSP trials compared the resistant variety (INIAP-Fripapa) to the most common existing variety (Superchola) and found that the former was associated with far less spraying (five versus nine for Superchola) and a 37 % reduction in chemical and spraying costs. The tuber moth package, however, involved a unique program of research supported by the IPM CRSP. During a participatory appraisal conducted at the start of the IPM CRSP, farmers made the research team aware that the most visible damage from the tuber moth occurred during seed storage. These perceptions of damage induced applications of highly toxic chemicals during storage. Since seed potatoes are stored in close proximity to kitchens, food storage, and locations where children play, finding effective means of reducing damage in storage was high on the list of project priorities. The research identified short-period seed solarization, followed by small doses of low-toxicity pesticides mixed with baculovirus as the best (most profitable) control method. The first research priority was to identify and test low-toxicity alternatives; these priorities were based on perceived cost savings and human health improvements from different research themes.

For the Andean potato weevil, the participatory assessment revealed that producers had good knowledge of the pest and the damage it causes, and, most importantly, the heavy use of highly toxic pesticides (Carbofuran was most common and has since been banned in Ecuador) for its control (Gallegos et al. 1997). The CRSP prioritized identification of low-toxicity compounds to be used against the adult insects, and these compounds were tested against a control, Acephate.[5] During these controlled experiments, biological control elements such as *Beauveria bassiana* and *Metarhizium anisopliae* were included. Relatively poor experimental results with respect to biological controls subsequently led to increased research to find appropriate strains of *Beauveria* and *Metarhizium* (see Table 10.1). Research continued to examine effectiveness of IPM techniques such as traps for the adult insect; this research involved the examination of different plant materials to include in the cardboard trap, combined use of biological controls (using *Beauveria bassiana*) and low-toxicity pesticides in the traps, and field spacing of traps. Over time, other practices were investigated and added to the recommended package as appropriate. In a final stage, the IPM package for the Andean potato weevil was tested on farmer fields against several alternative management practices.

[4] The Pesticide Evaluation Report and Safer Use Action Plan (PERSUAP) was a requirement of all USAID-funded projects using significant amounts of chemicals. The purpose of the Plan is to comply with USAID regulations and to provide project personnel with tools to better manage field operations.

[5] Carbofuran could not be used as an experimental control due to the PERSUAP regulations.

Table 10.1 Tukey test at 5 % for *P. vorax* adult mortality through application of beneficial fungi. Santa Catalina. 2002

Isolate (place of collection)	% insect mortality at 5 days	10 days	15 days	20 days
Beauveria Huacona San José	29 a	100 a	100 a	100 a
Beauveria Chanchaló	25 a	100 a	100 a	100 a
Beauveria Sablog	10 b	65 b	78 b	90 abc
Beauveria Santa Catalina	7 bc	72 b	96 a	96 ab
Metarhizium Guano	7 bc	44 c	71 bc	80 bc
Beauveria San José de Minas	6 bc	31 d	69 bc	76 c
Metarhizium Santa Martha de Cuba	5 bc	27 d	57 c	80 bc
Metarhizium FCA-CADET	4 bc	32 d	70 bc	86 abc
Control zero	0	0	0	0
Coefficient of variation	38.52	9.71	11.75	9.85

Source: Barriga (2003). Note: the letters a, b, and c reading down the columns signify no statistically significant difference between treatments with the same letter. For example, at 5 days, mortality rates for isolate Huacona San Jose and Chanchalo are the same, and these rates exceed those of Sablog, etc.

As noted, the IPM packages employed combinations of methods and the statistical analysis built on complementarities between the practices. For example, the project discovered promising low-toxicity products for control of the Andean potato weevil. Field trials were established and the chitin inhibitor, Triflumuron, was identified as providing the best control with lowest cost and no negative environmental consequences. Triflumuron was subsequently tested as an insecticide in cardboard traps, and was used in trials for different spraying methods. In the spraying trials, various designs were investigated including a cross-hatch and applications directed to different parts of the plant. At the end of the experimental cycle, the IPM package included the low-toxicity alternative, chemical applications directed to the lower leaves on alternating rows of potatoes, and the use of Triflumuron in traps.

Economic analysis showed that the IPM packages were profitable compared to alternatives. Experiments were set up to evaluate different permutations of the packages and compared to standard farmer practices. The economic analysis showed that while yields between IPM and farmer field plots were not significantly different, cost savings associated with IPM were associated with $270–560[6] higher profits per crop per hectare. Given that two potato crops are possible in a year, this represents a substantial income gain to farmers (Mauceri et al. 2007). The cost breakdown shows that farm labor inputs are slightly higher with the IPM packages and seed prices can also be higher, while savings emerge from substantially less use of purchased inputs. These savings do not reflect other savings such as avoided health and environmental damage due to fewer applications of less toxic pesticides; human health improvements remain an under-investigated area of IPM research in the Andes. Several aggregate analyses of benefits showed that the IPM program for the Andean potato

[6] In USD 2003.

weevil saved farmers $87 per hectare in the Central region and $42 per hectare in the South. The IPM program against the tuber moth in the North was projected to generate net benefits of $62 per hectare (Quishpe 2001; Barrera et al. 2002).

Outreach and Evaluation of Outreach Effectiveness

Diffusion of potato IPM in Ecuador was limited by factors specific to Ecuador and factors affecting IPM diffusion worldwide. In Ecuador, public agricultural extension was effectively discontinued in the early 1990s and, although the extension system has recently been revitalized by the hiring of hundreds of new extension professionals, at the time of the project there was no public agricultural extension. Almost all subsequent outreach efforts were in conjunction with funded projects and these projects needed to ensure that outreach was cost effective. IPM diffusion generally faces the following challenges: (i) IPM generally consists of complex packages that require substantial training; (ii) many IPM techniques are not amenable to private sector sales because of their public good nature,[7] and IPM must thus compete with profit-oriented private sector suppliers of pest control practices; and (iii) as pest resistance to insecticides develops, new technologies are needed thus requiring a dynamic research presence to maintain IPM adoption rates.

As a result of these challenges, the IPM CRSP continued with the Fortipapa emphasis on outreach efforts to facilitate IPM diffusion. Several outreach mechanisms were available. Farmer Field Schools (FFSs) are an intensive participatory training program, designed specifically to overcome IPM knowledge constraints (Feder et al. 2004). They involve weekly training sessions during a full crop season (Godtland et al. 2004). Field days are daylong events in which researchers demonstrate IPM practices and IPM packages 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). All of these outreach practices were employed in Carchi and a key concern was to evaluate their effectiveness.

Between 1999 and 2003, 28 FFSs were conducted, many field days were held, and other outreach practices were instituted. Participants in a FFS were selected as based on their interest in participating and their willingness to share their knowledge and experiences with other farmers.[8] In the FFS, farmers and researchers met

[7] IPM knowledge can be considered a public good, because if one farmer uses it, he/she cannot prevent other farmers from also using it; his/her benefits from use are also not affected by adoption by neighboring farmers. These conditions lead to the well-known outcome in the economics literature that the private sector will undersupply a public good.

[8] Farmers are purposively selected for participation in FFS, based on individual dynamism, willingness to learn and experiment, and leadership in the community. FFS 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).

once per week during the 6-month potato growing season. Each session lasted approximately 3 h and combined practice- and theory-based learning; the idea behind the FFS is that farmers need to become aware of the life-cycle of the pest in order to devise and evaluate non-chemical control practices.[9] All farmers were invited to participate in field days. During the field days, attendees were taught low-intermediate complexity IPM practices using demonstrations, short lectures, and poster-based educational materials. Carchi stakeholders were also exposed to IPM through mass-media dissemination efforts including pamphlets, newspaper articles, and radio messages (Carrion et al. 2016).

An evaluation of training methods conducted in 2003 showed that IPM practices most commonly adopted by potato growers included: (i) modified crop rotations (58.7 % of farmers adopted), (ii) early harvesting (57.8 %), (iii) disposal of crop residues (50.5 %), (iv) seed disinfection (56.9 %), and (v) directed-spray pesticide application (48.6 %) (Mauceri et al. 2007; Carrion et al. 2016). Evidence from an evaluation of the effectiveness of IPM outreach/training methods show that participation in field days is positively associated with farmer IPM knowledge and has a statistically significant and strong impact on adoption of IPM. FFSs are expensive, but provide the most complete IPM knowledge and FFS participants in Carchi readily share information with neighboring farmers. Mass media is cheap, but only effective when used in combination with other more intensive training methods (Mauceri et al. 2007).

Since 2003, formal IPM training and outreach has disappeared from Carchi. While the INIAP office remains open, few outreach events have been held and no organized formal IPM training has occurred. Scattered research has been conducted on specific practices by INIAP, and these are related to newly emerging pests and diseases (e.g. *Rhizoctonia*) and not targeted at IPM packages.

IPM training in Carchi was abandoned due to resource constraints and this abandonment could have implications for continued spread of IPM. In the past decade, high potato price variability has become a serious problem for area farmers. Farmers in Carchi have decreased their land dedicated to potato production. In 2003, 8,600 ha were planted with potato in Carchi; by 2012, area planted had fallen by nearly one-half to 4,600 ha (SINAGAP 2012). Because of the uncertainty about the persistence of IPM knowledge and use, a study was conducted in 2012 to evaluate how IPM use and knowledge patterns changed in the province (Carrion 2013). A survey of 404 randomly selected potato farmers in Carchi was used to measure IPM knowledge, sources of knowledge and use of IPM.

Survey results show that farmers who participated in a FFS had the highest knowledge scores, followed by those whose main source of information was from field days. These differences are significant at the 5 % level (Table 10.2). Farmers

[9] Evaluations of the FFS have shown that, immediately following the completion of the FFS, participants are more knowledgeable about pests and pest-management practices than non-participants (Feder et al. 2004; Gotland et al. 2004). There is very little evidence that this knowledge is durable. A recent review shows that FFS have changed agricultural practices and raised yields in pilot projects, but have not been effective when taken to scale (Waddington and White 2014).

Table 10.2 Main sources of 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
Mass media	23	35	63	2

Source: Reproduced from Carrion et al. (2016)
Any training using FFS or field days occurred prior to 2003
Pearson $chi^2(12) = 22.13$ $Pr = 0.005$. The chi^2 test statistic is testing whether the paired observations on training and knowledge level by source are independent of each other. Independence is rejected at conventional levels of significance

without formal IPM training had limited knowledge of IPM, but a surprisingly high proportion of them had moderate knowledge. This is evidence that IPM knowledge continues to be widespread in Carchi. IPM knowledge retention clearly varies by information source and it increases with the intensity of the training program. FFS and field day participants are more knowledgeable and also more likely to retain this knowledge.

The survey also found that IPM use continued to be relatively widespread in Carchi even with the disappearance of formal training. Intensive use of IPM was lower in 2012 compared to when the project ended in 2003, but proportions of farmers in the low-medium adoption range increased.[10] The proportion of farmers in non- and low-adoption categories changed substantially between 2003 and 2012 (Fig. 10.1). In 2003, 30 % of farmers did not adopt any IPM practice, while by 2012 this proportion fell to less than 10 %. Non-adoption was largely replaced by low and moderate adoption, and by 2012, nearly 50 % of surveyed farmers were using at least a few IPM practices. The study also found that training method had a long-lasting impact on adoption; the proportion of farmers who participated in a FFS prior to 2003 who were in the low-moderate IPM class grew dramatically. In Carchi, IPM use has become more widespread, but even intensively trained farmers are now using relatively fewer IPM techniques (Carrion et al. 2016).

Even farmers with no formal training in IPM had adopted multiple practices by 2012. These farmers obviously learned from neighbors, many of whom had participated in a FFS. Adoption rates among those farmers with no formal training were generally lower than those farmers who had formal IPM training. Former FFS participants had the highest rates of adoption of practices that require more knowledge or that are more labor intensive such as traps for Andean potato weevil, and fixed and mobile yellow insect traps (Carrion et al. 2016). Many farmers reported "trying" IPM practices but abandoning them over time. Factors associated with high

[10] IPM adoption is a continuum and the study constructed categories of adoption from low to high adoption based on the number and complexity of practices still in use (Carrion et al. 2016).

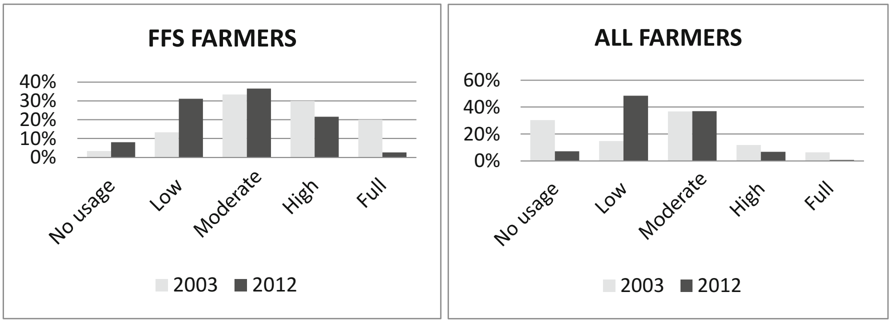

Fig. 10.1 IPM adoption over time, Carchi, Ecuador, 2003 and 2012 (Source: Mauceri et al. (2007) and Carrion (2013); n = 109 and n = 404, respectively. Reproduced from Carrion et al. (2016). Full usage corresponds to adoption of all recommended practices)

rates of abandonment included those requiring more intensive labor use. Others were abandoned because farmers viewed them as too complex, ineffective, or because they no longer felt threatened by the pest. Many farmers, for example, noted that leafminer populations had been declining, probably due to increased beneficial insects in the Province, and that yellow sticky traps were therefore no longer necessary (Carrion et al. 2016).

Lessons Learned

Due to long-standing pest pressures and intensive use of pesticides, Carchi, Ecuador was a good area for the introduction of a package of IPM practices. Prior research had indicated that pesticide applications had reached critical levels and economic and health consequences of pesticide overuse in potato production were evident. The participatory appraisal at project onset helped prioritize pest research and the project itself built on an impressive body of work by CIP and INIAP. This prioritization and good base of research allowed the IPM CRSP to move quickly into refinement and validation of packages. For example, Fortipapa had developed a number of potato clones with resistance to late blight; the IPM CRSP was able to avoid costly and lengthy research on the development of resistant varieties and instead focused on testing the improved clones for acceptance by local producers and consumers. Given the market orientation of Carchi potato producers, it was incumbent that any new variety be acceptable to local consumers.

In fact, potato breeding for resistance to late blight faces an ongoing challenge of consumer acceptance. The preferred late blight resistant variety developed by the Fortipapa program (INIAP-Fripapa) was released in 1995 and planting had spread to about 30 % of the potato area by 2003. However, by 2013, the variety was no longer planted in Carchi, supplanted by Superchola, which had been planted in Ecuador since before 1985. Superchola has better market acceptance, and for various reasons, INIAP-Fripapa certified seeds are no longer available in Carchi input markets. Given the challenges associated with resistance breeding and provision of certified seed, the research focus on fungicide rotations with low-toxicity compounds made sense.

Emergence of new potato pests, for example, *Rhizoctonia*, requires that IPM packages be adjusted over time. This emergence implies that even in areas where IPM packages have been tested and validated, it is still necessary to maintain a small maintenance research component. Potato pest challenges in Carchi may never be completely overcome and the natural response to the emergence of new pests is likely to be application of new chemical products. A national IPM program needs to be aware of these needs and the IPM research complex should be sufficiently agile to provide research outputs on a needed basis. Other threats to IPM include growing labor costs in many developing countries – researchers need to be aware that labor constraints may become increasingly binding over time and labor-intensive IPM practices may, as a result, become unviable.

Carchi is a place where pesticide use had become deeply entrenched and the persistence of IPM use shows that the intensive research-outreach program can have lasting impacts. In Ecuador, however, IPM producers have never taken advantage of growing markets for low-input products and IPM branding may be a fruitful avenue toward increased IPM uptake over time.

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