LCAF-2018-07-00169

Assessing environmental impacts and risks of pesticide application in Swiss crops by combining LCA and risk analysis

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Abstract
The impacts on the environment and the ecotoxicological risks were assessed for five crops in Switzerland and three crop protection scenarios with low, mean and high treatment frequency. LCA and risk assessment were applied in parallel. A considerable reduction potential existed between the scenarios, particularly for the 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.

Keywords: *Crop protection; pesticide; ecotoxicity; LCA; risk assessment*

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Introduction

Pesticide application in agriculture is increasingly an issue of public concern. Policy makers and private stakeholders, such as label organisations, are striving to reduce the impacts and risks of pesticide applications for the environment. In the present study, different crop protection scenarios were analysed for five crops in Switzerland: rape seed, wheat, carrots, potatoes, and sugar beets. The assessment was conducted from two different perspectives, namely i)the calculation of the ecotoxicity potentials of treatment sequences by means of life cycle assessment (LCA), and ii) a detailed risk assessment of entire treatment sequences by means of the SYNOPS model.

For each of the crops, three crop protection scenarios were defined: the MEAN scenario represents an average cultivation practice, the HIGH scenario refers to a situation with frequent treatments, while the LOW scenario represents a cultivation practice according to the guidelines of the label organization IP-SUISSE. A detailed description of the study and the full results are reported by Waldvogel et al. (2018).

Material and methods

The crop protection scenarios were defined based on data from the monitoring programme of agri-environmental indicators (AEI data) of Agroscope for the years 2009-2014 (de Baan et al., 2015) and expert judgement. For each crop, the treatment frequency of the MEAN resp. HIGH scenario were based on the 50th resp. 75th percentile of the treatment frequency in the AEI data. For each treatment, the most commonly used active ingredient per pesticide category (e.g. insecticides) was chosen. The LOW scenario was derived from the MEAN scenario, by taking into account the guidelines of the label organization IP-SUISSE, which restricts pesticide application (e.g. no fungicides, insecticides or growth regulators in wheat and rape seed) and avoiding potentially problematic active ingredients. All scenarios were validated by experts from Agroscope and other institutions, and adapted, where needed.

As mentioned above, the assessment methodology was twofold: On the one hand, the environmental impacts were assessed by LCA methodology, which calculates average long-term impacts on continental and global scales. We applied USEtox V2.02 (Fantke et al., 2017) for the aquatic ecotoxicity and ReCiPe 2016 (hierarchist, Huijbregts et al., 2016) for the terrestrial ecotoxicity potentials. Hereby, the PestLCI Consensus Model was used to account for the transfer of pesticides into different environmental compartments as part of the life cycle inventory analysis. This model quantified the emissions in five environmental compartments: air, off-field surfaces, groundwater, agricultural soil, and deposition on the plant. The model was derived from PestLCI2.0 (Dijkman et al., 2012), and adapted in the pesticide consensus process (Rosenbaum et al., 2015).

On the other hand, the risks of pesticide applications to the environment were assessed with the SYNOPS model (**Syno**ptic Evaluation Model for **P**lant-Protection Products, Gutsche & Strassemeyer, 2007). This model 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. For each pesticide application, SYNOPS calculates the potential inputs into surrounding environmental compartments, accounting for the application conditions, the properties of the active ingredient, and the environmental conditions. Finally, the risk per active ingredient is calculated in each environmental compartment as an 'exposure/toxicity ratio' (ETR): the concentration of each active ingredient is divided by the toxicity of the active ingredient for various surrogate species. The risks of individual active ingredients are finally aggregated to enable the overall evaluation of a treatment sequence. Risks are calculated for surface waters, soil, and off-crop habitats (beneficial organisms and bees). The direct transport of active ingredients (by overspraying or drift) is calculated in all environmental compartments. Run-off, drainage and erosion are additionally modelled as entry pathways in surface waters. The model has been parametrized for Switzerland by defining 240 soil-climate-topography scenarios.

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 (reference flow: hectare and year), in order to ensure a comparability of risk assessment results (from SYNOPS) and LCA. This first analysis therefore excludes any impacts of upstream processes and of other processes than pesticide application (such as heavy metals from fertilizer). Second, the full LCA results were calculated with the functional unit of 1 kg of fresh product. This second analysis includes all other processes according to a life cycle approach, like manufacturing and application of fertilisers, manufacturing and use of machinery (including fuel), production of seed, etc. Furthermore, selected impacts were calculated in addition to ecotoxicity: energy demand, abiotic resource depletion, global warming potential and terrestrial eutrophication. For these calculations, the Swiss Agricultural Life Cycle Assessment (SALCA) method was applied (Nemecek et al., 2010).

Results

In the first analysis step, we calculated ecotoxicological impacts of pesticides using LCA and compared them to the risk assessment. Generally, the scenario HIGH showed the highest impacts in all analysed crops, followed by MEAN and LOW (Tab. 1); for some indicators the differences were very significant. 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 are completely omitted, whilst there was hardly any reduction for sugar beet. Whereas the risk in the off-crop habitats for LOW was considerably reduced in all crops but sugar beet, the risks for surface water were only sharply reduced for rape seed, and the risks for soil were slightly lower for wheat and potatoes. Ecotoxicity potentials and risks associated with HIGH were in some cases significantly increased compared to MEAN. For carrots and sugar beet, the effects with HIGH were slightly-to-strongly increased for both assessment approaches. With LCA, HIGH exhibited significantly higher effects for rape seed, potatoes and sugar beet than MEAN. With risk assessment, the total risks were also clearly increased for HIGH in the case of wheat.

The evaluation of eleven additional spraying sequences showed that in the majority of cases, the active ingredients ruled out in LOW had a higher ecotoxicity potential or risk than those allowed in LOW. Forgoing these active ingredients therefore proved to be an expedient measure in most cases.

As a rule, just a few active ingredients dominated the ecotoxicological environmental impacts and risks. For both methods – LCA and risk assessment – the dominant active ingredient was determined for each crop and spraying sequence. 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, and that extrapolation from one compartment to another is scientifically not sound.

In the second analysis step, a complete LCA was conducted. Taking other toxic substances than pesticides into account substantially altered the results for aquatic ecotoxicity. 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.

With other environmental impacts (energy demand, abiotic resource depletion, global warming potential and terrestrial eutrophication), the LCA results per kg of product of the three examined spraying sequences differed only slightly from one another, since the scenarios were chiefly characterised by the use of pesticide. Only for wheat and rape seed slightly higher environmental impacts were detectable, owing to the lower yields of the LOW scenario.

Discussion

The methods used for the LCA and risk assessment have methodological limitations, and are unable to reproduce the complex environment in every detail: for example, neither the chemical breakdown products of the active ingredients (metabolites) nor the risks to bird, mammal or human health were taken into account for either method in the present study. Owing to their different objectives, the methods used for the risk assessment (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.

Conclusions

The combined analysis of environmental impacts (LCA) and risks to the environment (SYNOPS) provides a more complete assessment and allows for a more robust decision support. LCA assesses average long-term impacts over the whole life cycle, while risk assessment 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.

Acknowledgement

This research was supported by the Federation of Migros Cooperatives. We acknowledge the active participation of IP-SUISSE in the definition of the scenarios.

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%.

		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%

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