Life cycle human exposure and risk assessment of pesticide application in Colombia: The example of potatoes

Stefanie Hellweg[1,*], Claudia Binder[2], Jaime Diaz Gomez[3], Jairo Arturo Guerrero Dallos[4], Ronnie Juraske[1], Camilo Lesmes[2], Carmen Mosquera[4], Glenda Garcia-Santos[5]

[1] ETH Zurich, Institute of Environmental Engineering, Switzerland
[2] Ludwig-Maximilians-University Munich, Germany
[3] Uni Boyaca, Tunja, Colombia
[4] Uni Nacional, Bogota, Colombia
[5] University of Zurich, Switzerland
[*] Corresponding author. E-mail: *Hellweg@ifu.baug.ethz.ch*

ABSTRACT

Although the human health effects of pesticides have decreased, chronic health problems are still significant in many developing countries and emerging economies. In this project we examined the various exposure pathways of pesticide application over the whole life cycle of potatoes grown in Colombia. Exposure pathways included e.g. workers' exposure during pesticide preparation and application and consumer exposure by ingestion of the pesticide-treated crops. A dynamic model was developed for pesticide crop uptake and evaluated with measurements performed within a field trial in the region of Boyacá, Colombia. Pesticide concentrations were measured periodically in soil and potato samples from the beginning of tuber formation until harvest. The model was able to predict the magnitude and temporal profile of the experimentally derived pesticide concentrations well, with all measurements falling within the 90% confidence interval. Pesticides residues in potatoes were rather low and below health-based threshold values in the case investigated. However, the study was performed in an unusually dry year with smaller amounts of fungicides applied than in other years. Therefore, to study exposure and risk in the region under normal circumstances, an enquiry about pesticide use was conducted among 79 farmers of the region and the model applied to the application pattern of pesticides reported by the farmers. Results show that substitution of a few active ingredients could lower consumer exposure significantly. With regard to workers' health, dermal exposure was found to be enhanced in only several cases. Several measures are suggested to lower workers' exposure. Finally, human intake of pesticides was quantified and compared throughout the life cycle of potatoes. Cumulated intake fractions of consumers' ingestion and farmers' dermal exposure were comparable, but individual doses for farmers were much higher and above no-effect-levels. This highlights that individual risk assessment studies are needed in addition to LCA, which typically cumulates intake.

Keywords: pesticides, toxicity, plant-uptake model, farmers' exposure

1. Introduction

Pesticides can help to avoid harvest losses and increase yields, but may come at the expense of health effects if not correctly applied. Although the human health effects of pesticides have decreased significantly in industrialized countries, misuse of pesticides in developing countries is still problematic. Possible factors contributing to these effects include the application of old products with high persistence and toxicity and missing or insufficient protection of workers during pesticide application and use. Consumers, farmers and authorities are interested in understanding and ultimately mitigating the life-cycle environmental and health impacts related to the use of pesticides.

The goal of this project was to examine the various exposure pathways of pesticide application over the whole life cycle of potatoes grown in Colombia. Potatoes were chosen for this study as it is the vegetable that is consumed most (e.g. per capita consumption in Columbia of 42 kg/capita/y), involves small-scale farming and is the crop with high pesticide use in Colombia.

2. Methods

We collected data, performed experimental studies and developed models to quantify the magnitude of exposure to pesticides from the preparation of pesticide solution, the application on the field, as well as post-harvest consumer exposure due to ingestion of potatoes.

2.1. Crop uptake model and field measurements

A dynamic model for uptake of pesticides in potatoes was developed and evaluated with measurements. The model takes into account the time between pesticide application and harvest, the time between harvest and consumption, the amount of spray deposition on soil surface, mobility and degradation of pesticide in soil, diffusive uptake and persistence due to crop growth and metabolism in plant material, and loss due to food processing like cleaning, washing, storing, and cooking. Intake fractions were calculated according to Equation 1.

$$iF_{consumers} = PF \cdot C_{potato} \cdot Y \cdot n / M \qquad \text{Eq. 1}$$

Where iF is the intake fraction, PF the processing factor (loss of pesticide by processing, e.g. washing or cooking), C_{potato} the concentration in the potatoes, Y the yield, n the number of people exposed, and M the mass of pesticide applied.

A field trial was performed on a farm in the region of Boyaca. This trial included periodical measurements of pesticide concentrations in soil and in the potato samples from the beginning of tuber formation until harvest. Application patterns (times, amounts and types of pesticides applied) were recorded.

For a complete documentation of the model and the results of the field experiments see Juraske et al. (2011).

2.2. Farmers' exposure

Dermal and inhalation exposure experiments of pesticides in potato cultivation systems in Colombia were carried out. Farmers' exposure during preparation and knapsack-sprayer application of pesticide was quantified with tracer experiments and the whole-body dosimetry methodology (Lesmes-Fabian et al. 2012). Intake fractions of the farmer were calculated according to Equation 2.

$$iF_{farmer} = M_{dermal} / M \qquad \text{Eq. 2}$$

Where iF is the intake fraction, M_{dermal} the mass of pesticide deposited on the skin of the farmer applying the pesticides, and M the total mass of pesticide applied.

2.3. Survey

To understand and calculate exposure in the region, a survey was conducted. Pesticide application data was collected through interviews with 79 farmers in the region of Boyacá, covering a total cultivation area of 82 ha. This data was then combined with the models developed to estimate exposure.

3. Results

The survey showed that 22 different active ingredients were used with an average of 9.8 kg/ha. 90% of total mass applied due to only 4 pesticides (carbofuran, carbosulfan, mancozeb, and methamidophos). Figure 1 shows the distribution by mass of these pesticides.

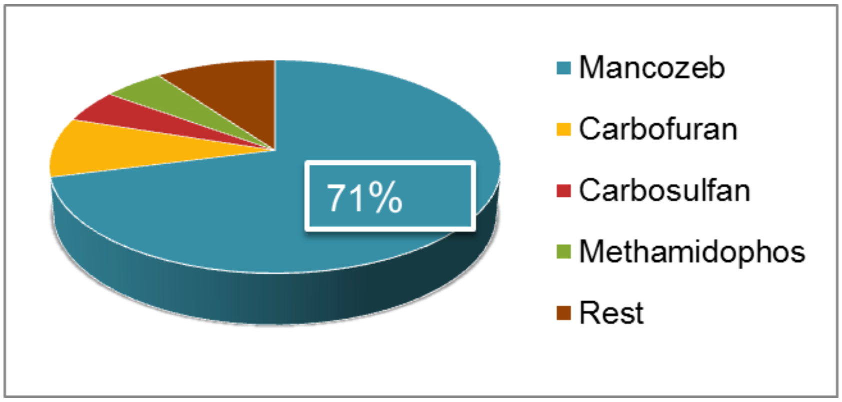

Figure 1: Share of pesticide masses applied in the study area

Modeled data for crop uptake was in good accordance with experimental data (Juraske et al. 2011). Cumulative intake fractions of consumers through ingestion of potatoes were $iF_{consumers} = 10^{-4}$ for cooked potatoes consumed directly after harvest (no cleaning/washing), $iF_{consumers} = 10^{-6}$ for cooked potatoes consumed 3 months after harvest (no cleaning/washing) and $iF_{consumers} = 10^{-5} - 10^{-7}$ for cooked potatoes that were previously cleaned and washed. Pesticides residues in potatoes were rather low and below health-based threshold values in the case investigated. However, the study was performed in an unusually dry year with smaller amounts of fungicides applied than in other years.

Table 1: Exemplary results of applied doses mean concentrations (n=3) and coefficient of variation of pesticides detected in soil (A) and pesticides applied but not detected in soil (B) in one field trial (Juraske et al. 2011). Samples taken at average tuber depth (12 cm).

(A)

	DDT	DDD	DDE	Carbofuran	Chlorpyrifos	m-parathion
Dose (kg ha^{-1})	-	-	-	-	0.435	-
Conc. (mg kg^{-1})	0.29	0.13	0.25	0.5	2.11	0.18
CV (%)	19	26	27	25	32	76

(B)

	chlorothalonil	cymoxanil	glyphosate	mancozeb	metamidophos	paraquat
Dose (kg ha^{-1})	0.54	0.08	0.14	0.66	0.55	0.08
Conc. (mg kg^{-1})	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

To study exposure and risk in the region under normal circumstances, an enquiry about pesticide use was conducted among 79 farmers of the region and the model applied to the application pattern of pesticides reported by the farmers. Questions were related to:

- Household description
- Potato field description
- Pesticide and fertilization management
- Occupational hygiene (use of personal protective equipment)
- Health problems related to the use of pesticides

Results show that substitution of a few active ingredients could lower consumer exposure significantly. However, in spite of some cases in which too much pesticide was applied too late before harvest, concentrations in potatoes were mostly low at harvest (below maximum residue levels MRLs). By contrast, farmers' exposure during application was significant, particularly dermal exposure. Dermal exposure depended on type of work clothing, cleaning of the application equipment, and application frequency. Although cumulated intake fractions of consumers' ingestion and farmers' dermal exposure were comparable, individual doses for farmers were much higher and above no-effect-levels. This highlights that individual risk assessment studies are needed in addition to LCA, which typically cumulates intake across all people exposed.

4. Conclusion

This study investigates various pathways for human health effects from pesticide exposure and, hence, focuses only on one impact category. While this was fine for the scope of the analysis in this case, also other impact categories than human toxicity need to be addressed when performing a complete LCA study.

The system showed to be rather resilient in terms of uptake of pesticide in the potatoes. Only in very few cases elevated residues were found, while for the majority of applications no health impacts from potato consumption are to be expected. By contrast, pesticide exposure of farmers from the application of pesticides was elevated and health impacts have been reported. The level of human health risk was especially for the pesticides like metamidophos. Exposure and health effects could be lowered by substituting the most toxic active ingredients, avoiding unnecessary application of pesticides, wearing appropriate protection clothing made of thick fabric and covering the whole body and cleaning all spill residues on the sprayer tank before starting the application.

The results of this study illustrate the importance of considering farmers/workers' exposure, which is often neglected in common LCA studies. However, it also shows the shortcomings of the LCA approach. In spite of the differences in individual exposure, LCA would have come to the conclusion that exposure of consumers and the farmers are comparable, as typically LCA does not consider individual but cumulative exposure. One farmer takes in the same amount of pesticide as a multitude of consumers together via potato consumption, resulting in similar intake fractions according to equations 1 and 2. However, the farmer is much more likely to exhibit health effects, as his individual dose of pesticide is much higher. This shows that risk assessment studies are always needed in addition to LCA, in order not to miss important effects.

6. References

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Questions and comments can be addressed to: staff@lcacenter.org

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