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ECOHEALTH

Pesticide Use in Commercial Potato Production: Reflections on Research and Intervention Efforts towards Greater Ecosystems Health in Northern Ecuador

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Abstract: Since 1990, an interdisciplinary and interinstitutional team of scientists has led a research-intervention initiative examining pesticide impacts on agricultural production, human health, and the environment in the highly commercial potato growing province of Carchi, Ecuador. This article synthesizes the key results of that initiative, analyzes the lessons concerning the process of transdisciplinary ecosystems health research from a methodological perspective, and identifies priority future research opportunities. Research on this initiative has covered a broad range of activities with a full spectrum of rural stakeholders. These have included: health studies of the incidence of pesticide poisonings and the neurological impacts of pesticide exposure on farmers and their families; environmental and personal exposure studies; economic studies on the role of pesticides in agricultural production; sociological studies of farmers attitudes, knowledge, and practices related to pesticide use; and participatory interventions to reduce pesticide-related impacts. Research results have shown that pesticide poisoning incidence in the potato growing zones of Carchi, Ecuador match the highest reported rates in the world. A majority of farm household members suffer significant neurological impairment. Economic and participatory research has shown that there are viable alternatives to the use of Class 1 highly toxic pesticides in the zone. Nevertheless, cultural and political factors are impeding substantial changes in current practices. Future research-intervention activities include longitudinal analyses of the health, environmental, and production impacts of participatory interventions, and a scaling up of analyses to encompass other regions in the Andean mountain ecosystem with more limited indicators of key constructs.

Key words: pesticides, agriculture, nervous system, poisonings, economics, Ecuador

INTRODUCTION AND ECOHEALTH APPROACH

Since 1990, a multiinstitutional and interdisciplinary team of scientists and rural development practitioners has led an ecosystem approach to human health or "Ecohealth" research-intervention program in the province of Carchi, Ecuador (Yanggen et al., 2003; Crissman et al., 1998). This project has examined the effects of the use of highly toxic pesticides in a commercial potato agroecosystem. This project adopted the Ecohealth approach that integrates economic, environmental, and community concerns into a

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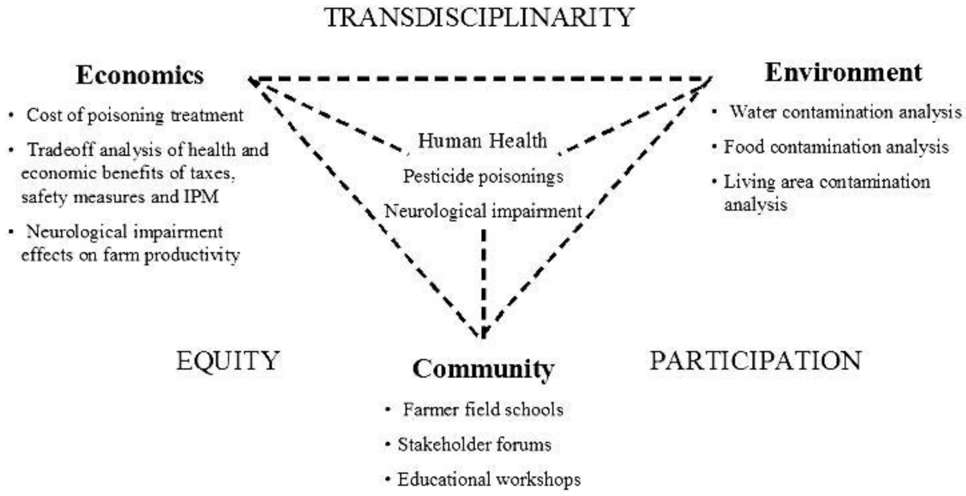

Figure 1. Ecohealth conceptual framework: application to pesticide use and potato production in Ecuador. IPM, integrated pest management.

holistic framework with human health in a central position (Waltner-Toews, 1996; Forget and Lebel, 2001; Lebel, 2003).

Figure 1 outlines some of the principal relationships between human health, economics, the environment, and the community addressed by our work in Carchi. As indicated in the diagram, the principal health outcomes focused on were pesticide-related poisonings and neurological damage. The three lists in the diagram indicate how specific research and intervention activities related human health to the other three factors. For example, in the economic-human health nexus, research calculated the economic costs of medical treatment associated with a typical pesticide poisoning. It is clear, however, that there exist complex interrelationships between all of these factors including feedback loops. Participatory community interventions, for example, helped reduce a variety of environmental contamination pathways leading to pesticide exposure of farm household members. This improved human health. Research then showed that improved health—also a key factor of production—was associated with increased farm productivity and, therefore, greater economic returns.

The other three elements of the Ecohealth approach incorporated in this project include: transdisciplinarity, participation, and equity. Transdisciplinarity involves not only the integration of diverse scientific disciplines but also the involvement of community members and policy makers, as well as scientists in the research-intervention activities. In the case of this project, for example, rural individuals helped researchers generate knowledge about pesticide issues, which, in turn, they presented in stakeholder forums on pesticide policy.

Participation is not a question of simply consulting "targeted individuals" but rather helping create spaces where local community members identify and analyze problems as well as work on solutions through interventions. In this project, for example, farm household members were given disposable cameras, took photos of pesticide handling within the household area, and then analyzed possible contamination pathways. Based on this analysis, community individuals themselves proposed possible solutions. Participation facilitated a greater consciousness raising and ownership, and thereby increased the potential for sustainable change.

Equity involves considering gender roles as well as the roles played by differentiated social groups. This differentiation was highly pertinent in the case of pesticide use in Carchi. Men, for example, were responsible for pesticide application, but medical tests indicated women had also been exposed to pesticides. Research into pesticide contamination pathways in the home helped identified other exposure pathways, such as women washing pesticide-soaked applicator work clothes. Analysis of social differentiation found, for example, that large landholders hired poorer day laborers to apply pesticides and thereby augmented that group's exposure risks.

We wrote this article with the following objectives in mind: i) to synthesize the key results of this participatory research and intervention initiative and reflect upon their implications; ii) to analyze the lessons learned concerning the process of interdisciplinary ecosystems health research from a methodological perspective; and iii) to identify priority future research opportunities.

The next section in this article describes the Carchi, Ecuador agroecosystem where our work has taken place.

The following section presents the results achieved, divided into four categories: farm households' knowledge and use of pesticides, pesticide contamination, human health impacts, and policy alternatives and intervention strategies. The final section reflects upon project-specific lessons learned and general lessons concerning the ecosystems approach to human health, and identifies future project priorities.

CARCHI, ECUADOR HIGHLAND AGROECOSYSTEM

Potatoes have been grown in the Andes for millennia. They continue to be an important crop in the Ecuadorian highlands and a food staple throughout the country. Carchi's location near the equator leads to minimal seasonal variation in climatic factors such as temperature, precipitation levels, and day length. This propitious climate in combination with fertile volcanic soils permit year-round planting and harvesting of potatoes in the highlands, making Carchi the most productive potato growing area in the country. Carchi produces 35% of the total national output of potato on only 25% of the land dedicated to the crop (Servicio Estadístico Agropecuario Nacional, 1995).

This productivity in combination with good market infrastructure have resulted in a highly commercial orientation of production. Production is sold both nationally and in neighboring country (notably Colombian) markets. This market integration has led to much greater price instability in the context of shortages or surpluses in other regions that cause sharp swings in prices. International sales beyond neighboring countries remain limited due to potatoes' bulkiness and perishable nature relative to, for example, staple grain food crops.

Carchi potato production has made extensive use of agrochemicals since the 1960s (Barsky, 1984). Today, Carchi farmers depend on a relatively high quantity of external inputs, including insecticides for the control of the tuber-boring larva of the Andean weevil (*Premnotrypes vorax*) and fungicides to control late blight (*Phytophtora infestans*). Ecuador has no national pesticide industry and therefore wholly relies on imports. Large international companies have actively supported pesticide use as has the Ecuadorian government through a broad range of policies. These policies have included: preferential tariffs, an overvalued currency (effectively subsidizing pesticide importation), tax exemptions, price controls, and subsidized credit (Lee and Espinosa, 1998).

In spite of the high level of commercialization, smallholder households dominate production in the zone, cultivating on average approximately 6 hectares typically consisting of several, spatially scattered fields (Barrera et al. 1999). The production technologies in the province vary. Both animal traction and tractor-pulled mechanized tillage are common in the zone, while a substantial proportion of farmers continue to practice manual land preparation. On the other hand, virtually all farmers apply pesticides and use hand-pump backpack sprayers. Larger farmers tend to rely on hired labor for potato production, whereas on smaller farms, household labor dominates. Potato production is the economic mainstay of the farm system, with typical rotations starting with two cycles of potatoes, a follow crop to gather the residual fertilizer used on potatoes, and finishing with several years of pasture-fallow used for forage for small-scale dairy or fattening.

The farm households themselves are composed predominantly of Spanish-speaking "mestizo" people of mixed indigenous and Spanish origin. Most adults have at least a primary school education, as reflected by a nearly 90% literacy rate. Work by Paredes (2001) grouped farm households into four principal categories according to production strategies, access to resources, and exposure to pesticides: risk-takers, intermediates, secures, and day laborers. Risk-takers cultivate extensive production areas and invest large sums of money in capital inputs and labor. They tend to rely on day workers and generally do not apply pesticides themselves. The intermediates generally have their own land, as well as managing land areas of larger landholders (typically risk-takers) and receiving a share of the harvest as compensation. These farmers apply moderate amounts of agrochemicals, they generally hire day laborers as well as participate in farm work themselves and, therefore, experience substantial exposure to pesticides. The secures have very small land holding and, due to limited incomes, tend to apply less pesticides. However, because they rely principally on family labor, labor exchanges, and often work as agricultural day laborers, they are nonetheless frequently exposed to pesticides. The day laborers are the poorest socioeconomic category. They do not own land and therefore work for the larger landholders. As workers, they do not make decisions about pesticide application but frequently carry out this task on others' farms.

SYNTHESIS OF RESEARCH AND INTERVENTION FINDINGS

Agricultural Households' Use and Knowledge of Pesticides

We gathered information on pesticide use and knowledge using formal surveys and direct participant observation (Mera-Orcés, 2000; Paredes, 2001). The formal survey consisted of a sociological "KAP" study (knowledge attitudes and practices) of 60 families with 332 individuals in the four cantons of Carchi with the highest levels of potato production. The participant observation anthropological techniques involved researchers living with a subset of families of the KAP study in three different Carchi communities, and accompanying and assisting family members in their daily activities. Consistent with the Ecohealth approach, both methods were tailored to gather information separately by gender. The combination of methods provided valuable insights, correcting biases stemming from each data collection technique alone.

Our surveys showed pesticides use in all potato fields. On average, each field received seven pesticide applications per season, and each application contained on average 2.5 different products. Applied almost exclusively by men using backpack sprayers, carbofuran and methamidophos were the dominant insecticides used and, respectively, constituted 47 and 43% by weight of the active ingredients of insecticides applied (Crissman et al., 1994). The World Health Organization (WHO) classifies both of these products as highly toxic (category Ib), and formulations of each are increasingly restricted in the United States, Europe, China, and Southeast Asia. Mancozeb constituted 80% by weight of active ingredient of all fungicides applied to potatoes. Mancozeb, from the dithiocarbamate family of fungicides, has recently been under scrutiny in the Northern Andes due to suspected reproductive (Restrepo et al., 1990) and mutagenic effects in human cells (Paz-y-Mino, et al., 2002).

Potato production uses the greatest quantities of pesticides compared to other crops in the project communities, receiving 90% of total financial outlays for these products. Ninety-five percent of farmers interviewed stated that pesticides were indispensable for potato cultivation. While most observers recognize that pesticides help control pests and reduce production risks, the conventional wisdom is that farmers irrationally overapply pesticides. Nevertheless, Antle et al. (1994) showed that, at the average levels of use, the marginal productivity of pesticides was greater than their marginal cost (i.e., one additional dollar spent on pesticides generated more that one additional dollar of income). Thus, from a short-term financial perspective, farmers received positive rates of return on their pesticide investment.

Farmers in the zone had limited knowledge of alternative production opportunities. The majority of farmers were not able to accurately name potato varieties resistant or tolerant to late blight. Weevil larva traps are among the most promoted and generally most promising integrated pest management (IPM) technologies in the zone. Yet only 11% of farmers had heard about them. Actual use was certainly lower.

In spite of the near universal use of large doses of highly toxic pesticides in Carchi, the typical rural household member had little knowledge of the specific dangers of pesticides and generally did not use protective equipment. Only one-fifth of the farmers had received any training concerning the safe use of pesticides (principally from pesticide industry representatives, followed by the national agricultural research center and the Ministry of Agriculture). Farmers' principal source of information came from their own experience and from reading product labels. Advice from local retail outlets was negligible (Espinosa et al., 2003).

Despite a near 90% literacy rate in the zone, more that 70% of men and 80% of women did not understand the meaning of the color coding on the pesticide labels. These labels are intended, in large part, to facilitate understanding of nonliterate individuals. Further, farmers do not select or purchase pesticide products by their active ingredient. About 75–90% had never received any warnings from vendors concerning dangers or suggested precautionary measures (Espinosa et al., 2003).

The cultural belief system that has emerged with the introduction and growth of pesticide use contributes to the ubiquitous unsafe use of highly toxic chemicals. Farmers commonly believe that repeated exposures to pesticides allow individuals to build up a resistance to their toxic effects. Furthermore, the ability to tolerate the nausea and other immediate effects of pesticide intoxications are generally associated with strength and manliness (Paredes, 2001). Perhaps not surprisingly, then, the use of safety equipment was woefully lacking. When preparing pesticide mixtures, 86% of farmers did not use gloves, 92% did not use a mask, and 97% did not use eye protection. During fumigation, only 38% used a piece of plastic on their back (under the backpack sprayer), 26% protective poncho, and 26% protective pants. Often this ''safety gear'' is not specialized equipment. A protective ''poncho'' is typically a leather jacket, and a mask can be an old shirt tied around one's face (Espinosa et al., 2003)

Pesticide Contamination

Given the widespread use of pesticides, we identified and quantified exposure pathways. These included direct exposure during application, handling, and storage, and indirect exposure through groundwater and food. Due to these poor safety measures, a high percentage of farmers wet parts of their body with pesticide spray during application: face (84%), hands (87%) legs (86%), feet (78%), and back (73%). These reports of applicator exposure were confirmed through controlled trials collecting residues on gauze patches and analyzing the residues with liquid chromatography (Merino and Cole, 2003).

In addition, participatory training to demonstrate exposure pathways used fluorescent tracers to confirm the presence of pesticide residues on farm family members and in the household (Fenske et al., 1986). Using their own backpack sprayers, farmer volunteers used these nontoxic tracers in their typical process of pesticide mixing, application, and clean up. After spraying and cleanup, the family members and the house were examined and filmed under fluorescent lights. Tracer, representative of potential pesticide residues, was clearly visible on the hands, back, and legs of the applicators. Residues were also found on nonapplicators, including children, who had accompanied the applicator to the field and on various surfaces inside the farm household. The videos were shown in community meetings, eliciting many shocked reactions from viewers.

To examine contamination of the environment, the focus was on carbofuran, an insecticide likely to persist in soil, water, and food. The principal testing method used enzyme-linked immunosorbent assay (ELISA) kits from Strategic Diagnostics Inc. (Newark, DE). The research team found that concentrations of carbofuran in the soil (Jaramillo, 2000) and in surface water (Kosten, 2001; Merino and Cole, 2003) were below the standards established by the United States Environmental Protection Agency (EPA). Two factors likely explain these results. First, the half-life of carbofuran in the conditions of the highland tropical Ecuadorian Andes is less than half that reported in previous studies done in developed countries with temperate climates. Second, the high organic matter content of the black Andean soil characteristic of the zone contributes to the absorption of carbofuran. An important caveat, however, is that specific incidents of contamination may occur above this usual level. The researchers recorded frequent observations of farmers washing their spraying tanks in streams, a practice that can create temporary point contamination with dangerously high levels of pesticides. In fact, farmers reported incidents of cattle deaths after drinking from streams, supposedly due to this practice.

The analysis of pesticide residues in potato tubers using the ELISA kits also did not find significant levels of contamination. Initially, this research analyzed cooked potatoes that had been peeled (the way in which potatoes are typically consumed in the zone) for trace residues of pesticides and found no quantifiable levels. When repeated for uncooked potatoes with peels, these tests did detect carbofuran, but well below minimum international safety standards' levels (Merino and Cole, 2003).

Anthropological participant observation research provided strong qualitative evidence of pesticide contamination in the home. These observations included poor storage practices, washing of application equipment and clothes in the home area, and applicators that entered the home before washing or changing their pesticide-soaked clothes. The research team used two techniques to quantify the presence of pesticide residues in the home. These included cotton swabs rubbed on key areas around the house that were later tested for pesticide residues using the ELISA kits, as well as the same technique of tracers put in the spray tanks and use of fluorescent light. These techniques confirmed the presence of pesticide residues in diverse areas of the house such as the kitchen table and floor, the clothes washing area, and the outside patio (Merino and Cole, 2003).

Human Health Impacts

Research on human health impacts brought together existing secondary data and collected new data on pesticide poisonings and long-term neurotoxic effects of pesticide exposure. Survey and participant observation data collection allowed us to confirm or contradict findings from the different sources. According to the Ecuadorian Ministry of Public Health (MSP), Carchi has the highest level of pesticide poisoning in the country with pesticides as the second leading cause of death after traffic accidents, for both men and women. Hospital records showed numerous cases of poisonings of women and children, in addition to the men that are the main pesticide applicators (Mera-Orcés, 2000; Cole and Mera-Orcés, 2003). The formal surveys cited above asked men and women for their recollections of poisonings. Few were reported. However, sociologists living with families in the communities recorded reports of a dismayingly large number of incidents including deaths of children (Mera-Orcés, 2000, 2001; Paredes 2001). The research team instituted an active surveillance system with local health practitioners and documented a rate of 171/100,000, over 10 times the number of poisoning cases as were captured by the existing Ministry of Health data and among the highest rates reported in the world (Cole et al., 2000). These poisonings have an important economic effect not only for the individuals involved but for the rural economy in general. The immediate costs of a typical poisoning, taking into account medical attention, medicines, and days of recuperation equaled the value of 11 days of lost labor wages. The social costs of fatal cases are even greater, and beyond the simple economic calculation presented here.

Research on neurological impairment from pesticide exposure used an augmented version of the Neurobehavioural Core Test Battery (NCTB) developed by the World Health Organization (Cassito et al., 1990) and described in standard reference texts (Lezak 1995). Performance on a battery of 13 tests was compared between potato farm household members and a control group. The household members consisted of 144 farmers directly exposed during application and 30 women not directly exposed to pesticides. The control group consisted of 72 urban residents of a nearby small town who had had no contact with pesticides. Results showed the psychomotor abilities of pesticide applicators were diminished and there was a significant reduction in strength, coordination, and tactile sensation. The cognitive capacity of both the applicators and their families was significantly affected in terms of both their concentration and visual-spatial abilities. In general, the diverse tests indicated that up to two-thirds of the exposed population showed significant neurobehavioural impairment, including not only pesticide applicators but also field workers and family members (Cole et al., 1997, 1998ab).

The mean age and education standardized neurobehavioural score of family members in potato growing households was nearly 1 SD below that of the control population. Some farm members had average neurobehavioral scores 3 SD below the mean of the control group. This level of impaired function is associated with difficulties in carrying out physical tasks requiring coordination and precise movements, and in cognitive tasks such as making decisions concerning efficient farm management. Persons with such impairment in Canada might commonly receive disability benefits because of their difficulties performing both waged employment and household management roles.

Alternative Policies

The pesticide use, knowledge, exposure, and health effects research described above provided evidence relevant for policy making. Consistent with the ecosystems health approach, disciplinary research was tightly coordinated making it possible to jointly examine results from different disciplinary teams adding considerable extra depth to the analysis. For example, the neurobehavioral scores described above were measured on family members of the same farms where economic farm production data was collected. This made it possible to use the neurobehavioral score as a health variable in an econometric analysis of farm-level productivity.

This farm-level productivity was estimated econometrically using a log-linear cost function. Explanatory variables included yields, input prices, fixed production factors (e.g., farm size) and, as mentioned, neurobehavioral scores. Data was collected at a plot level from 40 farms during a 2-year period. Results showed that farmers who had suffered significant neurological impairment were less productive than those not significantly affected (Antle et al., 1998b). In sum, pesticide exposure reduced both the physical and intellectual capacity of farmers to manage their farms.

Making use of the linked data sets, we implemented an integrated assessment method called Tradeoff Analysis (Stoorvogel et al., 2004). With the Tradeoff Analysis Model we simulated the effect of alternative policies such as increased taxes on pesticides. These taxes tend to lead farmers to decrease pesticide use and hence reduce adverse health impacts. The researchers found that a tax on all pesticides would improve the health of farmers but at the cost of reducing farm profitability. However, if taxes were applied to only the most highly toxic pesticides, both the health of the farmer as well as the profitability of the farm would increase, due to the improved productivity associated with improved farmer health. This gave a win-win solution: an increase in farm productivity would more than compensate for the increased production costs caused by the taxes (Antle et al. 1998ab).

Tradeoff Analysis also showed that both IPM and applicator safety measures improved economic returns as well as health outcomes. IPM also has the potential to decrease environmental contamination via pesticide leaching into soils and ground water. Combining these two technologies improved health and productivity outcomes even further in another example of a win-win scenario (Crissman et al., 2003).

Intervention Strategies

These research results provided a strong case for interventions. The Ecohealth perspective acknowledges, however, that interventions based on dominant ways of learning, doing, and organizing are blocking rural progress in developing countries (Forget and Lebel, 2001). Furthermore, the biophysical functioning of agroecosystems is closely intertwined with the social, political, and economic organization of society. Therefore the Ecohealth initiative in Carchi sought to enable a multifunctional actor-driven participatory approach to rural innovation and agricultural development as a means to meeting economic, environmental, social, and cultural goals (Sherwood and Thiele, 2003).

The "interactive" or "participatory" modality is a relatively new approach for catalyzing rural development that draws principally on multiparty social analysis of local problem contexts (Leeuwis and van de Ban, 2003). This approach has gained ground as an effective means to facilitating endogenous development. The interactive modality requires the facilitation of negotiated learning and action, commonly taking actors to new forms of social organization and activity. Ultimately, this approach demands a redistribution of decision-making power and resources towards local actors.

The aim of our Ecohealth project was therefore to link farmers, development practitioners, scientists, and donors in a learning and action initiative targeting, in particular, the social and ecological dependency on highly toxic pesticides for agricultural production. We pursued many different types of interventions on different levels. These include individual and community education through interactive or participatory training, field days, public awareness through mass communications, community health days, technical workshops for government and nongovernmental organization (NGO) professionals, visits to community, provincial, and national level policy makers, policy awareness seminars at provincial and national level, and finally, lobbying through international public awareness. These are reviewed by Antle et al. (2003) and Sherwood et al. (in press).

Participatory training was largely based on farmer field schools (FFS), with the goal to improve understanding of agroecosystem functioning and reducing pesticide use (for details on FFS application in Latin America, see LEISA, 2003). In FFS, farmers experimented with a wide variety of IPM methods of controlling pests. In experimental fields, farmers applied and generated IPM methods that substantially reduced pesticide use and costs, maintained yields, and thus improved the net profitability of potato production.

A second thrust focused on exposure reduction and pesticide risk reduction. Educational activities raised the consciousness of farmer household members to the dangers of pesticides. Improvements in personal protective equipment use were observed, with three-quarters of the FFS participants in one pilot community investing in specialized protective clothing. In this case, both applicators and their wives reported quick improvement in health due to this change.

A third set of interventions related to the promotion of dialogue among diverse stakeholders concerning pesticide issues. In October of 1999, over 100 representatives from government, industry, research and development organizations, the media, and farmer representatives participated in a meeting presided over by the provincial governor and the provincial directors of the agricultural and health ministries. The outcome of this meeting was a document entitled, "The Carchi Declaration for Life, Environment, and Production in Carchi" which called for a number of actions including the following:

- Assure greater control on the part of the Ecuadorian Agricultural Health Service (SESA) of the formulation, sale, and use of agrochemicals, including the prohibition of highly toxic products (WHO category Ia and Ib).
- Introduce information concerning the impact of pesticides on health, the environment, and farming productivity to the basic educational curriculum.
- Include integrated Pest management (IPM) as part of degree requirements for university level agricultural technical training.
- Commit further resources to research and training in integrated crop management with an orientation towards the reduction of pesticide use and pesticide risk reduction.

- Promote awareness raising in rural communities on the collateral impacts of agricultural practices and the use of more environmental and health friendly practices.
- Demand the direct financial support of the agrochemical industry in the completion of these resolutions.

After a series of informational meetings with the National Pesticide Committee (NPC; this congressionally mandated committee was composed of representatives of the ministries of agriculture and livestock, public health, and the environment, and a representative from the pesticide industry), a forum of national stakeholders was organized in May of 2001. Representatives from the Ministry of Agriculture and Livestock, and the Food and Agriculture Organization (FAO) opened the meeting. Members of the research team and farmers presented research result, followed by question and answer sessions and general debate. At the end of the meeting, the NPC, with the notable exception of the pesticide industry representative, called for a series of actions similar to those described above in the Carchi Declaration. Evidence of substantial support from civil society organizations followed with a petition signed by thousands of individuals from Carchi and four other Andean provinces. Several news reports appeared in the national media including newspapers and television programs. Yet no significant action has been taken by the Ecuadorian government to address the dangers of pesticides and move towards more sustainable agricultural production approaches.

ANALYSIS OF LESSONS LEARNED

Project-specific Lessons Concerning the Ecosystems Approach to Human Health

There were both great complementarities as well as important tensions in the transdisciplinary health research and intervention approach that we have carried out. A principal synergy involved the contribution of research results to help orient the intervention strategies. Video and other visual images of the fluorescent tracers of pesticides on individuals' body surfaces as well as in the home were particularly useful for motivating farm household members to minimize exposure to pesticides. Also the development and economic analysis of IPM technologies provided solid starting points for technological interventions in farmer field school experimental plots. Research results also helped enrich the policy debates promoted by this project by providing explicit evidence on the diverse impacts of pesticides. For example, much of the debate prior to this research initiative focused on the possible but undocumented environmental impacts of pesticides. This research showed that the human health consequences of pesticide exposure were relatively more important.

Transdisciplinary research also demonstrated disciplinary complementarities. Qualitative sociological and anthropological research often provided important insights to help guide more quantitative research. For example, participant observation techniques used by researchers helped identify specific pesticide contamination pathways into the home. These were later confirmed with laboratory analysis of pesticide residues. Similarly, informal interviews with a broad range of farm household measures uncovered numerous reports of child poisonings. Formal interviews with male and female heads of households did not capture this information; perhaps because adults felt uncomfortable admitting that the children under their care had suffered poisonings. This finding helped better orient health data collection to highlight children. The reverse direction of quantitative research orienting qualitative research was also of importance. The most notable example was the finding of neurobehavioral impairment among nonapplicator rural household family members. This spawned a line of qualitative research to identify the pathways of household and bystander exposure.

Tensions among disciplinary approaches also arose. For example, quantitative research objectives necessitated a baseline survey of a representative cross-section of farmers concerning their knowledge, attitudes, and practices related to pesticides. However, participatory interventions required that farmers come forward creating a volunteer selection bias, confirmed by Paredes (2001). The longitudinal evaluation objectives required a stable cohort of farm and community participants to document changes in knowledge, attitudes, and practices. Yet certain farm families quit the participatory interventions while others decided to stay on creating attrition biases.

Another type of tension existed between "hard" and "soft" approaches. "Hard" scientists and development workers, usually those from biophysical disciplines or economists, tended to emphasize technological solutions. Meanwhile, "soft" scientists and development workers, more often influenced by sociological and anthropological paradigms, tended to emphasize solutions based on process-oriented interventions and aiming to achieve social change. Sometimes differences were irreconcilable and only resolved by a dominant actor, such as the project manager, or by reiteration of a donor's priorities. In the more usual process, project staff members were forced to articulate their differences, understand those of others, make compromises, and reach consensus on collective action for the good of the research-intervention project.

Implications of Research and Intervention Results

Among the many implications of our work, we feel that two are central:

- The health problems caused by pesticides in potato production systems are severe and are affecting a high percentage of the rural population of Carchi Province.
- There exist solutions that are economically viable, that can substantially improve the health of the province's population and that can sustain the agroecosystem.

Yet why, given the gravity of the identified problem and the existence of viable solutions, has so little changed in the use of highly toxic pesticides? Several points merit consideration.

The use of pesticides in the zone is the outcome of a historical process where government policies and agents have systematically promoted the use of pesticides as described in the section on Carchi, Ecuador Highland Agroecosystem. These measures have contributed to the massive use of highly toxic pesticides by farmers who neither fully understand the dangers associated with their use nor practice minimal safety measures to limit their exposure. Reversing this situation will need a commitment by government to reduce the health hazards of pesticides similar to the efforts made to promote their use in the first place.

Representatives of the pesticide industry have publicly stated that the farmer-applicators themselves are to blame. Yet we have seen that innocent individuals, in particular women and children who do not apply pesticides, have also been seriously affected. Furthermore, the actions of the pesticide industry contradicts the conclusions of what is arguably the most extensive research initiative on pesticide use in developing countries sponsored by the industry itself. After reviewing the impacts of industry-sponsored "safe use" programs in several countries, the researchers concluded that achieving "safe use" was next to impossible among small farmers in developing countries (Atkin and Leisinger, 2000). These results coincide with our findings in Carchi. Atkin and Leisinger further conclude that any company that can not ensure the safe use of highly toxic pesticides should remove them from the market, yet, in the case of Carchi, intensive marketing of cheaper, more toxic products continues unrestricted.

Conclusions Concerning the Ecosystem Approach to Human Health and Future Project Priorities

The ecosystem approach to human health places human beings and their health at the center of development concerns, while seeking to ensure the durability of the ecosystem of which they are an integral part (Forget and Lebel, 2001). We believe our application of this approach to pesticide use in potato production systems in the Ecuadorian Andes demonstrates the usefulness of this approach.

Transdisciplinarity, in particular, was of key importance in terms of seeking solutions to the social problems related to pesticide use. Most of the project leaders have been trained in the reductionist and disciplinary approaches of their particular field (economics, social science, toxicology, medicine, etc.). It is clear, however, that disciplinary research results generated in isolation are not sufficient to bring about changes in the health and environmental problems associated with pesticide use in Carchi.

Farm households and farming communities in the province have developed a profound dependency upon chemical pesticides. Pests such as Andean weevil and late blight pose the risk of catastrophic crop losses, and farmers are understandably hesitant to abandon pesticides. The participatory involvement of farming communities in adapting and validating IPM for the zone was thus critical to achieving acceptance of these alternative practices. Likewise, farmer participation in analyzing pesticide exposure pathways helped achieve a better understanding of contamination and was a critical element in raising consciousness within communities in order to bring about change.

The research and intervention activities of this project have an applied and problem-solving orientation. The research results are intended to provide information that allows policy makers to make informed decisions concerning appropriate actions. The systematic involvement of diverse stakeholders in project activities helped policy makers to formulate the Carchi Declaration based substantially on project research findings. Furthermore, a subsequent attempt by the pesticide industry to promote "safe use" of highly toxic pesticides in Carchi met broad resistance from local stakeholders, backed up by project findings that "safe use" of highly toxics was generally not feasible given the socioeconomic conditions in rural areas.

The intervention activities of this project have had some important successes, for example, in terms of promoting IPM techniques and the adoption of risk reduction practices associated with pesticide handling. However, project interventions have largely operated on a micro-scale in a few select communities. Working with stakeholders, such as diverse NGOs and the national agricultural research institute, has helped to promote the widespread adoption of participatory methodologies such as farmer field schools as well as IPM.

In sum, the transdisciplinary linkages between researchers, communities, and policy makers have been critical for realizing the successes of the applied problem-solving activities of the project. Nevertheless, the successes of the project remain modest when compared to the overall magnitude of the problem of pesticide use in potato production systems of Ecuador. There is therefore a need to substantially scale up the project's future activities.

In order to scale up, we propose the formulation of strategies that permit greater regional coverage. Local health care practitioners should be trained in active surveillance of pesticide poisonings in a cross-section of Andean potato-based production zones. These same practitioners could also be trained in simple neurological tests for adverse neurotoxic effects of long-term chronic exposure to pesticides. Agricultural scientists would document farmer use of pesticides and a variety of agricultural practices in the same zones. The combined results of these monitoring and testing activities would permit reasonable estimates of health problems associated with pesticide use in the identified research zones and, by extension, other Andean regions.

Another issue to be faced in scaling up is the time and resource intensiveness of intervention activities. Future participatory interventions need to work through collaborative platforms with internationally sponsored projects, as well as national agricultural and health services. Training of trainer programs in agroecosystem health in collaboration with partner institutions can pyramid interventions to substantially larger scales. Such an approach is part of a broader strategy to build strategic alliances with NGOs, pesticide action networks, and sympathetic members of government specifically committed to working on pesticide policy. Coordination with such partners can leverage research-intervention results by ensuring that policy-relevant information is available to those working to bring about change in this arena.

Résumé: Depuis 1990, une équipe interdisciplinaire et interinstitutionnelle de scientifiques a entrepris une recherche visant à examiner les impacts des pesticides sur la production agricole, la santé humaine et l'environnement dans la province de Carchi, en Équateur, oŭ la production commerciale de la pomme de terre est très importante. L'article qui suit résume les principaux résultats de cette initiative, analyse d'un point de vue méthodologique les enseignements tirés de la recherche transdisciplinaire sur la salubrité des écosystèmes et indique les voies prioritaires dans lesquelles devrait s'engager la recherche à l'avenir. Les recherches menées à bien dans le cadre de cette initiative ont suscité un éventail considérable d'activités menées avec les intervenants les plus divers du milieu rural: études de l'incidence de l'empoisonnement par les pesticides et des impacts neurologiques de l'exposition aux pesticides des agriculteurs et de leur famille; études environnementales et études d'exposition personnelle; études économiques sur le rôle des pesticides dans la production agricole; études sociologiques sur les attitudes, connaissances et pratiques des agriculteurs en ce qui concerne l'emploi des pesticides; interventions participatives destinées à réduire les effets indésirables reliés aux pesticides. Les résultats de la recherche ont montré que l'incidence de l'empoisonnement par les pesticides dans les zones consacrées à la production de la pomme de terre dans la province de Carchi atteint les taux les plus élevés observés dans le monde. La plupart des membres des ménages d'agriculteurs souffrent de troubles neurologiques importants. La recherche économique et participative a montré qu'il existe des solutions de remplacement viables aux pesticides hautement toxiques de classe I dans la région. Néanmoins, des facteurs culturels et politiques empêchent des changements substantiels dans les pratiques courantes. Les activités de recherche futures prévoient des analyses longitudinales des effets des interventions participatives sur la santé, l'environnement et la production de même que l'execution d'analyses sur une plus grande échelle afin d'englober d'autres régions de l'écosystéme andin dont les indicateurs clés sont plus limités.

Mots clés: : **pesticides, agriculture, systéme nerveux, empoisonnement, économique, Équateur, Andes**

Resumen: Un equipo interdisciplinario e interinstitucional de científicos realizó un proyecto de investigación-interventión relacionado con los impactos que el uso de plaguicidas tiene en la producción agrícola, la salud humana y el medio ambiente en Carchi, Ecuador. Esta provincia es la mayor productora de papa al nivel nacional y esta casi en su totalidad a cargo de agricultores de pequeña escala. Los agricultores de Carchi aplican can-

tidades elevadas de insumos externos, en especial plaguicidas para el control del gusano blanco (Premnotrypes vorax) y el tizón tardío (Phytophthora infestans). Ochenta por ciento de los insecticidas usados son altamente tóxicos, y aplicados con bombas de mochila. La investigación sobre los plaguicidas se concentró en las siguientes ńreas: los impactos neurológicos en los aplicadores y sus familias; incidencia de intoxicatión; estudios sobre conocimientos, actitudes y prńcticas de manejo de plaguicidas; impactos económicos y estudios de exposición ambiental. Las actividades de interventión incluyeron la realización de Escuelas de Campo de Agricultores (EGAs), reuniones comunitarias para analizar los senderos de exposición a plaguicidas, promoción de medidas de seguridad y realización de talleres con tomadores de decisiones y otros actores claves. Este artículo resume los resultados claves de esta iniciativa, y analiza las lecciones aprendidas sobre el proceso de investigación interdisciplinaria en salud de ecosistemas desde un punto de vista metodológico e identifica oportunidades prioritarias de investigación futura. Esta iniciativa encontró que mńs de la mitad de la población rural de Carchi tiene daños neurológicos significativos y que Carchi tiene el nivel mńs alto de intoxicaciones con plaguicidas en Ecuador y entre los mas altos documentados en el mundo. También se pudo comprobar que existen prńcticas alternativas y políticas que ademńs de ser económicamente viables, pueden contribuir a mejorar sustancialmente la salud de los habitantes de esta provincia. Actividades futuras de investigación-intervención van a incluir anńlisis longitudinal de los impactos de las escuelas de campo y esfuerzos de subir de escalas para incluir otras regiones en los Andes.

Palabras clave: pesticidas, agricultura, sistema nervioso, envenenamiento, economía, Ecuador, Andes

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