Conference Reports: 19th Discussion Forum on LCA

Life Cycle Impact Assessment of Pesticides

When Active Substances are Spread into the Environment

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Abstract. Pesticides are biologically active substances that are directly released to the environment during the use phase of their life cycle. Pesticides are widely used and play an important role in the production of vital goods such as food, feedstuffs and cotton. The Discussion Forum 19 focused on the impact assessment of pesticides applied in agriculture. The discussion forum started with three talks about new approaches to estimate pesticide emissions and to assess their fate in the environment. The following short presentations illustrated the application of some of these methods in case studies and highlighted the problem of data availability. The last two presentations provided insight into risk assessment models used for pesticide registration from a company perspective and from the viewpoint of the authorities.

Keywords: 19th Discussion Forum on LCA; agriculture; data availability; pesticides; risk assessment models

Introduction

Pesticides are widely used in agriculture. In the EU, 300.000 t of pesticide active ingredients were applied in 1998. Due to this large amount and their inherent toxicity, the ecological performance of pesticides has been much debated. Companies have undertaken extensive Risk Assessment studies for many years now because of legal requirements. By contrast, LCA has only recently started to develop tools to estimate the emissions of pesticides, their fate in the environment, and their effects on humans and ecosystems. Most of these approaches are based on models developed for Risk Assessment. The 19th Discussion Forum had the goal to give an overview of methods for the LCIA of pesticides and to show directions for further development.

1 Pesticide Assessment in LCA

The discussion forum was opened by GEORG GEISLER (ETH Zurich), the organizer of this forum.

MICHAEL HAUSCHILD (Technical University of Denmark) presented a new tool, PESTLCI, to estimate emissions of pesticides from agricultural fields. In this approach, the field is considered to be part of the technosphere. The emissions from the technosphere are the fractions of the applied dose of a pesticide that reach the environment surrounding the field. PESTLCI estimates these emissions. The data requirements are restricted to information that is generally available in LCA, such as substance data, crop type, and crop development stage at the time of application. With this information, the model calculates the fractions of applied pesticide that are taken up by the plant or that reach the environmental compartments air, surface water, and groundwater. The model is separated into different modules, each of which is concerned with one emission pathway. The processes considered are: settling of the pesticide spray on leaves and soil as well as direct emissions to air by wind drift; evaporation, degradation, and plant uptake of pesticide intercepted by the canopy; evaporation, degradation, and runoff of pesticide initially deposited on the soil. The model results may be used as input to any impact assessment method. They may also be used to establish mere mass balances. Such a mass balance was calculated for four pesticides with different partitioning and degradation behaviour. One important result from this case study was that evaporation from soil may be an important emission pathway. The model is available on request from mob@ipl.dtu.dk.

After this general talk about all potential exposure pathways of pesticides in agriculture, GEORG GEISLER focused on the emissions of pesticides to the groundwater. He especially addressed the problem of large emission variability due to different substance properties, site factors, and agricultural management factors. Geisler used the EU Risk Assessment framework for pesticide registration, FOCUS, to set up realistic scenarios for pesticide application in the EU. In total, more than 1000 scenarios were defined. These scenarios differed in substance properties (K_{oc}, $DT_{50,soil}$), site factors (e.g., temperature, precipitation, soil texture, soil organic carbon content), and agricultural management (application season, crop type). Leached fractions of pesticides were simulated in these scenarios using two leaching models, Pelmo and Macro. The variability of the scenarios ranged from no leaching at all to leaching of around 30% of the applied dose. Groundwater leaching was found to be most sensitive to the substance properties of the pesticides and, to a lesser extent, to spatial parameters. Agricultural management contributes fewest to the total variability. For use in LCA, probabilities of occurrence within the EU were assigned to all scenarios. This allowed the calculation of weighted average leached fractions, which can directly be used in LCA as a European default value.

In a joint presentation, RAPHAEL CHARLES and OLIVIER JOLLIET (EPF Lausanne) proposed a method to assess damage to humans via ingestion of pesticide-treated crops. Charles presented an approach to dynamically model the behavior of pesticides in plants. According to the model simulations, the plants generally absorb pesticides rapidly via leaves, so that initial concentrations in the plant may be high. In the long term, plant uptake from the soil also becomes important. Degradation and dilution due to plant growth counterbalance the accumulation

processes of plant uptake. The results show that concentrations of pesticides at harvest may vary by a factor of 100 between substances with identical mode of action. Jolliet presented how these results could be used in the effect assessment. The plant model is incorporated into the multimedia model IMPACT 2002 to calculate pesticide intake fractions. The effect assessment distinguishes between carcinogens and non-carcinogens. Dose-response slopes based on the Effect Dose 10% were used to quantify the number of persons that may be affected with cancer or non-cancer effects. To quantify the severity of impact to humans, the DALY concept was applied. While an average DALY-value was used for cancer effects, the DALY-factor for non-cancer effects was extrapolated due to a lack of data. This DALY-value is multiplied to the number of affected people in order to calculate the final damage. The method was applied to several pesticides. The results illustrate that pesticide intake via ingestion of plants is an exposure pathway of equal or higher importance than diffuse exposure via air or drinking water. Moreover, it was shown that the damage depends strongly on the time-span between application and harvest and that higher quality data on degradation halflives of pesticides in plants are needed.

2 Short Presentations

Sébastien Humbert (EPF Lausanne) presented a case study of active ingredients applied in Costa Rica. The impacts of the 31 most common active substances in Costa Rica were studied using the fate, exposure, and effect model IMPACT 2002. The results showed that only 3 active substances cause more than 80% of the impacts on ecosystems and 5 substances more than 90% of the impacts to human health. Humbert proposed substitution of harmful active substances with environmentally more benign pesticides.

Gerard Gaillard (Swiss Federal Research Station for Agroecology and Agriculture) compared different farming methods for cereals with the LCIA method Critical Surface Time. He concluded that the impacts from pesticides are generally small in comparison to fertilizers that contain heavy metals. Large differences in agricultural inputs were observed between different farming methods. Stopping the use of fungicides, insecticides, and growth regulators lead to a decrease in the quantity of plant treatment products by 50%, but the environmental advantages were minor from an overall point of view.

Heike Podey (ETH Zurich) described trends in the development of insecticides during the last 50 years. The number of active ingredients on the market has increased. While the volatility of insecticides generally decreased over the years, the acute toxicity increased. To analyze the potential tradeoffs in environmental performance indicated by these trends, more reliable substance data is needed. Handbooks and databases contain information about such substance data, but the data quality from these sources is low. Registration dossiers, by contrast, generally provide good quality data, but they are only scarcely available.

Jerome Payet (EPF Lausanne) analyzed the procedure to define PNEC values. Currently, the PNEC is often based on the most sensitive species. As a new approach, Payet proposed the use of the geometric mean or the median of a set of effect values. This would result in an increase in the PNEC values, often by several orders of magnitude. The main advantage of this approach is that the ranking of substances according to median effect values is more robust than the ranking according to the most sensitive species.

3 Pesticide Assessment in Risk Assessment

The last session focused on the assessment of pesticides in Risk Assessment and on the regulatory framework of pesticide registration. Andreas Huber (Syngenta Crop Protection AG) outlined and compared two approaches: Risk Assessment and Regional Mass Balances. Current registration practices in many OECD countries require the prediction of potential exposure of terrestrial ecosystems as well as ground and surface waters associated with the use of pesticides in agriculture. These estimates are usually based on a predefined realistic worst-case of pollution for each exposure route. Typically, exposure scenarios consist of particularly vulnerable combinations of soil, climate and land use characteristics, which are subject to a location-specific probability of occurrence. The focus of any Risk Assessment done for regulatory purposes is the compliance with threshold values, in most cases concentrations in environmental compartments. By contrast, a Regional Mass Balance aims to predict e.g. annual average losses of a compound after normal agricultural use. In summary, Risk Assessment tries to predict realistic worst-case concentrations of pesticides under certain scenario conditions, while Regional Mass Balances estimate average masses assuming regular conditions.

Markus D. Müller (Swiss Federal Research Station) outlined the perspective of the authorities. For the legal pesticide registration process, companies have to provide extensive studies. These include laboratory and field studies about the fate of pesticides in soil, water, sediment-water systems, and, if relevant, air. These studies include the identification of metabolites, which in many cases are more mobile than the parent compounds. Concentrations in the different environmental compartments are predicted with models, e.g. Pelmo for groundwater leaching. The predicted environmental concentrations in soil and water are evaluated in terms of possible adverse effects to representative organisms (e.g., earthworms, algae, fishes). In total, it takes the companies 7 to 10 years to produce all the data required for registration. Due to this long time period and the high costs involved, the companies insist on strict confidentiality of data. As a consequence, a very large body of high-quality data is produced on pesticides, but this information is generally not accessible to scientists and the public.

4 Discussion

The participants of the forum initiated many discussions. One point of discussion was the relevance of different emission pathways of pesticides from the field. According to the model of Hauschild, air emissions of pesticides are the most important pathway for exposure of humans and ecosystems. However, this model does not calculate concentrations of pesticides in food, which could be relevant according to Charles and Jolliet. The model of Charles and Jolliet calculated concentrations in plants ingested by humans that were below the regulatory threshold in most cases. In spite of these low concentrations of pesticides in plants, this exposure pathway was found to be important because humans directly ingest parts of plants. This finding, however, is strongly dependent on the severity weighting of impacts with DALYs, concerning non-cancerogenic effects.

The validation status of the different fate models for pesticides was also discussed. Generally, validation data is scarce. The model of Charles and Jolliet, for example, calculates pesticide concentrations in plants below the limit of detection of analyti-

cal methods. Hauschild, Charles, and Geisler validated parts of their modeling approaches with data from field studies. Jolliet claimed that uncertainty of +/- 1 order of magnitude in DALY scores due to pesticide uptake via plants could be tolerated, because the range of DALY scores obtained for pesticide product comparisons is often considerably greater than that value. All authors acknowledged the large variability of pesticide emissions from the field or of exposure to pesticides. The work of Geisler provided weighted average default values and an extensive sensitivity analysis of spatial and temporal variability for pesticide emissions to groundwater.

Concerning pesticide Risk Assessment and Mass Balances as used by industry and authorities, the need for high spatial and temporal resolution in modeling was pointed out. Also, the link between specific spatial and temporal conditions of the environment on the one hand and specific agricultural management practices on the other hand was stressed to be important. For instance, soil properties vary strongly between different regions in Europe, but also the major crops grown vary with the region. To analyze such correlated variability, spatially explicit modeling, e.g. with GIS-methods, is routinely used in Risk Assessment. Pesticide regulation also has to deal with very specific exposure pathways. Müller gave an example of the contamination of honey with one pesticide, related to the application of this pesticide in spring.

The quality of model results depends largely on the quality of input data. Main limitations in data quality were identified for pesticide substance properties and concerning data to determine DALY-weightings for non-cancer effects in humans. Huber and Müller gave arguments in favour of the confidentiality of pesticide substance data in pesticide registration dossiers. Huber also mentioned that spatially resolved data for GIS-applications were becoming more and more publicly available.

5 Conclusions

The Discussion Forum 19 gave an overview of current practice and trends in the LCIA of pesticides and provided an outlook for method improvement. Methods used in LCIA and Risk Assessment were presented and extensively discussed. It became obvious that Risk Assessment approaches are more mature than LCA approaches concerning specificity and resolution in time and space. Also, the correlation between spatial variability on the one hand and regionally different crops and agricultural management practices on the other hand is not taken into account in LCA. This higher specificity of Risk Assessment methods is due to the regulations that oblige companies to perform extensive Risk Assessment studies, while LCA is still an optional instrument. In contrast to LCA, Risk Assessment is not well suited to compare the severity of different exposure pathways to pesticides. Regional Mass Balances are better suited to compare exposure pathways, but are very data intensive. Thus, LCA is more adequate than Risk Assessment or Regional Mass Balances for product comparisons and for assessments comprising broader scopes than just pesticide application, such as the environmental evaluation of agricultural products.

Currently, there are promising activities going on to improve methods to estimate pesticide emissions and to perform an adequate Life-Cycle Impact Assessment of these emissions. The results of some of these activities presented on the Discussion Forum have just become available or they are in the finalizing phase. Soon, pesticides can therefore be more adequately assessed in LCA. However, it also became clear that LCIA methods for pesticide assessment still face some drawbacks: The underlying assumptions and the model performances need further validation and verification.

The presentations of the Discussion Forum are available at http://www.texma.org/LCA-Forum/lca-forum.html. In this webpage, there is also more information about the Discussion Forum series as well as an announcement of the coming events, such as the next forum on the **ecoinvent** database in Zurich on September 19 (in German) and December 5 (in English), see below.

20th LCA Discussion Forum: ecoinvent 2000
Results of the Harmonisation, Update, and Extension of LCA Data in Switzerland
In German: Friday, September 19, 2003 • ETH Zürich, Switzerland
In English: Friday, December 5, 2003 • EPL Lausanne, Switzerland
(in conjunction with the SETAC Case Study Symposium December 3-4, 2003)

With the leadership of EMPA several institutes and departments of ETHZ, EPFL, PSI, EMPA, EAWAG, FAL, and FAT[1] have funded the Swiss Centre for Life Cycle Inventories. Together with several Swiss Federal Offices (BUWAL, BFE, BBL, ASTRA, BLW) they started the project 'ecoinvent 2000' in order to combine and extend their respective LCI data in a joint LCA database. During this project, several thousand LCI datasets have been prepared, unified and updated. From September 2003 coherent high quality LCI data will be available for the sectors energy, transport, waste treatment, buildings and construction, metals, wood, chemicals, detergents, paper, and agriculture. Commonly used and state-of-the-art LCIA methods complete the LCA database.

The content of the ecoinvent database will be presented for the first time at the 20th Discussion Forum on **September 19, 2003** in Zürich (in German) and on **December 5, 2003** in Lausanne (in English), in conjunction with the 11th SETAC Case Studies Symposium and the Annual ISEE meeting (see http://www.setac.org/lca11.html). In the morning session of both events, the goals of the ecoinvent 2000 project and the methodological background are presented. Additionally, the usefulness of ecoinvent data in respect to integrated product policy (IPP) is emphasised and an outlook on the possible future developments of the Swiss Centre for Life Cycle Inventories is given.

In the afternoon, participants will have the opportunity to get a closer look at the database content and an insight into selected topics. In several parallel sessions important aspects of the database content are explained and discussed. During an apero, participants will have the opportunity to learn more about the ecoinvent implementation by LCA software suppliers.

Program and registration form for the Zürich event (September 19, 2003) are available on http://www.texma.org/LCA-Forum/lca-forum.html or can be ordered by email (lcaforum@epfl.ch). Detailed information on the December event at EPFL will be sent out in late summer. To learn more about the ecoinvent database, please visit the website under http://www.ecoinvent.ch. Here you can explore a test version of the ecoinvent database free of charge. Contact for content related questions: Rolf Frischknecht, ecoinvent Centre, frischknecht@ecoinvent.ch.

[1] ETHZ: Swiss Federal Institute of Technology, Zürich; EPFL: Swiss Federal Institute of Technology, Lausanne; PSI: Paul Scherrer Institute; EMPA: Swiss Federal Laboratories for Materials Testing and Research; EAWAG: Swiss Federal Institute for Environmental Science and Technology; FAL: Swiss Federal Research Station for Agroecology and Agriculture; FAT: Swiss Federal Research Station for Agricultural Economics and Engineering.