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Short communication

Transport and fate of atrazine and lambda-cyhalothrin in an agricultural drainage ditch in the Mississippi Delta, USA

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Abstract

Drainage ditches are integral components of agricultural production landscape, yet their contaminant mitigation capacity has been scarcely examined. If ditches are indeed capable of contaminant mitigation, then their use may serve as an alternative agricultural best management practice (BMP). A 50 m portion of an agricultural drainage ditch, located in the Mississippi Delta Management Systems Evaluation Area (MDMSEA), USA, was amended with a mixture of water, atrazine (2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine) (herbicide) and lambda-cyhalothrin (λ-cyano-3-phenoxybenzyl-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethyl cyclopropanecarboxylate) (insecticide), simulating a storm runoff event. Pesticide amendment was achieved using a diffuser to disperse the mixture at an inflow point along the ditch (designated as "0 m"). Pesticide concentrations in water, sediment, and plants were monitored for 28 days. One hour following initiation of simulated runoff, mean percentages of atrazine concentrations measured in water and sediment were 37 and 2%, respectively, while mean percentages of lambda-cyhalothrin concentrations in water and sediment were 12 and 1%, respectively. Atrazine and lambda-cyhalothrin mean percentage concentrations in plants (*Polygonum* (water smartweed), *Leersia* (cutgrass), and *Sporobolus* (smutgrass)) were 61 and 87%, respectively. Therefore, plants serve as an important site for pesticide sorption during runoff events. Aqueous concentrations of both pesticides decreased to levels which would not elicit non-target toxicological effects by the end of the 50 m portion of the drainage ditch. This research provides fundamental answers concerning the capability of vegetated agricultural drainage ditches to mitigate pesticide-associated storm water runoff. Published by Elsevier Science B.V.

Keywords: Atrazine; Lambda-cyhalothrin; Ditches; Mitigation; Mississippi Delta

1. Introduction

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine) is one of the most intensively used herbicides in North America, with over 24 million kg applied to the United States corn (*Zea mays* L.) crop alone (Solomon et al., 1996; USDA, 1999). Some 61,000 kg of lambda-cyhalothrin (λ-cyano-3-phenoxybenzyl-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethyl cyclopropanecarboxylate), a pyrethroid insecticide, was applied to 19% of the nation's 1998 upland cotton (*Gossypium* sp.) crop. The lower

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Mississippi Delta states of Arkansas, Louisiana, and Mississippi accounted for approximately 47% of this usage (USDA, 1999). Public concern over the presence of these and other pesticides in surface and ground water has resulted in intensive scientific efforts to find economical, yet environmentally-sound solutions to the problem. This research suggests utilizing current agricultural landscape features (e.g. drainage ditches) for mitigation of pesticides associated with storm water runoff.

Drainage ditches are an integral component of the agricultural production landscape, particularly in the Mississippi Delta region of the United States. Most agricultural fields are surrounded by a network of ditches, whose purpose is to promote field drainage and reduce flooding on production acreage. In the past, the value and function of such marginal land has been generally ignored; however, due to their crucial role in transfer/transformation of contaminants (nutrients, sediments, pesticides, etc.), it is imperative that more intensive research examine the intricacies of drainage ditches for mitigation purposes.

Drainage ditches are truly the forgotten links between agricultural fields and aquatic receiving systems. Drent and Kersting (1992) reported the use of experimental ditches in The Netherlands for a variety of ecotoxicological evaluations. Research in The Netherlands focused on ditch management issues (Van Strien et al., 1989, 1991). However, little information concerning natural ditch classification, ecology, or potential mitigation capabilities is available. These unique ecosystems provide a myriad of potential services other than water drainage, including sediment trapping and nutrient and pesticide mitigation.

This research focuses on pesticide mitigation capabilities of drainage ditches, and it proposes that drainage ditches are a type of wetland habitat. By designating these systems as flowpath wetlands, one can better integratively design agricultural drainage ditches for purposes of agricultural runoff mitigation, or at least offer potential best management practices (BMPs) for continued effective drainage ditch maintenance. The objectives of this research are to (1) evaluate the pesticide partitioning (water, sediment, and plant) of atrazine and lambda-cyhalothrin within an agricultural drainage ditch, and (2) determine necessary ditch length for effective pesticide mitigation.

2. Materials and methods

2.1. Ditch exposure

A 50 m portion of an agricultural drainage ditch located within the Mississippi Delta Management Systems Evaluation Area (MDMSEA), near Indianola, MS, USA, was used for this study. The ditch was approximately 4 m wide (top width), 1.3 m deep, and had a bottom slope of 0.004. Ditch water width was approximately 1.5 m. Discharge during the simulated runoff event was 3680 l h^{-1}; velocity was less than 3 cm s^{-1}. Sampling sites within the ditch were established at the runoff point of contact, 10 m above point of contact, and 10, 20, 40, and 50 m below point of contact. Two weeks prior to simulated runoff event, plant densities were recorded at each sampling site (Table 1). Replicate sampling of transects within the designated ditch distance were accomplished using a 0.28 m^2 sample quadrat. Estimates of plant density and biomass were then calculated using descriptive statistics.

A simulated storm runoff event was conducted on the designated area of the drainage ditch in July 1998. A mixture of atrazine (triazine herbicide sold as Aatrex®), lambda-cyhalothrin (pyrethroid insecticide sold as Karate®), and water was amended directly into the ditch. Pesticide concentrations (28.9 mg l^{-1} atrazine and 0.46 mg l^{-1} lambda-cyhalothrin) were based on recommended application rates and worst-case storm runoff (5% pesticide runoff) predictions (Wauchope, 1978). This simulation was of a 0.64 cm precipitation event from a 2.03 ha contributing area. A 2.0 m length of 7.6 cm diameter PVC pipe (with 16, 1.5 cm holes) was used for simulating runoff from a diffuse area. Two, 3600 l water tanks (filled with groundwater) were connected to the end of the diffuser and used as water sources for the simulated rainfall. Atrazine and lambda-cyhalothrin were mixed with water in a 110 l container, then delivered to the top of the PVC diffuser through Tygon® tubing via an Atwood® V450 submersible pump at a rate of 0.019 l s^{-1} for 80 min. A 5 cm hose delivered water from the 3600 l tanks directly to the PVC diffuser at a rate of 1 l s^{-1}. Samples were collected from water tanks and analyzed for background concentrations of atrazine and lambda-cyhalothrin.

Table 1
Plant densities (mean ± S.D.), dominant species, and biomass estimates for an agricultural drainage ditch in the Mississippi Delta, USA[a]

Distance from injection point (m)	Dominant species	Estimated plant density (number of plants m^{-2})	Biomass ($g\,m^{-2}$)
0–10	*Polygonum amphibium* *Leersia oryzoides* *Sporobolus*	538 ± 471	666.5 ± 585
10–20	*Polygonum amphibium* *Leersia oryzoides* *Sporobolus*	408 ± 30	505.5 ± 37
20–40	*Polygonum amphibium* *Leersia oryzoides* *Sporobolus*	711 ± 1307	881.5 ± 1621
40–50	*Polygonum amphibium*	13 ± 13	16 ± 16

[a] *Polygonum amphibium* (water smartweed); *Leersia oryzoides* (cutgrass); *Sporobolus* (smutgrass).

2.2. Collection of water, sediment, and plant samples

Grab samples of water were collected in 1 l amber glass bottles at −7 day, 0 h, 1 h, 1.5 h, 2 h, 2.5 h, 3 h, 24 h, 7 day, 14 day, and 28 day post-application from each site. After samples were collected, they were stored on ice and returned to the laboratory for extraction (within 24 h). Sediment and plant samples were collected at −7 day, 0 h, 3 h, 24 h, 7 day, 14 day, and 28 day post-application from each site, wrapped in solvent washed foil, stored on ice, and returned to the laboratory to be dried. Sediment samples (820 ± 110 $g\,kg^{-1}$ silt) were collected from the top 3 cm using sterilized scoops. It should be noted that only the portion of the plant present in the water column (from sediment surface to water surface) was collected.

2.3. Extraction and analysis of water, sediment, and plant samples

Individual water sample volumes were recorded (500–800 ml). Whole water samples were placed in 2000 ml solvent washed screw-top glass jars fitted with Teflon® lined lids followed by the addition of 200 ml of ethyl acetate (distilled in glass) and 100 mg KCl. Remaining extraction procedures followed Smith et al. (1995). Sediment and plant samples were prepared and extracted according to Bennett et al. (2000). Atrazine and lambda-cyhalothrin analytes were analyzed by gas chromatography-electron capture detection using a Tracor 540 gas chromatograph equipped with a Dynatech Precision GC-411V autosampler and a 15 m × 0.53 mm i.d. J&W DB-1 (1 μm film thickness) Megabore® column (Bennett et al., 2000). Mean extraction efficiencies, based on fortified samples, were >90% for atrazine and >95% for lambda-cyhalothrin from water, sediment, and plants.

2.4. Modeling of pesticide transport

To perform regression analyses on collected data, the maximum concentration of each pesticide at each sampled location was plotted against the distance from the injection point (0 m). Water, sediment, and plant analyses were conducted independently. Formulas developed from regression analyses were used to predict pesticide concentrations at various distances within the ditch. Half-lives of both atrazine and lambda-cyhalothrin in water, sediment, and plants were determined by regression analysis on collected data, plotting maximum observed concentrations versus time.

3. Results

3.1. Atrazine

One hour following initiation of simulated storm runoff, 61% of the total measured atrazine was

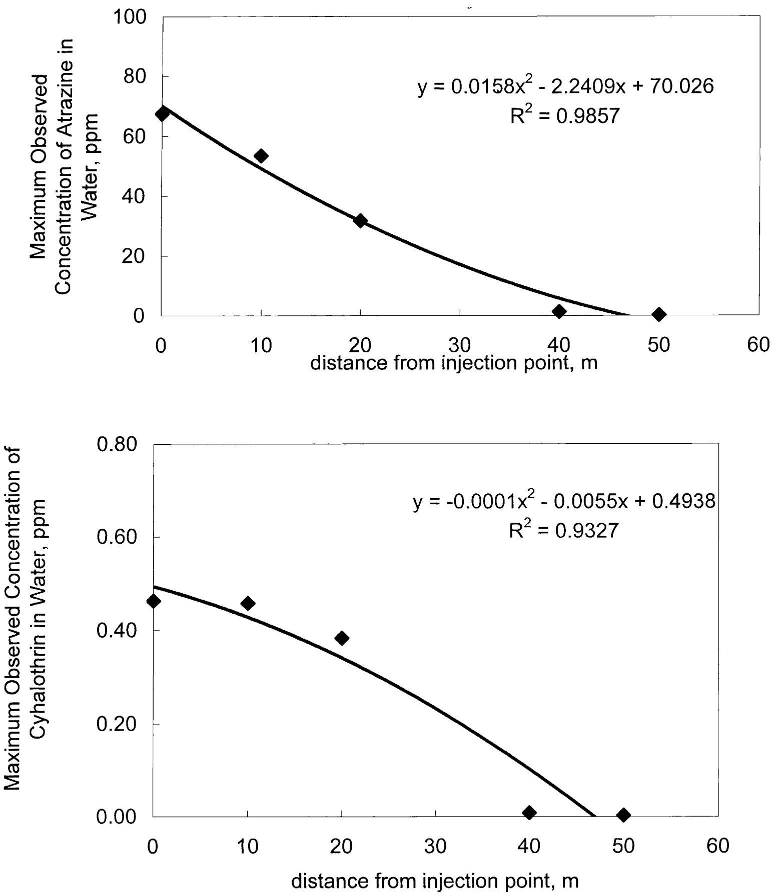

Fig. 1. Predictions of required distance for mitigation of atrazine and lambda-cyhalothrin.

associated with plant material (Table 1). Only 2% of the total measured atrazine was associated with sediment, leaving 37% associated with the water column, 24 h following initiation of simulated storm runoff, 59% of the total measured atrazine was associated with plant material, while 29 and 12% were associated with sediment and water, respectively. Examining various cross-sections of the ditch over the study's duration (28 days), 42–77% of the total measured atrazine was associated with plant material. Observed half-lives for atrazine in water, sediment, and plants were 5.4, 19.7, and 6 days, respectively, for the entire ditch. According to regression analyses and previous storm event assumptions (see Section 2.1), aqueous atrazine concentrations could be mitigated to a no effects concentration ($\leq 20\,\mu g\,l^{-1}$) in a 50 m length of agricultural drainage ditch (Fig. 1) (Table 2).

3.2. Lambda-cyhalothrin

Of the total measured concentration of lambda-cyhalothrin in the drainage ditch 1 h following initiation of simulated storm runoff, 72% was associated with plant material, 24 h following simulated storm runoff, 97% of the total measured lambda-cyhalothrin was associated with plants, while the remaining 3% was associated with sediment. For the study duration, total measured percentages of lambda-cyhalothrin associated with plants ranged from 61 to 93%. Observed half-lives for lambda-cyhalothrin in water, sediment, and plants were 4.6, 15.1, and 14.3 days, respectively.

Table 2
Predicted aqueous transport of pesticides in an agricultural drainage ditch in the Mississippi Delta, USA

Distance (m)	Atrazine ($mg\,l^{-1}$)	Lambda-cyhalothrin ($mg\,l^{-1}$)
0	67.42	0.46
5	59.22	0.46
10	49.20	0.43
15	39.97	0.39
20	31.53	0.34
25	23.88	0.29
30	17.02	0.24
35	10.95	0.18
40	5.67	0.11
45	1.18	0.04
50	0.00[a]	0.00[b]

[a] Denotes minimum value attainable with regression equations.
[b] Aqueous concentrations were predicted using regression equations provided in Fig. 1, based on maximum observed concentrations of both pesticides in water.

As with atrazine, according to regression analysis equations and previous assumptions, aqueous concentrations of lambda-cyhalothrin would be mitigated to a no effects level ($\leq 0.02\,\mu g\,l^{-1}$) in 50 m of the ditch (Fig. 1) (Table 2).

4. Discussion

The issue of surface water contamination by agricultural pesticides has been of growing concern for the last two decades (Basta et al., 1997). Pennington (1996) collected water samples within the Delta region of the Yazoo River basin (Mississippi) and found detectable concentrations of several cotton pesticides. In a study of Moon Lake, Mississippi, and its intensively cultivated agricultural watershed (cotton, soybean (*Glycine max* L. Mers.), and rice (*Oryza sativa* L.)) in the 1980s, Cooper (1991) detected permethrin sporadically in soil, surface water, fish, and sediments immediately after spray season, but the pesticide rapidly degraded to non-detectable levels by late fall. Thus, acute toxicity was the major concern. In a similar study of watershed components of a mixed-cover hill land watershed with 28% agriculture, Knight and Cooper (1996) found low concentrations of permethrin in sediment ($0.03\,ng\,g^{-1}$) and fish tissue ($0.11\,ng\,g^{-1}$) after spray season only. These studies show not only low concentrations, but also indicate that agriculture can continue to strive for improvement in decreasing pesticide contaminants in runoff.

Much research has focused on establishing more efficient BMPs to combat effects of surface water contamination by pesticides. One such BMP is the use of edge-of-field vegetated buffer strips to decrease pesticide concentrations entering receiving aquatic systems. Research concerning retention of atrazine in vegetated buffer strips suggests between 11 and 100% of atrazine may be retained in these strips (Arora et al., 1996; Misra et al., 1996; Barfield et al., 1998). Many BMPs incorporate the strategy that the “spring flush” will be the time of maximum pesticide runoff concentrations; therefore, a small window for potential runoff problems exists. Coupe et al. (1998) noted that in the Mississippi Delta, a longer growing season combined with different pesticide application needs for various crops allows the possibility of certain pesticides to occur in surface waters from April until August. Surface water samples collected between April and September 1995 revealed atrazine concentrations well below $5\,\mu g\,l^{-1}$ in three Mississippi Delta waterbodies, the Big Sunflower River, Deer Creek, and Steele Bayou (Coupe et al., 1998). According to Solomon et al. (1996), monitoring data from Midwestern watersheds indicated that atrazine concentrations in rivers and streams seldom exceeded $20\,\mu g\,l^{-1}$. For this reason, a holistic management scheme is needed to address the potential problems of runoff contamination.

Extensive research including sorption, tillage practice effects, and ecological risk assessments has been conducted for atrazine (Solomon et al., 1996; Basta et al., 1997; Novak, 1999). Because of atrazine’s chemistry and use, it is often found in surface and ground water samples. According to Basta et al. (1997), studies utilizing edge-of-field runoff scenarios report primary loss of moderately water soluble herbicides (e.g. atrazine) to be in dissolved forms. Novak (1999) suggested such herbicides in aqueous phases are more available for uptake by plants, while strong binding of soil-associated herbicides slows plant availability. If large percentages of herbicides (e.g. atrazine) in runoff are in aqueous phases, then presence of vegetation in drainage ditches can serve as potential binding sites, thereby reducing the likelihood of downstream contamination. However, a careful balance between vegetation type and herbicide concentration must be maintained, so herbicides associated with the runoff do not severely damage the plant community.

Much less research has been conducted on lambda-cyhalothrin. However, like other pyrethroid insecticides, it poses a serious threat to non-target organisms in downstream aquatic receiving systems (i.e. fish and aquatic invertebrates). Liess and Schulz (1999) evaluated insecticide-associated impacts from surface runoff on stream macroinvertebrate populations and concluded that runoff following storm events has the potential to alter stream macroinvertebrate community dynamics. If significant concentrations are allowed to enter downstream aquatic systems, community structures could be severely altered. Again, by incorporating drainage ditches as mitigation tools, lambda-cyhalothrin concentrations could be decreased before reaching the receiving lake, river, or stream.

5. Conclusions

This research introduced the concept and success of incorporating current agricultural landscape features (e.g. vegetated drainage ditches) into a management program to help mitigate pesticides associated with storm runoff from agricultural fields. Current data suggest that, based on described parameters (rainfall, pesticide runoff, and contributing acreage) atrazine and lambda-cyhalothrin could be mitigated with a vegetated drainage ditch. By continuing to develop a database on drainage ditch capabilities, researchers can better develop low-cost, environmentally-sound BMPs that will provide additional means of decreasing contaminants in agricultural runoff.

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