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Pesticide Substitution: Combining Food Safety with Environmental Quality

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1. Abstract

Various pesticides are authorized for use on agricultural food crops. Despite regulatory risk assessments aiming at ensuring consumer and environmental safety, pesticides contribute to human and environmental impacts. Guidance is needed to optimize pesticide use practice and minimize human and environmental exposure. Comparative pesticide substitution scenarios are presented to address this need. In a case study on wheat, different pesticides have been compared with respect to their substitution potential with focus on human health. Results demonstrate that health impacts can be reduced up to 99% by defining adequate substitution scenarios. Comprehensive scenarios need to also consider worker and environmental burden, and information on crop rotation, pest pressure, environmental conditions, application costs and efficacy. Such scenarios help to increase food safety and more sustainable use of pesticides.

2. Introduction

A large variety of pesticides and plant growth regulators are authorized in Europe and elsewhere for use on various agricultural food crops. Chemical risk assessments are being constantly conducted as part of the authorization procedure of pesticides, aiming to ensure occupational, consumer and environmental safety. However, the use of agricultural pesticides nevertheless contributes to the global human disease burden, mainly via occupational and bystander exposure, but also via consumer exposure to crop residues [1, 2]. Moreover, pesticides can escape agricultural fields via wind drift, run-off events and leaching through the field soil column, thereby also contributing to contamination of groundwater and non-target ecosystems [3, 4]. Farmers growing food crops can optimize their pesticide use in every-day practice to minimize human and environmental impacts, but guidance for such optimization is currently missing. Thereby, comparative approaches from life cycle impact assessment (LCIA) are required to look beyond arbitrary safety limits toward true risk minimization. In this study, we aim at introducing comparative substitution scenarios combining crop-specific pesticide amounts applied with pesticide-specific toxicity potentials for humans, as such substitution scenarios can help to characterize and minimize consumer health burden from pesticide use and can be extenced to include other aspects, such as occupational and environmental health [5].

3. Methods

First, human health impacts of several hundred pesticides were quantified, and residues in food crops grown and harvested for human consumption were identified as main contributor to overall human exposure toward agricultural pesticides for the general population for most pesticide-crop combinations [6]. Modeled crop residues were compared against measurements in several case studies showing (a) that modeled data are generally well in line wiht measured data and (b) that with the assumptions of typical application times and amounts (compared to worst-case assumptions as in risk assessment), residues are typically below regulatory maximum residue limints (MRL) [5, 7-9].

Further analyzing a subset of pesticides that are used in Europe, however, shows that only 10% of all considered pesticides applied to grapes/vines, fruit trees, and vegetables account for 90% of total annual human health impacts of around 2000 disability-adjusted life years [2]. Main aspect driving crop residue dynamics and parameter uncertainty is thereby pesticide dissipation from crops, for which data quality has subsequently been significantly improved based on fitting 4500 measured dissipation data points [10]. Exposure to crop residues has then been implemented in current LCIA methods as input for developing and evaluating comparative substitution scenarios with the aim to simultaneously improve the growing need for food safety, meet environmental quality targets and guide farmers to optimize agricultural practice with respect to pesticide use. In a case study on wheat, different pesticides have been finally compared with respect to their substitution potential with focus on consumer health as one of several performance indicators for pesticide substitution.

	scenario	pesticide	target pests***				m_{app}	$IS_{substance}$	IS_{class}	θ_{IS}
insecticides			A	B	C	D				
	#1	β-cyfluthrin	x	x	x		13.75	2.3E-09	1.5E-06	100%
		carbaryl		x	x	x	1.48	1.5E-06		
	#2	cyhalothrin	x	x	x	x	0.008	2.6E-09	2.6E-09	0.2%
		esfenvalerate		x	x	x	0.012	2.6E-11		
	#3	α-cypermethrin	x	x	x	x	0.015	2.3E-12	7.3E-12	<0.1%
		deltamethrin	x	x	x	x	0.009	5.0E-12		
fungicides			E	F	G	H				
	#1	cyproconazole	x	x	x	x	0.08	6.7E-05	6.9E-05	100%
		azoxystrobin	x	x	x	x	0.238	2.1E-06		
	#2	epoxiconazole	x	x	x	x	0.125	1.3E-05	1.3E-05	18.4%
		pyraclostrobin	x	x	x	x	0.175	2.0E-08		
		fenpropimorph		x	x	x	0.45	6.6E-12		
	#3	tebuconazole		x		x	0.219	9.7E-09	8.7E-07	1.3%
		chlorothalonil	x	x	x		1.5	7.4E-07		
		mancozeb	x	x	x		2.35	1.2E-07		
herbicides			J	K	L	M				
	#1	pendimethalin	x	x			1.4	8.7E-12	2.0E-11	100%
		fenoxaprop-p	x		x		0.069	1.1E-11		
		prosulfocarb	x	x		x	3.5	1.0E-19		
	#2	iodosulfuron		x	x		0.01	7.5E-16	7.6E-16	<0.1%
		propoxycarbazone-sodium	x			x	0.05	3.8E-18		
	#3	glyphosate	x	x	x	x	1.37	8.8E-22	8.8E-22	<0.1%

Table 1: Overview of tested scenarios with pesticides, target species, mass applied m_{app} [kg/ha], impact score per pesticide $IS_{substance}$ [DALY/ha], impact score aggregated over target class IS_{class} [DALY/ha], and relative impact score θ_{IS} normalized to scenario #1 for three pesticide substitution scenarios on wheat.
*** A: wheat bulb fly (Delia coarctata), B: cereal leaf beetle (Oulema melanopa), C: aphids (Aphidoidea), D: thrips (Thysanoptera), E: septoria leaf blotch (Mycosphaerella graminicola), F: wheat leaf rust (Puccinia triticina), G: wheat yellow rust (Puccinia striiformis), H: powdery mildew (Blumeria graminis f. sp. Tritici), J: slender meadow foxtail (Alopecurus myosuroides), K: annual meadow grass (Poa annua), L: common wild oat (Avena fatua), M: couch grass (Elytrigia repens).

4. Results and Discussion

In the substitution case study, it is demonstrated that for a function-based evaluation of pesticides cosumer health impacts can be reduced up to 99% by defining adequate substitution scenarios. Table 1 summarizes the information for the three scenarios of substituting a mix of (a) insecticides, (b) fungicides and (c) herbicides based on the combination of applied dose and human toxicity potential. Data on the common wheat pests are derived from [11, 12]. We recommend that such scenarios further include occupational and environmental burden, combined with information on crop rotation, pest pressure, environmental conditions, pesticide authorization, and pesticide-specific application costs, efficacy, and finally application practice as function of local conditions and national regulations.

5. Conclusion

It was demonstrated that substitution scenarios can be used as a powerful tool to evaluate different authorized pesticide combinations with respect to relevant performance indicators, such as human health. Guidance can be based on LCIA-based comparative assessment methods, using aggregated metrics (such as DALY) to comparatively incorporate multiple indicators, and integrating all relevant aspects influencing agricultural pesticide use, fate and exposure into a consistent set of pesticide use scenarios. With that, it will be possible for farmers to optimize their day-to-day pesticide use practice with focus on minimizing health and environmental impacts. Such substitution scenarios, hence, can contribute to ensuring a world with increased food safety and a more sustainable use of pesticides, thereby acknowledging pesticide regulations, spatiotemporal differences in pesticide use and efficacy and farming conditions.

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