Evaluation of plant protection strategies with LCA and risk assessment for five crops in Switzerland

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1. Introduction

The use of pesticides is increasingly debated due to unwanted side-effects on humans and the environment. To inform farmers how to reduce such side-effects, comparative assessments of risks and environmental impacts of different crop protection strategies are required. Life cycle assessment (LCA) is a method to quantify environmental impacts of products and services over their entire life cycle. LCA typically assesses average impacts on global or continental scale and over long-time periods. In contrast, risk assessment (RA) can evaluate maximum risks that local environments can be exposed to (e.g. field or catchment area). Therefore, a paralell application of LCA and RA can evaluate impacts and risks of crop protection strategies in a broader and more comprehensve spectrum.

In the present study, crop protection scenarios with different treatment intensity were analysed for five crops in Switzerland: rape seed, wheat, carrots, potatoes, and sugar beets [1]. The analysis was conducted with the two methods mentioned above, namely i) a detailed RA of the entire treatment sequences and ii) an evaluation of the ecotoxicity potentials of treatment sequences using LCA.

2. Materials and methods

For each crop, three crop protection scenarios were compared: the MEAN scenario represents an average treatment frequency, the HIGH scenario refers to a situation with frequent treatments, while the LOW scenario represents a reduced treatment frequency, according to the guidelines of the label organization IP-SUISSE. For each crop, the treatment frequency was based on the 50th and 75th percentile of the treatment frequency per pesticide category (e.g. insecticides) using a dataset from the Swiss agricultural environmental monitoring [2] for the MEAN and HIGH scenario, respectively. The LOW scenario was derived from the MEAN scenario, by taking the guidelines of IP-SUISSE into account, containing additional restrictions for pesticide application. All scenarios were validated by experts and adapted to represent realistic treatment sequeces, where needed.

For LCA, the transfer of pesticides into different environmental compartments was modelled with the pesticide consensus model, based on PestLCI [3]. To assess aquatic ecotoxicity, USEtox V2.02 [4] was applied; terrestrial ecotoxicity potentials were calculated using ReCiPe 2016. The analysis of the LCA results was carried out in two steps: first, only the impacts of pesticides were analysed for the cultivation of 1 ha of crop, in order to ensure a comparability with RA results. Second, a full LCA was conducted (functional unit 1 kg fresh product), including the entire life cycle (cradle to farm gate) of the crop (e.g. manufacturing and application of fertilisers, machinery etc.). Additional impacts were analysed (energy demand, abiotic resource depletion, global warming potential and terrestrial eutrophication) using the method Swiss Agricultural Life Cycle Assessment (SALCA) [5].

The RA was conducted with the model SYNOPS [6]. It allows a comparative evaluation of overall risks to the field-adjacent local environments and can be used for assessing individual treatments as well as entire treatment sequences. SYNOPS was used to model exposure and risks to various organism in surface waters, soil (in-crop) and terrestrial off-crop habitat (i.e. beneficial organisms and bees).

3. Results and discussion

In the first analysis step, we calculated ecotoxicological impacts of pesticides using LCA and compared these to RA. Generally, the scenario HIGH showed the highest impacts in all analysed crops, followed by MEAN and LOW (Tab. 1). The following factors can lead to a higher treatment frequency in the HIGH scenario: 1) annual variation, included in the definition of the scenarios, 2) less suitable site conditions (soil and climate) and 3) management regarding e.g. effect of cultivar, farming system, risk attitude of farmer. The LOW scenario showed substantially lower impacts and risks for wheat and rape seed, where fungicides, insecticides and growth regulators were completely omitted. With LCA, HIGH exhibited significantly higher effects for rape seed, potatoes and sugar beet than MEAN. With RA, the total risks were also clearly increased for HIGH in the case of wheat.

		Rape seed			Winter wheat			Carrots			Potatoes			Sugar beets		
		LOW	MEAN	HIGH	LOW	MEAN	HIGH	LOW	MEAN	HIGH	LOW	MEAN	HIGH	LOW	MEAN	HIGH
LCA	Aq. Ecotox.	20%	100%	1314%	0%	100%	101%	98%	100%	158%	77%	100%	188%	97%	100%	1475%
	Terr. Ecotox.	67%	100%	2554%	1%	100%	101%	99%	100%	120%	97%	100%	255%	90%	100%	3573%
SYNOPS	Aquatic organisms	25%	100%	406%	100%	100%	100%	100%	100%	135%	100%	100%	100%	100%	100%	165%
	Soil organisms	100%	100%	100%	88%	100%	100%	100%	100%	188%	82%	100%	101%	100%	100%	100%
	Off-crop habitats	0%	100%	100%	2%	100%	1678%	1%	100%	147%	24%	100%	100%	100%	100%	114%
	Aggregated risk	1%	100%	108%	98%	100%	120%	15%	100%	145%	96%	100%	100%	100%	100%	162%

Table 1: Relative aquatic ecotoxicity potentials (LCA) and risks (SYNOPS model) of pesticides for the five investigated crops (per ha of cultivated crop). Scenario MEAN set as 100%; greenish indicates relatively strong ecotoxicity potential and risk reductions and reddish indicates relatively strong to extremely strong ecotoxicity potential and risk increases.

As a rule, just a few active ingredients dominated the ecotoxicological environmental impacts and risks for both methods – LCA and RA. Forgoing the use of dominant active ingredients enabled a significant reduction of both ecotoxicity potentials and risks. The results for the different environmental compartments (water, soil, off-crop habitats) were partly very diverging. This underlines the necessity for a comprehensive coverage of environmental compartments.

In the second analysis step, a complete LCA was conducted. Taking other toxic substances than pesticides into account altered the results for aquatic ecotoxicity substantially. In all of the examined cases, pesticides accounted for less than half of the aquatic ecotoxicity potential, and heavy metals (mainly from fertilizers) were responsible for the bulk of the impacts. However, the assessment of the impacts of heavy metals is uncertain and remains a field for future research.

The methods used for the RA (SYNOPS) and LCA (PestLCI Consensus Model and USEtox 2.02) are based on different models and model assumptions; however, the use of these two complementary methods for the same issue allows several aspects to be taken into account simultaneously.

4. Conclusions

The parallel analysis of environmental impacts (LCA) and risks to the environment (RA) provides a more complete assessment and allows for a robust decision support. LCA assesses average long-term impacts over the whole life cycle, while RA focuses on maximum effects in the short-term, which are site- and context-specific. Thus, it supplements water and soil monitoring projects via the assessment of global long-term effects and the early detection of potential local risks. This study showed that a considerable reduction potential exists for pesticide treatment patterns, particularly for the situation with high treatment frequency. Only one or a few active ingredients dominated ecotoxicity impacts and risks. Avoiding these dominating active ingredients seems to be promising for mitigating ecotoxicological impacts. Furthermore, the study showed that it is necessary to consider all relevant environmental compartments and not to focus on water bodies alone. For aquatic ecotoxicity potentials assessed by LCA (USEtox method), pesticides contributed less than half in all scenarios, while heavy metals and other toxic substances were dominating.

5. References

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