Background information: Reduction of Environmental Impacts of Plant Protection Products Is Possible

Context and Purpose of Study

The use of plant-protection products (PPPs) in agriculture and the associated benefits and risks are currently highly debated. Current measurements point e.g. to high pollution levels in small Swiss streams in catchment areas of intensive agricultural use, and thus confirm the need for action. Food producers and retailers are also called upon to help provide solutions.

Against this backdrop, and mandated by the Migros Cooperative Association (MGB), Agroscope investigated the environmental impacts and risks of PPP use according to IP-SUISSE Guidelines as compared with PPP use according to the Proof of Ecological Performance (PEP). Five crops cultivated in Switzerland were studied: winter oilseed rape (OSR), winter wheat (WW), carrots (CAR), potatoes (POT) and sugar beet (SB). The assessment was conducted from two different perspectives, namely:

i) The calculation of the ecotoxicity potentials of PPP treatment sequences by means of life cycle assessments (LCAs);

ii) A detailed risk assessment of entire PPP treatment sequences by means of the SYNOPS model.

The aims of this study were:

- To quantify the potential for reducing ecotoxicity through application of the IP-SUISSE guidelines for selected crops;
- To determine the main contributions to ecotoxicological environmental impacts or risks where cultivation is according to IP-SUISSE guidelines and PEP, respectively.

In addition, an important sub-aim was to further develop the methodologies used, and to parametrise them for Swiss conditions.

Methods

With the LCA methodology and the SYNOPS risk-assessment method, two complementary approaches were chosen that allowed a comprehensive assessment of PPP use and created a robust basis for decision-making. On the one hand, the LCA provided a generic assessment of aquatic and terrestrial ecotoxicity, and furnished an impact assessment for all relevant environmental impacts, including the upstream and downstream stages, with reference to a functional unit (here, 1kg of harvested crop). On the other hand, the risk assessment enabled an estimate of the ecotoxicological risks of PPPs whilst taking into account site- and application-specific parameters.

Life Cycle Assessment

One model and two impact assessment methods were employed to calculate aquatic and terrestrial ecotoxicity potentials: The ***PestLCI Consensus Model*** was used to account for the transfer of PPPs 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 ***USEtox*** method, which quantifies the toxic effect on the ecosystem of an agent via characterisation factors, was used in the subsequent impact assessment with respect to water bodies. The EU recommends USEtox for the 'aquatic ecotoxicity potential' impact category. Terrestrial ecotoxicity potential was assessed with the 'ReCiPe 2016 (Hierarchist)' method.

In a first step, the ecotoxicity potentials of the PPP applications were assessed, and compared with the results of the risk assessment. In a second step, the LCA of the investigated scenarios was created, in order to highlight potential trade-offs. The analysis was conducted with the SALCA life cycle assessment method for the functional unit '1 kg of product' with the system boundary at the farm gate.

The report provides a representative illustration of the results for four environmental categories: (i) Terrestrial eutrophication; (ii) Global warming potential; (iii) Abiotic resource depletion; and (iv) Non-renewable energy demand. This approach enabled an assessment of the resource-, nutrient- and pollutant-related environmental impacts, as well as the determination of possible trade-offs between the environment impacts.

Risk Assessment

The ***SYNOPS*** model (= **Syno**ptic Evaluation Model for **P**lant-Protection Products) was used for the risk assessment. This model is suitable for a comparative evaluation of the environmental risks of individual treatments through to entire spraying sequences. For each PPP application, SYNOPS calculates the potential PPP inputs into surrounding environmental compartments, bearing in mind not only application conditions and properties of the active ingredient, but also the environmental conditions. Finally, the risk per active ingredient is calculated in each environmental compartment. For this, the toxicity of the active ingredient for various proxy organisms is compared with the active ingredient concentration, and a so-called 'exposure/toxicity ratio' (ETR) is calculated. To conclude, the risks of individual active ingredients are aggregated to enable the overall evaluation of a treatment sequence.

Risks can be calculated for three environmental compartments: 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 various environmental conditions in Switzerland (e.g. slope gradient or climate) were taken into account through the calculation of different environmental scenarios.

Scenarios Investigated

For each crop, three spraying sequences were defined and validated with the aid of experts:

- **PEPmean**: Corresponds to a 'typical' (i.e. common) spraying sequence based on PEP. For the definition of this spraying sequence, the average number of interventions per pesticide group (e.g. herbicides) and crop was calculated from the data furnished by the Central Evaluation of Agri-Environmental Indicators (AEI data) for 2009-2014. The most commonly used active ingredients in the spraying sequence were assumed in each case.

- **PEPhigh**: Reflects PEP farming under high pest, disease or weed pressure, and is based on the 75th percentile of the number of interventions per crop and pesticide group of the AEI data.
- **IP-SUISSE (IPS)**: Derived from the PEPmean spraying sequence, this spraying sequence was adapted for the crop in question according to the IPS guidelines by implementing bans and restrictions.[1]

For carrots, no AEI data were available, and the spraying sequences were defined with the aid of experts. Eleven supplementary spraying sequences were defined in addition to the above three spraying sequences in order to determine the effect of further active ingredients which are either banned by IP-SUISSE or require authorisation, but which are not among the most commonly used active ingredients, and were thus not taken into account in the standard spraying sequences.

The investigated spraying sequences do not cover the entire spectrum of possible PPP use in IPS and PEP farming of the five crops. Additional studies and calculations would be necessary in order to extend the statements of this project to all the registered active ingredients of these five crops. Moreover, various environmental scenarios were considered which differ in terms of slope gradient, climate, distance from body of water, and soil type. This allowed a wide range of site conditions to be taken into account.

Results

Below, we give an overview of the relative changes in ecotoxicological environmental impacts and risks of the IPS and PEPhigh spraying sequences vis-à-vis the reference spraying sequence PEPmean for the 'life cycle assessment' (LCA) and 'risk assessment' (RA) methods (Table 1). For the LCA, the aquatic and terrestrial ecotoxicity potentials was calculated without aggregation. For the risk assessment, three environmental compartments (water, soil and off-crop habitats) were considered separately, then aggregated.

Table 1: Relative change in the risks of the IP-SUISSE (IPS) and PEPhigh spraying sequences vis-à-vis PEPmean (reference) for the five crops studied, for evaluation via life cycle assessment (LCA) and risk assessment (RA). Dark-green = <50%; Light-green = 50%-90%; Orange = 111%-200%; Dark-red = >200%.

		OSR			WW			CAR			POT			SB		
		IPS	PEPmean	PEPhigh	IPS	PEPmean	PEPhigh	IPS	PEPmean	PEPhigh	IPS	PEPmean	PEPhigh	IPS	PEPmean	PEPhigh
RA	Water	25%	100%	406%	100%	100%	100%	100%	100%	135%	100%	100%	100%	100%	100%	165%
	Soil	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%
LCA	Water	20%	100%	1314%	0%	100%	101%	98%	100%	158%	77%	100%	188%	97%	100%	1475%
	Soil	67%	100%	2554%	1%	100%	101%	99%	100%	120%	97%	100%	255%	90%	100%	3573%

Potential for Reduction via Different PPP Strategies

According to the results of the risk assessment and the life cycle assessment, the IPS guidelines achieved a slight-to-very-significant reduction of the risk (RA) and of the ecotoxicity potentials (LCA) for all of the crops investigated, compared to an average management approach according to PEP (PEPmean). Winter oilseed rape chalked up an especially significant reduction with both assessment approaches, whilst there was hardly any reduction at all for sugar beet (Table 1).

[1] The guidelines for sugar beet were amended over the course of the project; however, it was no longer possible to take account of these changes in the present report.

For the life cycle assessment, IPS achieved a very high reduction for winter wheat, whilst there was only a slight reduction effect for potatoes (aquatic ecotoxicity) and sugar beet (terrestrial ecotoxicity).

Whereas the risk reduction in the off-crop habitats for IPS spraying sequences was high in all crops but sugar beet, the risks for bodies of water were only sharply reduced for winter oilseed rape, and the risks for the soil were slightly lower for winter wheat and potatoes.

Ecotoxicity potentials and the risks associated with the high pressure scenario (PEPhigh) were in some cases significantly increased compared to PEPmean. For carrots and sugar beet, the effects with PEPhigh were slightly-to-strongly increased for both assessment approaches. Moreover, with the life cycle assessment, PEPhigh exhibited significantly higher effects for winter oilseed rape, potatoes and sugar beet than PEPmean. With the risk assessment, the total risks were also clearly increased for PEPhigh in the case of winter wheat.

The evaluation of 11 additional spraying sequences showed that in the majority of cases, the active ingredients ruled out in IPS had a higher ecotoxicity potential or risk than those allowed in IPS. Forgoing these active ingredients therefore proved to be an expedient measure in most cases.

Determining the Dominant Active Ingredients

As a rule, just a few active ingredients dominated the ecotoxicological environmental impacts and risks. For both methods – LCA and RA – the dominant active ingredient was determined for each crop and spraying sequence. The results for the two methods differed significantly in some cases: for the RA, and with the ‘winter wheat’, ‘carrot’ and ‘potato’ crops, it was mainly active ingredients that also cropped up on the FOAG ‘List of Active Ingredients with Particular Risk Potential’ that dominated, whilst with the LCA, other active ingredients were often represented.

Forgoing the use of dominant active ingredients enabled a significant reduction of both ecotoxicity potentials and risks.

Taking Account of All Pollutants and Other Environmental Impacts in the Life Cycle Assessment

Taking other toxic substances in addition to PPPs into account in the calculation of the aquatic ecotoxicity potential substantially alters the results. In all of the examined cases, PPPs account for less than half of the aquatic ecotoxicity potential, and heavy metals are responsible for the bulk of the impacts. Nevertheless, there are major uncertainties when assessing heavy metal emissions (‘SALCA Heavy Metal’ model) and their ecotoxic effects with USEtox. Consequently, in future investigations the methods should be refined, and the role of heavy metals explored in greater detail. With other environmental impacts (energy requirement, abiotic resources, greenhouse potential and terrestrial eutrophication), the LCA results per kg of product of the three examined spraying sequences differ only slightly from one another, since the scenarios are chiefly characterised by the use of PPPs. Only with winter wheat and winter oilseed rape were slightly higher environmental impacts detectable, owing to the lower yields with IPS.

Conclusions

This study quantified the reduction potential from the application of the IPS guidelines, and identified the dominant active ingredients. In general, the ecotoxicity potentials and the risks from PPP use according to IPS guidelines were lower than for average management according to PEP. In the PEPhigh spraying sequence, the ecotoxicity potentials and the risks for the winter oilseed rape, carrot and sugar-beet crops with both methods (RA and LCA) were significantly higher than for PEPmean. With winter wheat, the only detectable difference between PEPmean and PEPhigh was with risk, whilst with potatoes only the ecotoxicity potentials were higher. Consequently, in order to keep the ecotoxicity potential and the risks as low as possible, it is important to apply the damage-threshold principle strictly and to refrain as far as possible from prophylactic PPP treatments. The study therefore shows that through the choice of active ingredient a significant reduction of ecotoxicological environmental impacts and risks can be achieved. Targeted bans on individual PPPs consequently enable considerable potential for reduction. The results for the various environmental compartments are in some cases similar, but in other cases entirely different. This means that the findings for one environmental compartment (water, soil, off-crop habitats) may not be applied to another without in-depth analysis. For the assessment of the environmental impacts and risks of PPPs, we therefore recommend focusing on achieving as complete a coverage of the environmental compartments in question as possible.

The calculation of the additional environmental impacts (energy requirement, abiotic resources, greenhouse potential and terrestrial eutrophication) revealed no trade-offs, with the exception of the effect of lower yields in the case of individual IPS crops.

For practitioners, a listing of the dominant active ingredients is of particular interest, since forgoing the use of these agents significantly reduces ecotoxicity potentials and risks in some cases.

The project enabled important methodological developments in the models used in the categories of life cycle assessment (PestLCI Consensus Model and USEtox) and risk assessment (SYNOPS), with a need for future research being identified.

The methods used for the risk assessment and life cycle 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 are taken into account for either method in the present study. Owing to their different objectives, 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.

This study makes an important contribution to the current discussion regarding the effects of PPPs on the environment. It supplements water and soil monitoring projects (e.g. through the Swiss Soil Monitoring Network (NABO)), via the assessment of long-term effects (LCAs) and the early detection of risks (risk assessment). The simultaneous assessment of environmental impacts via LCAs and of the environmental risks of PPPs via SYNOPs carried out here makes a comprehensive evaluation possible, thus offering a more robust basis for decision-making.

Full report: Waldvogel T., Mathis M., de Baan L., Haupt C., Nemecek T., 2018. Bewertung der Umweltwirkungen und Risiken verschiedener Pflanzenschutzstrategien für fünf Kulturen in der Schweiz. Agroscope Science 64, Agroscope, Zürich.

https://www.agroscope.admin.ch/agroscope/de/home/publikationen/suchen/agroscope-science.html

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