Life cycle analysis of horticultural products: Memo on transfer fractions of plant protection

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Introduction

This memo has been prepared to address modelling pesticides emissions of plant protection products (PPP) in the context of the development of a methodology for calculating the environmental footprints of horticultural products, the HortiFootprint category rules (HFCR, see Helmes et al, 2020). The goal of this HFCR is to provide a harmonised methodology after which consistent LCA studies can be performed for the European horticultural sector. The development of the methodology is following as much as possible the most recent guidance for developing product environmental category rules (PEFCR) published by the European Commission (Zampori and Pant, 2019).

The development of the HFCR was initiated by Royal FloraHolland, Dutch Fresh Produce Centre and Wageningen Economic Research, with co-financing from the Dutch Fund for Horticulture & Propagation Materials, ABN AMRO Bank N.V., the Dutch sector organisation for greenhouse horticulture (Glastuinbouw Nederland), MPS, Rabobank, Foundation Benefits of Nature and in co-production with experts from Blonk Consultants and PRé Sustainability.

At the start of the project, several topics were identified where additional guidance was needed for the horticulture sector as well as the guidance currently available in the PEF. The following methodological challenges were identified:

- modelling of transfer fractions of plant protection products;
- handling multifunctionality of combined heat and power systems;
- modelling of N and P emissions;
- modelling of capital goods.

This memo is one of the four memos elaborating on methodological challenges.

Background

The current public private partnership 'HortiFootprint' aims to develop an overall life cycle assessment (LCA) method applicable to horticultural crops. In addition to environmental impacts of climate change, water scarcity, eutrophication, etc., human toxicological impacts and ecotoxicological impacts are characterised in the LCA (called 'impact characterisation'). The HortiFootprint project follows the recent consensus method developments from the PEF initiative and will thus use the characterisation method USETOX to determine toxicological impacts, including those of PPPs.

USETOX translates emissions (from agricultural systems) to the environment in the impact on ecosystems and human health due to toxicity of the emitted substances, through a multimedia fate model and exposure modelling (Rosenbaum et al., 2015). Because USETOX makes use of emissions as input for the toxicity impact characterisation, while often only the amounts of PPP applied to the field/plant are known, emission fractions are required to translate the applied amounts into emissions to environmental compartments (Zampori and Pant, 2019). Transfer fractions convert the applied amount of PPP to emission of environmental compartment. See equations below (all parameters are differentiated to the PPP active ingredient and receiving environmental compartment).

I = E * CF (I=impact, E=emission, CF=characterisation factor)
E = Mapp * TF (E=emission, Mapp=mass of PPP applied, TF=transfer fraction)
CF = FF * EF (CF= characterisation factor, FF = factor reflecting fate, EF = factor reflecting effect)
I = Mapp * TF * FF * EF

USETOX is not designed to convert applied amounts of PPP to emissions with emission fractions, and its compartments do not match the direct emissions occurring in agriculture. According to the proposal by Van Zelm et al. (2014) and Fantke (2019), the match between emission models and USETOX is illustrated in Table 1. USETOX has the receiving compartments: indoor air, occupational air, urban air, rural air, fresh water, seawater, natural soil and agricultural soil. The complete amount of applied PPP should be accounted for in terms emissions to rural air, fresh water, natural soil and agricultural soil, while a loss of short-term degradation is allowed. Characterisation factors for the remaining receiving compartments (indoor air, occupational air, urban air and seawater) are not considered, since emissions of PPPs to these receiving compartments are negligible.

Table 1 *Link between emissions compartments of USETOX and emission models*

		USETOX emissions compartments			
		Air	Agricultural soil	Natural soil	Fresh water
Modelled emissions, according to Van Zelm et al. 2014)	Drift from application	X			
	Volatilisation from plants	X			
	Volatilisation from soil	X			
	Runoff		Distribution or choice of one compartment, To be determined.		
	Drainage				X
	Groundwater				X
Emissions mentioned in addition by Fantke (2019)	Agricultural soil at PPP application site		X		
	Agricultural soil other		X		
	Crops of application	Distribution or choice of one compartment, to be determined.			
	Surface water				X
	'Degradation'	Not included, because it is a 'real' loss of PPP			

Method gap

The current approach to link PPP applications and the impact characterisation model (Zampori and Pant, 2019) is to distribute the applied amount over the compartments according to fixed percentages, without considering the properties of the PPP or the specific cultivation system. This is acceptable if PPPs have a very small impact, if plant-based food is only one ingredient among many, or for feed for animal-based products. However, PPPs receive a lot of stakeholder attention and if quantified, their environmental impact should be reliable. Zampori and Pant (2019) mention that the emission fractions can be strongly debated, but points that averages are reasonable. It quotes a report from Wageningen Environmental Research (WUR-Alterra, 2016) that does not support this claim. In fact, averages will not reflect the broad spread in transfer fractions for different PPPs under different cultivation circumstances. The 'fixed fraction approach' is seen as temporary, to cover the lack of directly applicable solutions.

A reliable model and the required input data should be identified for determining more reliable and more representative transfer fractions, differentiated among PPPs and cultivation circumstances. The required accuracy of the transfer fractions should be decided in order to employ the model and input data in a parsimonious way: as simple as possible, as complex as required. It needs to be determined which input variables would be most meaningful to describe the agricultural system at hand and PPP properties in addition to input data readily available from the database underlying USETOX or other PPP databases.[1] A clear vision should be developed on which methods will be used to improve the current situation during the current pilot phase of the PEF initiative in the course of 2020.

Structure of solution

A tiered approach is envisioned, going from Tier I of basic modelling to Tier III of advanced modelling, as illustrated in Table 2: there are cases where Tier I is acceptable such as in (partially) animal-based food (as mentioned in 'Method Gap'), and there may be an option to follow complex methods when interesting (Tier III). The middle ground especially needs to be covered (i.e. Tier II), because many possible applications of the new PEFCR will have a partial interest in toxicity impacts, in which the efforts for and the information from the LCA study do not focus on such impacts exclusively. The importance of modelling PPP transfer for protected agriculture differently than for open agriculture is illustrated in the next section.

Table 2 *Tiered structure for estimation of transfer fractions*

Cultivation Type	Tier	0 (not accepted)	I (PEFCR Guide)	II (Generic model)*	III (**)
Open	Air	0%	1%	To be determined, use basic model with basic input dataset, resulting in highly variable transfer fractions	Not required for HortiFootprint; ideas are welcome
	Fresh water	0%	9%		
	Agr. soil (if open soil)	100%	90%		
	Agr. soil (if substrate)	100%	90%		
	Natural soil	0%	0%		
Protected	Air	0%	1%		
	Fresh water	0%	9%		
	Agr. soil (if open soil)	100%	90%		
	Agr. soil (if substrate)	100%	90%		
	Natural Soil	0%	0%		

[1] Physicochemical properties are available in the database used in USETOX and other databases, and should not be counted as an additional data. Soil parameters, climate data and data on the application method would be useful additional data. Making the input parameters for the transfer fractions spatially dependent constants is an option to achieve additional accuracy, but using additional non-spatial input parameters might be a better option.

A model needs to be identified or developed that provides the transfer fraction for each PPP applied. Such a Tier II model can have different shapes:

- It can be a very advanced lookup table: a complex matrix with the input variables as dimensions.
- It can be an assembly of pre-existing model components from current scientifically robust models. The environmental indicator for PPP (EIP), currently under development in a cooperation of Wageningen Economic Research, Wageningen Environmental Research and CLM (Centrum voor Landbouw en Milieu) in a public private partnership (Wageningen Economic Research, 2020) can.

A basic user interface should be available so that any shape of this model could be used by LCA practitioners with intermediate experience. Both the EIP and the PESTLCI model may turn out to be too complex, i.e. Tier III. In that case, it needs to be defined how such a model can be simplified.

Aspects to be clarified in method development

What is the accepted uncertainty?

The uncertainties in toxicity impacts of PPP are great in LCA, due to the characterisation model. The emission fraction resulting from a Tier II emission model is multiplied by a highly uncertain characterisation factor. This implies that the emission model does not have to be extremely accurate, but should not multiply the uncertainty in the characterisation factor substantially. The uncertainty of Tier I and Tier II approaches should be determined and compared. It should be determined which uncertainty reduction can be a result of a reasonable effort. Fantke (2019) points out that the uncertainties of LCA toxicity impacts are such that preferability of one PPP over another cannot be determined with the current state of the art. However, comparisons of scenarios with simple variations (under the condition of all other things being equal) should be facilitated.

Differentiation

Several types of differentiation should become visible by moving from the fixed factor approach (Tier I) to a Tier II model.

- It is estimated that the application method strongly influences the transfer fractions, so it is proposed to include variables describing application methods for differentiation. All common application methods will be included.
- Crop morphology determines PPP fate within the field, and consideration should be given to working with crop archetypes. The suitable descriptors should be determined and within-crop variability should be assessed.
- Climate and weather are relevant variables. Measures for wind, rain and temperature should be considered and could be related to a region, resulting in regionalised sets of climate constants.
- Furthermore, soil type determines the transfer to some extent, so it needs to be determined which variables describe soil type in a meaningful way. The carbon content of the soil, reported directly or derived from the soil type, might be a useful predictor.

PPP transfer from protected agriculture

The conceptual differences between transfer fractions and between protected and open field agriculture are substantial. During the first phase of the HortiFootprint project, an improved approach for transfer fractions derivation was explored for greenhouse crops. The transfer fraction to air was made dependent on the vapour pressure of the PPP and the application method, replacing a fixed 9% with a input-dependent range of 1–27%. As a consequence, a larger or smaller fraction of the applied amount remains for the emission to water and soil. However, the emission to water is determined by the irrigation system with or without recirculation, which is not at all represented in the default value of 1%. Moreover, the emission to soil potentially does not occur because of drainage or cultivation on the substrate, resulting in an additional water emission through the irrigation system and significant levels of degradation. Hence it cannot be argued that the transfer fractions of 1% to water and 90% to soil are representative or even worst-case transfer estimates. The OLCA-pest project for protected agriculture focuses on protected agriculture for only a limited extent, but this is not certain. The EIP project will consider protected agriculture extensively.

Time frame and overlap of scope
Transfer fractions should consider only the primary distribution processes (in the first minutes to hours) in order to avoid overlap with USETOX, the impact assessment model. Such models consider the fate processes in the longer time frame (days to weeks) under their steady state assumptions.

Data demand
The scientific consensus recommendation from Rosenbaum et al. (2015) mentions a list of variables and themes for which data should be collected in the LCI phase. Not all themes have been operationalised into parameter descriptions. It is not entirely clear how application method or formulation type, presence of buffer zones, location/country, application time before harvest and crop growth stage during application, and adherence to good agricultural practice translate to the emission estimates. The OLCA-Pest project seems to be a result of the recommendation from this publication to establish default emission fractions to environmental media for integration into LCI databases. It is to be expected that the project will be of the best scientific state of the art.

The longlist of data for collection from Rosenbaum et al. might be too ambitious. On the intermediate Tier II level, perhaps three to six input variables could be collected to describe the agricultural system and the PPP properties, in addition to available data from USETOX and easily accessed PPP databases. It should be parameters that give the most useful differentiation and provide an action perspective to change to the grower. However, the feasibility of data collection in the context of the PEF initiative and the HortiFootprint project determines the choice of input variable more strongly than a limitation in the number of variables.

Conclusion

There are at least two promising developments that could yield Tier II transfer fractions and would be an significant improvement from the Tier I fixed fraction approach: the OLCA-Pest project and the EIP project. Both projects are not finished but will deliver their (first) results this year. Moreover, such results may be too complex to apply in the context of the HortiFootprint project and the PEF transition phase. They may need some simplification through the determination of default input variables. The EIP project aims to develop default input variables and a user-friendly interface. It is strongly recommended to align scientific developments such as in OLCA-Pest and the EIP project with practical needs from the PEF transition phase.

This transfer fraction method from the first phase of the HortiFootprint project reduces the uncertainty to a limited extent and requires further development and testing.

Because none of the explored methods has reached maturity, the current recommendation for the HortiFootprint category rules (Helmes et al., 2020) is to remain consistent but inaccurate with regards to transfer fractions and follow the recommendations from Zampori and Pant (2019) until a usable and scientifically recognised method becomes available.

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