Integrated Pest Management (IPM) in Andean highland potato production systems under a changing climate: lessons learned in Peru

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Potato Production and Pest Problems

Potato (*Solanum tuberosum*) is cultivated in diverse agroecosystems, which harbor different insect pests; accordingly, potato farmers need appropriate site-specific pest control solutions. We developed Integrated Pest Management (IPM) strategies for potato production systems of the high Andes, where potato is mainly produced by small-scale farmers at altitudes between 2800 and 4200 m under rain-fed conditions. Potato cultivation is severely constrained by many pest problems, but farmers main response is to control infestations of Andean potato weevils (*Premnotrypes suturicallus, P. vorax* and *P. latithorax*) by applying hazardous class Ia and Ib (e.g., carbofuran, metamidophos) insecticides. Andean potato weevils cause substantial yield losses that seriously threaten Andean farmers' food availability and food security. Losses largely vary (16–45%) even when insecticides are applied. If weevils are not routinely controlled, losses can even reach 80–100%. While Andean potato weevils represent the only major biotic insect pest constraint at altitudes above 3800 m, in inner Andean valleys, other important pests are the potato tuber moth, *Phthorimaea operculella,* and the Andean potato tuber moth, *Symmetrischema tangolias*. Potato tuber moths are estimated to cause losses of up to $500/haper year. Farmers often mistakenly consider them to be only storage pests. Occasional pests are flea beetles (*Epitrix* spp.), infestations of which are kept under control by insecticide applications for the Andean potato weevil. There is evidence that the long-term use of pesticides has affected natural enemy populations and biological control.

From Research to Technological Innovations and Applicable Solutions

Three newly developed innovations are building the basis of an effective IPM approach that allows controlling Andean potato weevils (especially) and two potato tuber moth species with substantially reduced amounts of insecticides, or none at all. The innovations are (1) physical barriers, which inhibit the migration of Andean potato weevils into potato fields; (2) attract-and-kill (the two products AdiosMacho-*Po* and AdiosMacho-*St*), to control the potato tuber moth species *P. operculella* and *S. tangolias* in potato field and storage; and (3) a talcum- *Bacillus thuringiensis* subsp. *kurstaki* (*Btk*) formulation and product to protect stored potatoes against *P. operculella* and *S. tangolias*. These technical innovations should be embedded into the best cultural practices of potato cropping (use of high quality pest-free seed, adequate crop rotation, optimal planting and harvest dates, best practices of weeding and hilling).

Economic and Ecological Benefits of the Agricultural Innovations

Plastic barrier: The economic and ecological benefit of the plastic barrier technology was evaluated in large-scale of-farm experiments with 40 potato farmers of two Andean communities at an altitude of 3,900 masl. The plastic barriers revealed a higher efficacy for the control of the Andean potato weevil than applications of insecticides: the level of damaged potatoes was reduced to <5-7%; in comparison, the damage level after control by insecticides was just down to a level of 18 and 20% on the demonstration fields in the two communities, respectively. The Environmental Impact Quotient (EIQ) for the use of plastic barriers resulted in 32.9/ha compared to 191.5/hain fields managed by farmers using insecticides. The costs for the installation of the barriers largely depend on the plot size. The relatively higher costs on small potato plots outweigh the positive damage abatement effects if not higher potato prices are achieved as through organic potato. *Attract-and-kill*: At a droplet size of 100 µl and 2,500 droplets/ha, the two attract-and-kill products AdiosMacho-*Po* and AdiosMacho-*St* effectively reduce the male population up to 98%, depending on the size of the potato fields—the larger the fields the higher the efficacy. This reduced the infestation by >80% compared to non-treated fields. The application of attract-and-kill in simulated potato storage conditions reduced tuber infestation by >85% under high-moth densities. Per treatment, the costs are calculated between $20 and $30/ha, whereas under small scale farmers storage conditions the costs are less than $1-2 (one drop of attract-and-kill/m2 of storage area). The attract-and-kill strategy has the great advantage of achieving a good level of control at a very low and insignificant amount of insecticides (<15 ml/ha). Because of its specificity and application in droplets, it does not harm natural enemies and is consistent with the aims of IPM. *Talco*-Btk: The low amount of *Btk* in the formulation makes the product highly competitive and cost effective compared to chemical pesticides, with estimated product costs of $3.50 for protecting 200 kg of potato.

From Research to Use

Training curriculum and capacity building

The introduction and diffusion of the IPM approach into pilot regions of the departments Junín and Huancavelica started in the

2010/2011 cropping period. Its main objective is to offer practical, economic, and ecological solutions to pest management for resource-poor farmers, while supporting the rehabilitation of an agroecosystem weakened over decades by the excessive use of insecticides. Agricultural extension staff and farmers were trained through formal curriculum and capacity-building, which also included economic considerations and farmers learning to do their own cost and benefit calculus for good decision making.

Generating new business opportunities

Plastic barriers: Plastic is a common material used in agriculture and elsewhere for different purposes, and is widely available in the Andean region in different qualities and sizes. Initially, we assumed that farmers or farmer groups could prepare and install the plastic barriers (0.40 m wide, of which 0.10 m are to be buried in the soil) from plastic material (3 m wide) available on the local market. However, the quality of the plastic varied greatly, which proved a major hindrance to adopting this technology. We thus started creating awareness in the private sector about new business opportunities and to introduce and make available plastic of an adequate size (40 cm wide) and high quality (UV-resistant with a duration of at least two to three years). In 2011, the company JAI PLAST in Lima started producing the material, which was then sold through a local retailer to farmers and organizations. This was an important step forward to delivering this technology to farmers and by linking them to the respective input market. To further promote this technology, retailers in different potato growing regions will be identified. *Attract-and-kill*: Before the attract-and-kill system can be put into practice, several prerequisites need to be met, including product registration according to national regulations. At present, the two products AdiosMacho-*Po* and AdiosMacho-*St* are in the process of registration at SENASA (Servicio Nacional de Sanidad Agraria) of the Ministry of Agriculture, Peru. Registration efficacy trials have been finalized both under field and storage conditions and the registration dossier prepared. *Talco*-Btk: The product talco-*Btk*, using the formulation developed by CIP, is currently being produced and sold to farmers by INIA (Instituto Nacional de Investigación Agropecuaria, Huancayo), Peru, as well as by a farmer association (Empresa Comunal de Servicios Agropecuarios San Miguel de Collahuasi, ECSASMICO) in collaboration with SENASA in the department of Ancash. Plans are also underway to register and commercialize this product with the private sector in Peru so that it can be more widely distributed and used by farmers.

Starting Small and Scaling Up

Initial direct beneficiaries

The demand for organic certified food, both for the national and international market, has strongly increased in Peru. Native, anthocyanin-rich potato with their colorful flesh has been discovered for the production of potato chips. Infestations of Andean potato weevils, however, severely constrain its cultivation, and seemingly render organic production unfeasible or unprofitable. However, the easy-to-use technology of plastic barriers has fundamentally contributed to obtaining the certificate for the organic production of native potatoes in the department of Huancavelica. Hence, direct beneficiaries are mainly small-scale farmers organized in farmer associations producing certified organic native potato.

The net economic benefits of plastic barriers in terms of damage abatement and cost effects depend significantly on market conditions and farmers' collective action to jointly install barriers on larger field sizes. At current farm gate prices the mean expected farmer benefit of barrier adoption is positive (US$73/ha) but might not present a strong adoption incentive. Organic potato when successfully marketed with a high price premium can result in significant additional mean income of US$8771/ha ('optimistic' scenario).

Adaptation of IPM to Future Climates and Pest Risks

Insect pest distribution and population growth potentials are mainly temperature-driven; hence a rise in temperature through global warming may either increase or decrease insect development rates and related crop damages depending on the insect species' optimum temperature range. Hence for better preparing policy makers and farmers and adapting IPM to new pest situations a better understanding is needed to predict potential changes in pest risks on global, regional and local scales. We use process-based climatic phenology models for potato pests and apply three risk indices (establishment risk index, ERI; generation index, GI; and activity index, AI) in a geographic information system (GIS) environment to map and quantify changes for climate-change scenarios of the year 2050 based on downscaled climate-change data of the A1B scenario from the WorldClim database. All applications and simulations are made using the Insect Life Cycle Modeling (ILCYM) software developed by The International Potato Center, Lima, Peru (www.cipotato.org/ilcym). *P. operculella, e.g.* will progressively increase its damage potential in all regions where the pest already prevails today, with an excessive increase in warmer cropping regions of the tropics and subtropics. Further, a range expansion into tropical temperate mountainous regions with a moderate increase of its damage potential is also predicted; i.e., that in Bolivia, Ecuador and Peru 44,322 ha, 9,569 ha, and 39,511 ha of potato will be under new risk of infestation. The Guatemalan potato tuber moth, *Tecia solanivora* (Povolny), is considered one of the most serious potato pests in Central and South America. Today, the pest is spread throughout Central America and is present in Colombia and Venezuela. In 1996, it reached Ecuador

but from where it didn't expand further yet into other countries of South America. However, in 1999 its introduction had been reported from the Canary Islands. Globalization and the trade of agricultural products will further increase the risk of the pests' range expansion. According to model predictions under current temperature conditions the pest may potentially expand into Peru and also to some potato growing areas of Bolivia and Chile. The future establishment, distribution and abundance of this pest will be affected by climate change. Global predictions for 2050 indicate a reduction in the high risk areas where the pest has been established (e.g., Guatemala, Honduras and Nicaragua). A slight range expansion is expected to Chile with a high establishment potential of the pest (ERI>0.8). Further, by 2050 the abundance of the pest will potentially increase by 1 to 2 generations more per year in Central America and South America (e.g., Colombia, Ecuador, Peru and Venezuela).

Conclusions

The potential changes in pest risks call for creating better awareness and promote the inclusion of pest risks adaptation plans at country level. Further, the capacity of NPPO needs to be improved to adequately incorporate pest risk mapping results in adaptation planning of IPM to manage future pest risks on regional and country level.