Emission and toxicity modelling for pesticides: operationalising the pesticide consensus

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1. Introduction

Current field emission modelling and toxicity characterisation of pesticides suffer from several shortcomings like unclear boundaries between Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) phases after pesticide application, mismatches between LCI databases and LCIA methods, missing characterisation factors, missing environmental compartments in impact assessment, or missing environmental impact pathways. The Glasgow pesticide consensus workshop in 2013 [1] started a consensus process with three scientific workshops and a stakeholder workshop [2]. In order to operationalise and harmonise the emission quantification and impact characterisation of pesticides in life cycle assessment (LCA) and product environmental footprinting based on this effort, the OLCA-Pest project ("Operationalising Life Cycle Assessment for Pesticides", 2017-2020, funded by ADEME) was implemented with nine partner institutions. Based on the analysis of potential gaps and overlaps between the PestLCI Consensus model for pesticide emission modelling, the dynamiCROP plant uptake model for human exposure and toxicity characterisation with special focus on pesticide residues in food crops, and the USEtox scientific consensus model for human toxicity and ecotoxicity characterisation, we propose solutions for the integration of pesticide emissions into LCI databases, in order to provide a consistent emission and impact modelling for pesticides in LCA.

2. Model analysis

The PestLCI Consensus model (pestlciweb.man.dtu.dk) is based on the outcome and recommendations of the pesticide consensus building effort [1] and the emission quantification model PestLCI 2.0 [3]. Developed as a web tool, PLCM delivers a set of primary distribution fractions (i.e. immediate distribution of applied pesticides to the air, crop surface, field soil, and off-field surfaces) and a set of secondary emission fractions, distinguishing between air, field soil and crop surface, ground water, and off-field surfaces. The off-field surfaces can be further divided into the environmental compartments, e.g. using the share of each land use type and water surfaces in a given area.

The dynamiCROP model (dynamicrop.org) quantifies human exposure to pesticides applied to food crops via ingestion of potential pesticide residues on harvested crop parts, and related health impacts [4]. dynamiCROP also calculates health impacts from the pesticides lost to air and field soil, combined with intake fractions for emissions to these compartments. The dynamiCROP model has been parametrised for six major food crops, implemented in USEtox. It provides as main output the residues remaining at harvest time in leaves, fruits, stems, and roots and tubers. The human intake fractions consist of intake fractions directly provided by the model for the pesticide residues on/in the harvested products and furthermore processes like washing or cooking, and the intake via the pesticide mass fractions lost to air and field soil.

USEtox (usetox.org) is a scientific consensus model endorsed by the Life Cycle Initiative hosted at UN Environment for characterizing human and ecotoxicological impacts of chemical emissions [5]. The main outputs are the characterisation factors for human toxicity and freshwater ecotoxicity, both, at midpoint and endpoint levels, related to emissions at continental level to air, freshwater, agricultural soil, natural soil, and sea water. The model distinguishes a continental and a global scale, of which only the continental scale is used for emission input, while the global scale is required to have a complete mass balance, i.e. for accounting for impacts from (continental scale) emissions on the global level.

The analysis of the models showed that several overlaps exist between PLCM, dynamiCROP, and USEtox. These overlaps can be avoided or minimised by using the primary (initial) distribution of PLCM and linking it as input to dynamiCROP (to calculate crop residues and related human intake fractions), and to USEtox for emission-based toxicity characterisation. This is consistent with the recommendations from the pesticide consensus effort [1].

3. Proposal for model linkage and its consequences

The initial distribution fractions from PLCM to air, off-field surfaces and field soil can be directly used as inputs to dynamiCROP. The emissions to the leaves of the crop from PLCM can be linked to the leaf/fruit surface deposit compartment in dynamiCROP, in order to calculate the crop residues and related human exposure and toxicity impact factors. The initial distribution fractions can be linked to emission compartments in USEtox as follows: air → continental rural air, field soil surface → continental agricultural soil, off-field surfaces → distributed to continental freshwater, continental agricultural soil, and continental natural soil according to the share of the different surfaces in the considered area. The distribution fractions to the field crop will be linked to characterisation factors for human toxicity as described above. This approach is not limited to the USEtox method only; it is also applicable to other toxicity impact assessment methodologies. It ensures that the total mass of pesticide emitted is recorded in the LCI.

A new emission compartment "crop" should be introduced into LCI databases in order to allow for a consistent modelling of emissions and toxicity impacts. The emitted amount of pesticide should be divided into the following compartments: air/low population density, soil/agricultural, water/surface (river & lake), soil/forest (or soil/natural), and a new compartment for the emissions to the crop in the field. The latter should be further subdivided into 18 archetype crop classes, by distinguishing "food" and “non-food" uses, yielding 36 sub-compartments, which allows for an adequate human toxicity impact assessment. The distinction between food and non-food uses of harvested products allows to consider situations, where not all products are finally consumed (use for biofuels, materials, or animal feed). Default emission fractions for different standard application situations (crop classes and pesticide target classes) will be calculated by PLCM and provided for LCI databases and background LCI datasets. These emission fractions are site-generic and independent of the soil, climate or topography. This will allow easy integration into LCI databases, since only the knowledge of the crop and the target class is required. Where specific data about the application situation are available, customised emission fractions can be easily calculated by the PestLCI Consensus web tool.

In LCA studies with specific focus on pesticide applications, like the comparison of plant protection strategies in a given region, the approach described above might be too unspecific, since the soil, climate or topography can strongly influence the emissions. For such cases the PLCM also calculates secondary emission fractions after a given time interval between application and emission, specified by the user. However, gaps or double counting can occur, since most toxicity impact assessment methods take all processes after the application into account. To which extent this approach can be recommended to LCA practitioners is currently being explored in case studies within the OLCA-Pest project.

4. Conclusions and outlook

For operationalising the pesticide consensus, the proposed linking of PLCM, dynamiCROP and USEtox provides a consistent framework for the assessment of pesticide emissions and related toxicity impacts for use in agricultural LCA. The default emission fractions allow an easy integration into LCI databases and background datasets. The approach is currently being tested in several case studies within the OLCA-Pest project, which will lead to recommendations related to the use of the models and the interpretation of the results for the wider LCA community.

5. References

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