Aquatic risk assessment of agricultural and residential uses of pyrethroid insecticides in the US: an overview

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Introduction

The Pyrethroid Working Group (PWG) is conducting a higher-tier ecological risk assessment for 9 synthetic pyrethroid insecticides in support of U.S. registration review. Many elements of the assessment are presented in other posters in this symposium. This poster provides an overview of the PWG assessment, including the conceptual model, aquatic toxicity and ecological effects, and refined aquatic exposure modeling.

Standard worst-case screening level assessments for pyrethroids indicate potential concerns for some aquatic taxa, but stepwise refinements in exposure and effects analysis indicate lower risk. These refinements address the unique properties of pyrethroids, especially their exceptionally high hydrophobicity. The extensive ecotoxicity database for pyrethroids, including mesocosms as well as single-species tests, supports a detailed evaluation of potential ecological effects. Similarities in environmental fate and toxicity among pyrethroid active ingredients justify increased confidence in risk assessment conclusions. This poster uses the assessment for deltamethrin as an example.

Conceptual Model of Pyrethroid Behavior

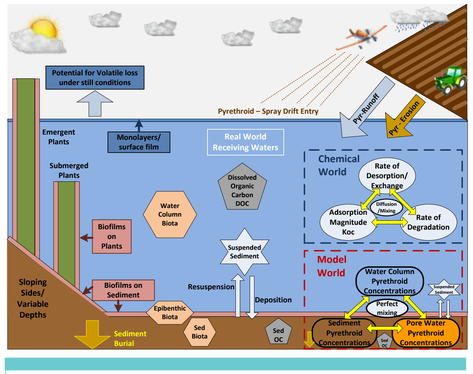
The environmental behavior of pyrethroids is dominated by their exceptionally high hydrophobicity. Pyrethroids in runoff and in receiving water bodies are mainly associated with particulate and dissolved organic matter. Thus, accurate characterization of partitioning and simulation of sediment movement are necessary for estimation of aquatic exposure and potential effects.

The applicability of equilibrium partitioning (EqP) to pyrethroids is well established. Only freely dissolved pyrethroid is bioavailable and contributes to toxicity to aquatic biota. Toxicity to sediment-dwelling organisms is a function of freely dissolved pyrethroid concentration in the sediment pore water. Pyrethroid toxicity to water column biota is reduced by partitioning to suspended particles and dissolved organic matter.

Another key factor affecting pyrethroids is their potential for rapid biodegradation and hydrolysis. This differentiates pyrethroids from many other hydrophobic chemicals such as PCBs and PAHs. Pyrethroid degradation products are non-toxic.

Other factors influencing pyrethroid behavior include adsorption to aquatic plants and biofilms (with subsequent biodegradation and hydrolysis in the high-pH microzone around plant surfaces), volatile losses from surface monolayers, and imperfect mixing within water bodies.

Despite their high lipophilicity, the rapid metabolism and elimination of pyrethroids by animals results in low bioconcentration factors and minimal transport through the food web.



Pyrethroid Uses

Pyrethroids are labeled for a wide variety of agricultural applications and for outdoor residential uses. The principal agricultural uses are shown in the table below. (Source: GfK Kynetec AgroTrak Database)

Crop	Acres treated with any pyrethroid (2012)	% of acres treated with any pyrethroid (2012)
Corn	12,002,940	13%
Soybeans	9,791,192	13%
Cotton	3,486,010	28%
Alfalfa	3,100,540	17%
Vegetables	2,873,914	47%
Wheat, Spring	2,097,915	15%
Wheat, Winter	1,763,525	5%
Tree Nuts	1,371,783	68%
Sunflower	1,186,330	64%
Rice	851,315	32%
Sweet Corn	709,606	128%
Citrus	661,436	79%
Peanuts	582,355	41%
Other Crops	2,095,443	19%

Additional information about the pyrethroid risk assessment is provided in other posters and platform presentations at this IUPAC Conference: 213, 214, 215, 216, 219, 220, 223, 224, 371, 377, 378, 654, 758, 757, 758, 759, 760, 765, 785, 885, 950, and 951.

Exposure Analysis

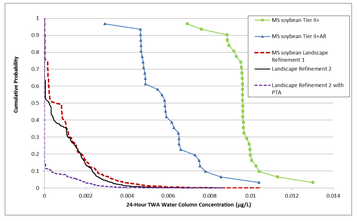
The pyrethroid exposure analysis was based on the standard USEPA farm pond scenario (1-ha pond receiving runoff and drift from a 10-ha field). After a baseline analysis using standard USEPA Tier II modeling tools (PRZM/EXAMS), EXAMS was replaced by AGRO-2014 to better simulate the fate of exceptionally hydrophobic compounds in the receiving water. Additional refinements for agricultural and residential uses are outlined below.

Agricultural Uses

Tier II+: In addition to replacing EXAMS with AGRO-2014, incorporated the vegetative filter strip, ground and aerial no-spray buffers, and droplet size drift mitigations that are required on all pyrethroid labels.
Tier II+AR: Incorporated timing and application method (air/ground) reflecting agronomically realistic practices, still maintaining the maximum application rate and number of applications per season.
Landscape Refinement 1: Refined Tier II+AR output by incorporating national distributions of percent cropped area (PCA) across NHD+ catchments where the crop of interest is grown.
Landscape Refinement 2: Incorporated national distributions of runoff/erosion vulnerability across NHD+ catchments based on site-specific soil and climate.

Additional factors affecting pyrethroid exposure potential were also examined. For example, the assumption that 100% of the crop of interest is treated with pyrethroid was refined using actual data on percent treated area (PTA) for each crop. Likewise, the assumption that multiple applications are always made at times of maximum permissible wind speed was explored using site-specific weather data.

Output of modeling at Tier II+ and Tier II+AR consisted of 30-year time series of pyrethroid concentrations in the water column, pore water, and bulk sediment, from which the 90th percentile (1-year-in-10) maximum annual estimated exposure concentrations (EECs) were derived. Output from Landscape Refinement 1 consisted of probability distributions for 30-year time series at each of 10 PCA values representing the national distribution of PCA for the crop of interest. Output from Landscape Refinement 2 consisted of 30-year time series for each of 110 combinations of PCA and runoff/erosion vulnerability. The influence of each refinement on EEC distributions for deltamethrin use on soybeans is illustrated in the figure at right.



Residential Uses

USEPA's SWMM model was coupled with AGRO-2014 for refined assessment of aquatic exposure from residential uses. SWMM simulates end-of-pipe chemical concentrations from urban watersheds, analogous to use of PRZM for agricultural runoff. SWMM was calibrated using pyrethroid monitoring data for a high density residential area in California, and the same scenario was applied to 6 other regions throughout the US. Pyrethroid use was based on surveys of professional pesticide applicators in each region, and the simulations incorporated recent regulations limiting the treatment of impervious surfaces to reduce runoff.

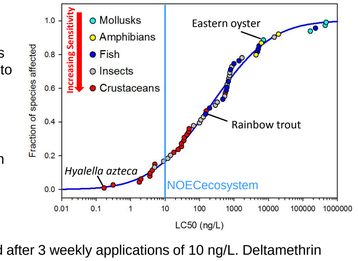
Monitoring Data

Pyrethroid monitoring data for surface water and sediment throughout the US (~35,000 analyses in ~7300 samples) indicated that concentrations predicted by exposure modeling are rarely if ever observed. This finding is especially significant in light of the fact that many monitoring programs target sites and events when pesticide concentrations are highest, such as in agricultural drains and storm water sewers during runoff events.

Effects Analysis

A large body of aquatic toxicity data exists for pyrethroids, especially deltamethrin. All pyrethroids are most toxic to arthropods such as insects and crustaceans, much less toxic to fish and amphibians, and non-toxic to mollusks and plants. The species sensitivity distribution (SSD) for deltamethrin is shown in the figure at right. These trends are highly consistent across all pyrethroid active ingredients.

Toxicity in sediment is a function of freely dissolved pyrethroid in pore water. Pore water toxicity was estimated from sediment toxicity based on Koc values determined under toxicity test conditions using solid phase micro-extraction (SPME), which measures the freely dissolved fraction. Pore water toxicity concentrations were in the same range as toxicity in water alone, consistent with EqP (see Conceptual Model).



Mesocosm studies showed that no ecologically adverse effects occurred after 3 weekly applications of 10 ng/L. Deltamethrin disappeared from the water column much more rapidly (half-lives 1 to 14 h) than in laboratory studies that were the basis for exposure modeling. No adverse indirect effects were observed on higher trophic levels. Bioassessments in several California streams confirmed that benthic macroinvertebrate community structure is not correlated with pyrethroid concentrations.

Risk Characterization

Risk Quotients

Risk Quotients (RQs) are used to compare exposure and toxicity (RQ = EEC/toxicity endpoint). RQs are based on 90th percentile EECs (from the probability distributions in each tier) and toxicity endpoints representing the most sensitive fraction of species (lowest LC50 or NOEC, or HC5), and are therefore inherently highly protective. RQs are compared with regulatory Levels of Concern (LOCs) to characterize risk. USEPA uses LOC = 0.05 for acute risk to endangered species, 0.5 for acute risk to non-endangered species, and 1 for chronic risk.

RQs for deltamethrin at each tier of the risk assessment are shown in the table below for soybeans and residential use (CA). RQs for plants, mollusks, and fish are near or below the LOC even at the lower tiers. RQs for arthropods exceed the LOC at Tier II, but decline with refinement of the exposure estimates at higher tiers.

Risk Quotients for deltamethrin: soybeans and CA residential use

KEY
RQ < LOC for listed species
RQ < LOC for non-listed species
RQ < 2x LOC
RQ > 2x LOC

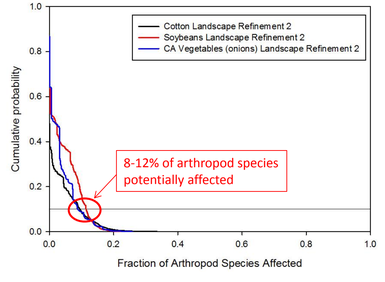
[a] Freshwater
[b] Saltwater

	Plants	Mollusks	Fish			Arthropods (Insects and Crustaceans)			
Soybeans			Acute	Chronic FW[a]	Chronic SW[b]	Acute water	Chronic FW	Chronic SW	Pore Water
Tier II	<0.01	<0.01	0.35	0.50	0.35	319	3.1	18	7.5
Tier II+	<0.01	<0.01	0.08	0.13	0.09	13	1.4	7.6	1.2
Tier II+AR	<0.01	<0.01	0.07	0.14	0.10	10	0.98	5.5	1.3
LR1	<0.01	<0.01	0.02	<0.01	<0.01	3.4	0.31	1.8	0.33
LR2	<0.01	<0.01	0.01	<0.01	<0.01	3.1	0.31	1.7	0.13
LR2+PTA	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	0.01	0.049	<0.01
Residential (CA)									
Tier II	<0.01	0.02	1.3	1.4	0.98	1170	8.6	48	15
SWMM-AGRO	<0.01	<0.01	0.01	0.03	0.02	1.7	0.18	0.99	0.17

Joint Probability Curves Combine EEC Distributions with SSDs

Joint Probability Curves (JPCs) depict the magnitude and likelihood of effect, using all available toxicity data. The assemblage of tested species is considered a surrogate for an aquatic community, and the effect on the community is expressed as the fraction of species affected. "Affected" in this case means the EEC exceeded the LC50 for at least 24 hours. JPCs were recommended by ECOFRAM (1999) for risk characterization in probabilistic risk assessments.

For deltamethrin, JPCs generated from the EEC distributions at Landscape Refinement 2 (figure at right) indicate that for these 3 crops, 8 to 12% of arthropod species may potentially be affected in 10% of water body years in catchments that contained the crop between 2008 and 2012.



Uncertainty Analysis

Evaluation of uncertainties in the landscape and model inputs suggest that the refined exposure estimates and RQs remain highly conservative, probably by at least an order of magnitude.

Conclusions

This tiered aquatic risk assessment shows that deltamethrin exposure from residential and agricultural uses according to current labels is unlikely to cause ecologically significant effects in aquatic systems. This conclusion is supported by results from mesocosm studies and bioassessments. The same approach is now being applied to 8 other synthetic pyrethroids. Results to date are consistent with the expectation (based on the similarities in physical-chemical and environmental fate properties and toxicity) that the conclusions for deltamethrin also apply to the other pyrethroids.

Acknowledgements

The Pyrethroid Working Group (PWG) is a US task force whose members include eight primary pyrethroid registrants (AMVAC Chemical Corporation, BASF Corporation, Bayer CropScience LP, Cheminova A/S, DuPont Crop Protection, FMC Corporation, Syngenta Crop Protection, LLC, Valent U.S.A. Corporation).