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Mitigation of two pyrethroid insecticides in a Mississippi Delta constructed wetland☆

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A wetland length of 215 m × 30 m mitigated pyrethroid runoff from a 14 ha field.

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ABSTRACT

Constructed wetlands are a suggested best management practice to help mitigate agricultural runoff before entering receiving aquatic ecosystems. A constructed wetland system (180 m × 30 m), comprising a sediment retention basin and two treatment cells, was used to determine the fate and transport of simulated runoff containing the pyrethroid insecticides lambda-cyhalothrin and cyfluthrin, as well as suspended sediment. Wetland water, sediment, and plant samples were collected spatially and temporally over 55 d. Results showed 49 and 76% of the study's measured lambda-cyhalothrin and cyfluthrin masses were associated with vegetation, respectively. Based on conservative effects concentrations for invertebrates and regression analyses of maximum observed wetland aqueous concentrations, a wetland length of 215 m × 30 m width would be required to adequately mitigate 1% pesticide runoff from a 14 ha contributing area. Results of this experiment can be used to model future design specifications for constructed wetland mitigation of pyrethroid insecticides.

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1. Introduction

In 2001, the world market for pesticides was nearly $32 billion, with insecticides making up 28% of those expenditures (Kiely et al., 2004). Over 340 million kg of conventional pesticide active ingredient were used in US agricultural applications that same year (USEPA, 2004). Lambda-cyhalothrin [λ-cyano-3-phenoxybenzyl-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethyl cyclopropanec arboxylate] is a fourth generation pyrethroid insecticide sold under such trade names as Karate®, Matador®, Grenade®, and Sentinel® (EXTOXNET, 1996) (Table 1). In 2002, it was the third most commonly applied pyrethroid insecticide in the US with over 117,000 kg active ingredient used (Gianessi and Reigner, 2006). From 1991 to 2000, over 58,000 kg of active ingredient were applied to corn (*Zea mays*), cotton (*Gossypium hirsutum*), soybeans (*Glycine max*), rice (*Oryza sativa*), and wheat (*Triticum aestivum* L.) (USDA, 2004). Cyfluthrin [cyano (4-fluror-3-phenoxy-phenyl) methyl 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate] is also a fourth generation pyrethroid insecticide (Table 1). Sold under the trade name Baythroid®, over 67,000 kg of active ingredient were applied in the US in 2002 (Gianessi and Reigner, 2006). Primarily used on cotton and corn, over 43,000 kg of active ingredient cyfluthrin were used in the US between 1991 and 2000 (USDA, 2004).

Although pesticides have been used for centuries, dating back to at least ancient Rome, little public concern over potential non-target effects existed until the 1962 publication of Rachel Carson's *Silent Spring* (Delaplane, 2000). Since that time, intense scrutiny has been placed not only on the pesticide industry, but also on the impacts of pesticide usage upon water quality of the US. Organochlorine insecticides, credited for many problems highlighted by Carson were eventually phased out, replaced by organophosphates. Although still in use, organophosphates are being replaced by the more efficient pyrethroid class of insecticides (Amweg et al., 2006). Even with advancements in pesticide chemical properties, USEPA (2007) data reported over 1300 water bodies in the US were listed as impaired due to pesticides.

While some have advocated elimination of pesticides across the board, studies have indicated the dire consequences of such action. Oerke et al. (1994) estimated declines in crop yields by as much as 50% without the use of pesticides. Knutson et al. (1990) suggested the significant decline in crop production may result in increased acreage to compensate for production, increased food expenditures, and increased inflation. Such a need for increased

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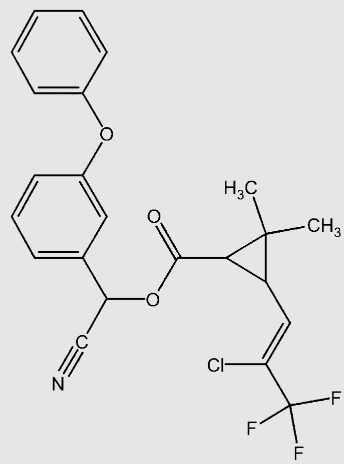
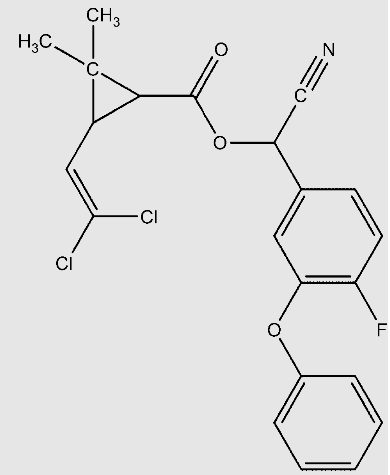
Table 1
Physical and chemical properties of lambda-cyhalothrin and cyfluthrin

	Lambda-cyhalothrin	Cyfluthrin
Structure[a,b]		
Molecular weight[a,b]	449.9	434.29
Water solubility (mg/L)[a,b]	0.005	0.002
Vapor pressure (mm Hg at 25°)[b,d]	1.5×10^{-9}	3.24×10^{-8}
K_{OW}[c,d]	10,000,000	4.58×10^{5}–6.4×10^{5}
K_{OC}[b,c]	180,000	62,400
Hydrolysis ($t_{½}$) (d)[a,b]	233.1	193 (25 °C at pH 7)

[a] Casjens (2002).
[b] EXTOXNET (1996).
[c] Schroer et al. (2004).
[d] Hand et al. (2001).

crop acreage would put a strain on the intensively cultivated Mississippi Delta's agricultural ecosystem. To balance the value of pesticide usage yet maximize environmental safety, management practices targeting mitigation of pesticide runoff have been developed.

Constructed and natural wetlands have been successful in mitigating runoff associated with agricultural pesticides (Wolverton and Harrison, 1973; Higgins et al., 1993; Rodgers et al., 1999; Moore et al., 2002; Schulz et al., 2003a,b; Schulz, 2004). One of the three critical aspects of constructed mitigation wetlands is the presence of vegetation. Benefits of plants include physical filtration, surface area for microbial attachment, and stabilization of bed sediments (Brix, 1994). Wetland plant organic matter may also aid in mitigation by increasing the potential transfer of pesticides from the water column to plant material (Moore et al., 2007). The objective of this research was to evaluate the use of a constructed wetland system in the Mississippi Delta, USA, for mitigating lambda-cyhalothrin and cyfluthrin concentrations associated with a simulated storm runoff event.

2. Methods

2.1. Study site description

Beasley Lake (Sunflower County, Mississippi, USA) is a 25 ha oxbow lake surrounded by 850 ha of land within the watershed (Locke, 2004). In 2003, a constructed wetland system (180 m × 30 m), comprised a sediment retention pond and two individual cells, was established adjacent to the lake (Weaver et al., 2004; see Moore et al. (2007) for schematic diagram). Dominant vegetation included *Cyprus iria* (rice field flatsedge), *Sorghum halepense* (johnsongrass), *Digitaria ischaemum* (small crabgrass), *Polygonum lapathifolium* (pale smartweed), and *Alternanthera philoxeroides* (aligatorweed) (Weaver and Zablotowicz, 2004). To facilitate collection of water, sediment, and plant samples, 10 stations at distances from inflow of 1 (site 1), 10 (site 2), 15 (site 3), 30 (site 4), 60 (site 5), 85 (site 6), 90 (site 7), 120 (site 8), 150 (site 9), and 170 m (site 10) were established within the constructed wetland system (Moore et al., 2007).

2.2. Simulated storm runoff event

Simulated storm runoff was introduced to the constructed wetland system in July 2003. Karate™ (19 g lambda-cyhalothrin active ingredient total), Baythroid™ (79.5 g cyfluthrin active ingredient total), 568 L of suspended sediment slurry (inflow suspended sediment concentration of 403 mg/L), and surface water from Beasley Lake (Table 2) were mixed together in a 7570 L chamber for 1 h prior to actual amendment into the sediment retention pond of the wetland system for four consecutive hours. During the 4-h amendment, lake water was also constantly added to the wetland system via the sediment retention pond. Amount of pesticides used was based on the recommended application rates (0.12 kg lambda-cyhalothrin/ha; 0.57 kg cyfluthrin/ha); wetland contributing acreage (14 ha); and assumed 1% pesticide runoff (Wauchope, 1978). Simulated rainfall contributions to the storm event were based on a 1.3 cm event, with assumed rainfall runoff of 50% (~917,000 L). Source water from Beasley Lake was transported via pump into the wetland system at a rate of approximately 3800 L/min for 4 h in order to complete the simulated runoff event.

2.3. Collection of water, sediment, and plant samples

Grab samples of wetland water were collected in 1-L amber glass bottles at 15 min intervals for the first hour, then again at 0.06, 0.08, 0.13, 0.17, 0.38, 1, and 2 d

Table 2
Pesticide concentrations (μg/L) in Beasley Lake source water (from Moore et al., 2007)

Sample collected	Pesticide 5/19/03
Atrazine	0.227
Methyl parathion	0.015
Metolachlor	0.011
Chlorpyrifos	0.000
Cyanazine	0.002
Fipronil	0.011
Fipronil sulfone	0.001
pp′-DDE	0.002
pp′-DDD	0.003
pp′-DDT	0.014
Chlorfenapyr	0.004
Bifenthrin	0.006
Lambda-cyhalothrin	0.002