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Bridging the gap between life cycle inventory and impact assessment for toxicological assessments of pesticides used in crop production

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HIGHLIGHTS

- A framework is provided to link life cycle inventory and impact assessment for pesticides.
- The framework prevents overlaps and gaps between LCI and LCIA modeling.
- Efficient and inefficient management practices can be distinguished.

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ABSTRACT

In Life Cycle Assessment (LCA), the Life Cycle Inventory (LCI) provides emission data to the various environmental compartments and Life Cycle Impact Assessment (LCIA) determines the final distribution, fate and effects. Due to the overlap between the Technosphere (anthropogenic system) and Ecosphere (environment) in agricultural case studies, it is, however, complicated to establish what LCI needs to capture and where LCIA takes over. This paper aims to provide guidance and improvements of LCI/LCIA boundary definitions, in the dimensions of space and time. For this, a literature review was conducted to provide a clear overview of available methods and models for both LCI and LCIA regarding toxicological assessments of pesticides used in crop production. Guidelines are provided to overcome the gaps between LCI and LCIA modeling, and prevent the overlaps in their respective operational spheres.

The proposed framework provides a starting point for LCA practitioners to gather the right data and use the proper models to include all relevant emission and exposure routes where possible. It is also able to predict a clear distinction between efficient and inefficient management practices (e.g. using different application rates, washing and rinsing management, etc.). By applying this framework for toxicological assessments of pesticides, LCI and LCIA can be directly linked, removing any overlaps or gaps in between the two distinct LCA steps.

1. Introduction

Over the last years, a significant number of Life Cycle Assessment (LCA) studies were conducted on agricultural products. Several of them are reported in scientific journals (e.g. Basset-Mens and Van der Werf, 2005; Mouron et al., 2006; Torrellas et al., 2012), but most of them are in the form of reports commissioned by stakeholders and oftentimes in the national language (e.g. Blonk et al., 2007; Schmidt, 2008; Weidema et al., 2008; Ademe, 2010). To perform such LCAs, a detailed inventory of all resources used and all emitted chemicals needs to be conducted. This includes an inventory of agricultural inputs and outputs, e.g. fertilizers and pesticides, that are of importance. Termed the Life Cycle Inventory (LCI), this phase supplies the amount of inputs used per functional unit, generally per kg of agricultural product or per hectare, but also assesses the amount of them emitted to each environmental compartment. Subsequently, in the Life Cycle Impact Assessment (LCIA) step, the chemical emissions are converted into impact scores for ecotoxicity and human toxicity.

For classic industrial applications, the flux exchanges between Technosphere, the studied anthropogenic system, and Ecosphere, the natural environment, can often be easily assessed because the system boundaries, e.g. factory walls boundaries, discharge pipes & chimneys are clearly defined. For agricultural applications, the boundaries between Technosphere and Ecosphere are not so easy to define. An agricultural field and its soil can be set to belong to the Ecosphere, as is done by e.g. Ecoinvent (Frischknecht et al., 2007), or the Technosphere, as is done by e.g. PestLCI (Dijkman et al., 2012). Furthermore, substance transfers between environmental compartments are complex. Given the unclear boundaries between Technosphere and Ecosphere in agricultural case studies

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it is complicated to establish what LCI needs to characterize regarding degradation and partitioning of the pesticides in air, water, and soil at the local scale, and where LCIA takes over, moving onto a larger temporal and spatial scale such as long-range transmission of air pollutants at regional, continental, and global scale. Up to now, LCA practitioners, who are often not even aware of the boundaries problem, have been using different hypotheses to build agricultural inventories. They apply, for example, a regional or global scale model of substances transfers in the LCI phase (e.g. EMEP/EEA, 2009), or they apply a simplified approach assuming that pesticides are entirely emitted to the soil compartment (Nemecek and Kägi, 2007; Panichelli et al., 2009), or that 85% is emitted to soil, 5% to crops, and 10% to air (Margni et al., 2002; Audsley et al., 2003). Previous framing and conceptualization of agricultural LCA focused on combining either LCI or LCIA inputs from various methods or applicable to various countries (e.g. Bentrup et al., 2004; Kah and Brown, 2007). To date, neither clear distinction nor guidance is provided on how to apply LCI and LCIA models so they link up with respect to toxicological assessments of pesticides applied in agriculture.

This paper aims to provide guidance to better define the boundaries between what should be included in LCI and where LCIA takes over. For this, we provide an overview of the possibilities of both LCI and LCIA methods regarding toxicological assessments of inputs used in crop production. Guidelines are provided to overcome the gaps between LCI and LCIA modeling and remove the overlaps, as well as to harmonize the comparisons of agricultural LCA results.

2. Current practice and available methodologies

2.1. From spraying to environmental damage: biophysical phenomena and farmers practices

When a pesticide is released into the environment during spraying, not the entire applied chemical reaches the target crop – for fungicides and insecticides, or weed – for herbicides). Different fractions are directly emitted to air (drift), soil, and, in some cases, surface water (Fig. 1), where non-target organisms can be affected. The amount of pollution depends on both the substance applied and the pesticide application practice. The latter is a combination of the technology used (type of sprayer and nozzles) and human practices, such as the type of equipment used and adjustment or timing of pesticide application depending on weather condition and the evolution of crop diseases. If this practice is efficient, i.e. applied at the correct dose directly where and when it is needed, damage is expected to be small. These drift water contaminations can be drastically reduced directly by the use of low drift equipment or indirectly by buffer zones, i.e. zones with grass or specific crops around the field, where spraying is prohibited (see Fig. 1) (De Snoo and De Wit, 1998). The buffer zones increase the distance that runoff water has to cover in order to reach watercourse. Furthermore, in the case of aerial spraying, buffer zones will catch over-sprays, leading to reduced environmental damage. Spraying by airplanes can cause pollution in areas outside the crop field via spray drift. This leads on the one hand to environmental damage in a larger area and on the other hand, if the phytosanitary efficacy is low, this increases the need for more pesticide treatments on the crop field. In addition to emissions during pesticide application, contaminations may occur before, during the preparation of the pesticide formulation while filling the sprayer tank, and after the treatment, by managing the mixture remaining in the sprayer tank and during washing and rinsing operations (Ramwell et al., 2007). The fate of pesticides packaging residues could also be a contributor to those impacts. These emissions can be drastically reduced by the use of integrated technologies, such as filling/washing areas associated with purification systems using a biological or physicochemical treatment (see e.g. De Wilde, 2009). In LCA, the aim is to identify average impacts, and not a worst case scenario. Therefore, it should be noted that contaminations due to inefficient behavior should only be included when appropriate data are available, i.e. actual data regarding these inefficient practices, or when the ultimate goal of the LCA is to compare agricultural practices.

Commercial pesticide products rarely consist only of their pure active substance, but are usually formulated with several other ingredients. Pesticide formulations have been developed to improve the efficiency of the active substance against pests, fungal diseases, and weeds. Surfactants are among the most important components used and can improve the biological activity by modifying spray droplet size, drift phenomenon, retention, and spreading on leaf surfaces or by enhancing immediate uptake and penetration of the active ingredient into the crops. Formulation may also improve the properties of a chemical for handling,

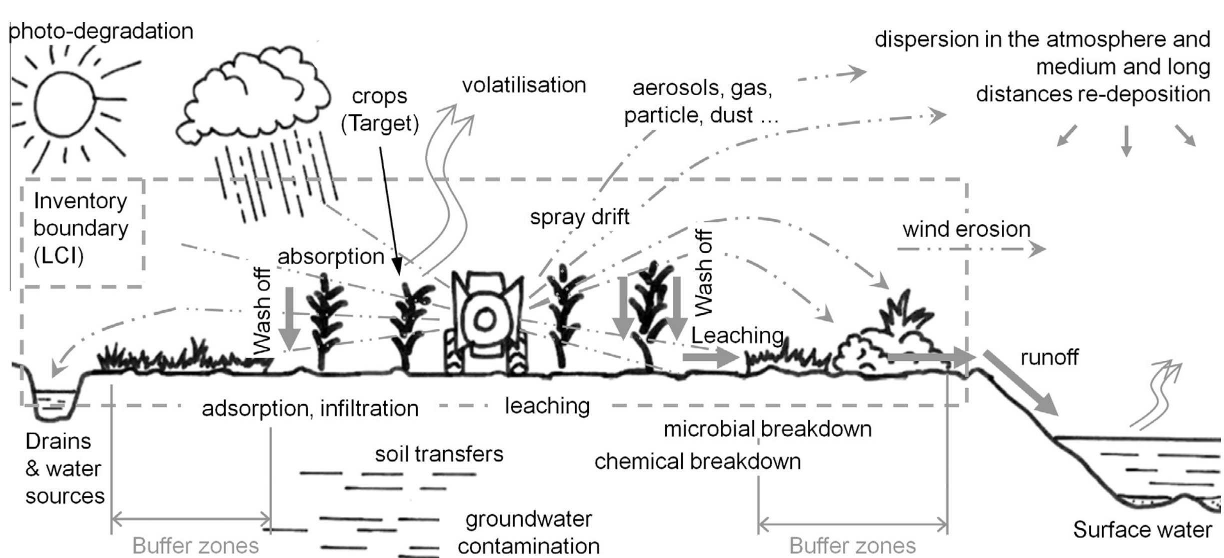

Fig. 1. Examples of transfer mechanisms from pesticide spraying to emissions in air, soil, and water.