Chapter 2

From Vegetated Ditches to Rice Fields: Thinking Outside the Box for Pesticide Mitigation

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Pesticide contamination of surface waters has been a global concern for decades. In agricultural areas, pesticides enter receiving waters through irrigation and storm runoff, spray drift, or even atmospheric deposition. Management practices incorporating vegetation and phytoremediation have demonstrated success in reducing pesticide loads to rivers, lakes, and streams. This chapter will focus on a variety of vegetative management practices (e.g. constructed wetlands, drainage ditches, and rice fields) which have been studied in the intensively cultivated Mississippi Delta. Summaries of research results will be presented, as well as potential future directions for additional research.

Introduction

The current world population is estimated at over 6.89 billion people, growing at a rate of nearly three people each second (*1*). Agriculture is under increasing stress to produce more food and fiber to meet growing population needs, while

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also reducing its potential impacts upon the environment. Farmers continue to use pesticides on their crops in order to maximize yield on the landscape. In 2001, approximately 547 million kg of pesticide active ingredient were used in the United States, while worldwide pesticide use was estimated at 2.3 billion kg (*2*).

Even with advances in application technology, a portion of the applied pesticide, through spray drift, will end up in an unintended area such as an adjacent aquatic ecosystem. Additionally, during storm events, pesticides may be mobilized either in the dissolved or particulate phase (with sediments) via runoff. As a result, potential damage to downstream receiving systems may occur. Nationwide, only about 3% (1,865) of the Clean Water Act 303(d) listed impairments are due to pesticides. Individual states' monitoring programs vary greatly, so it is possible that some states fail to monitor for pesticides at a resolution high enough to determine their presence. In states such as California, pesticides are the most prevalent contaminant reported, responsible for nearly 18% of the state's 303(d) impairments (*3*).

To prevent pesticides entering the receiving water environment at concentrations of concern, various management practices, both in-field and edge-of-field, have been suggested. Popular practices include, but are not limited to, winter cover crops, stiff-grass hedges, constructed wetlands, conservation tillage, slotted-inlet pipes, and grassed waterways. Given today's difficult agricultural economy, many farmers are hesitant to implement any management practice that (1) removes valuable land from production or (2) is not economically-beneficial (i.e. cost-sharing opportunities). With those two factors in mind, various management practices using phytoremediation techniques have been examined in the intensively agricultural area of the lower Mississippi Alluvial Plain. Vegetation is an important element within these practices, since plants aid in physical filtration, bed sediment stabilization, and provide increased or enhanced surface area for microbial attachment (*4*). This chapter will examine research on both traditional (constructed wetlands) and innovative (ditches and rice fields) management practices used to achieve pesticide mitigation. Just as water quality in agricultural settings is becoming a challenge, scientists, farmers, and conservationists must be willing to think "outside the box" to develop both successful preventative and mitigation strategies.

Constructed Wetland Studies

Wetlands are ecotones (transition zones) between upland areas and aquatic systems such as rivers, lakes, or streams (*5*). Estimates of wetlands in the conterminous United States from the early 1600s suggest over 89 million ha existed; however, within nearly four centuries, over half of those wetlands, some 48 million ha, had been lost due to development or agriculture (*6*). This severe loss of wetland habitat is at least partially responsible for a decline in water quality throughout the nation. Since the latter part of the 20th century, efforts have been made to construct wetlands in areas that once housed natural wetland systems. Reintroduction of these systems, especially in agricultural areas, serves to improve water quality following storm runoff or irrigation controlled-releases. Although some studies on the ability of wetlands to remove pesticides were conducted in the 1970s and 1980s, Rodgers and Dunn (*7*) were the first to suggest a method for developing design guides for constructed wetlands targeted specifically at pesticide removal. Their series of eight experimental wetland cells were constructed at the University of Mississippi's Field Station in the late 1980s and early 1990s. Out of this experimental design came three primary studies which were some of the first to suggest necessary wetland lengths for various levels of pesticide mitigation.

In the first experiment, constructed wetland cells (59-73 x 14 x 0.3 m) were amended with the organophosphate insecticide chlorpyrifos at three different concentrations: 73, 147, and 733 µg/L. These concentrations represented theoretical chemical runoff of 0.1, 1, and 5% of applied pesticides on a 32-ha field. For 12 weeks, water, sediment, and plant samples were collected spatially throughout the length of the constructed wetlands. Plants, consisting of the emergent soft rush *Juncus effusus*, accounted for approximately 25% of the measured chlorpryifos mass, while 55% of the mass was located in sediments. The wetland buffer length necessary to reduce the aqueous chlorpyrifos concentrations to 0.02 µg/L (no observed effects concentration or NOEC) ranged from 184 m to 230 m, depending on the initial concentration (*8*).

A second experiment was later conducted by amending wetland cells with a mixture of the herbicides atrazine and metolachlor at concentrations of 73 and 147 µg/L, representing a 0.1 and 1% theoretical chemical runoff (*9*, *10*). Water, sediment, and plant (*J. effusus*) samples were collected spatially and temporally for 35 d. Results indicated atrazine concentrations were below detection (0.05 µg/kg) in all sediment and plant samples, while only 10% of the measured metolachlor mass was present in plant samples. As with atrazine, metolachlor concentrations in sediment were below detection limits (0.05 µg/kg). According to Huber (*11*), 20 µg/L is the suggested atrazine concentration below which is not expected to adversely affect aquatic ecosystem health. Conservative wetland buffer lengths necessary to reduce the atrazine aqueous concentration to 20 µg/L ranged from 100 m to 280 m, depending on the initial atrazine concentration. For metolachlor, to reduce the aqueous concentration to 40 µg/L, necessary wetland buffer lengths ranged from 100 m to 400 m, depending on the initial concentration (*9*, *10*).

These first generation studies laid the foundation for later investigations which focused constructed wetland research on the influence of plants in pesticide mitigation. In 2003, 10 m x 50 m constructed wetlands were used to evaluate the fate of methyl parathion (*12*) in vegetated and non-vegetated systems. A storm event simulating 1% pesticide runoff from a 20-ha contributing area was used as an amendment. As with earlier studies, water, sediment, and plant samples were collected spatially and temporally for 120 d. Additionally, semi-permeable membrane devices (SPMDs) were placed near the outflow of each wetland cell. Only 30 min after the initial exposure, methyl parathion was detected in all spatially collected samples within the non-vegetated wetland replicates. In the same time frame, methyl parathion had only travelled 20 m in the vegetated cell. After examining SPMD results, it was noted that only the non-vegetated replicate cells had measurable concentrations of methyl parathion in the outflow. Utilizing chemical fate and distribution formulas, it was determined that a wetland length of 18.8 m would be required to reduce the inflow concentration (8.01 mg/L) to

0.1% of its original in vegetated systems. Alternatively, in non-vegetated systems, a wetland length of 62.9 m would be required to reduce the inflow concentration to 0.1% of the original. These data provided further evidence of the benefits of vegetation in mitigation of pesticides.

Following the success of these studies, a constructed wetland was designed and placed in the Beasley Lake watershed, a 915-ha agricultural experimental watershed in Sunflower County, Mississippi (*13*, *14*). The entire system was 30 m wide x 180 m long and included a sediment retention basin followed by two separate vegetated treatment cells. Ten collection sites were established spatially along the system. A simulated storm event containing the pesticides diazinon and cyfluthrin, as well as suspended sediment (403 mg/L) and surface water from Beasley Lake, was amended into the constructed wetland system. Water, sediment, and plant samples were collected over 55 d at each site. The percentage of individual measured pesticide mass found in vegetation was 43% (diazinon), 49% (lambda-cyhalothrin), and 76% (cyfluthrin) (*15*, *16*). Based on conservative effects concentrations and regression analyses, to mitigate 1% of the pyrethroid (lambda-cyhalothrin and cyfluthrin) runoff from a 14-ha contributing area would require a constructed wetland 30 m wide x 215 m long (*16*).

While the environmental benefits of using constructed wetlands to mitigate pesticide runoff have been demonstrated, there was still the challenge of implementation due to the costs. Aside from any construction cost of the wetland (which may be cost-shared with government programs in certain instances), there was a loss of production land associated with the construction. Based on data generated from Moore et al. (*16*), approximately 5% of the contributing area would be needed for a constructed wetland to effectively mitigate pesticide runoff from that land. Using that information, a cost table (Table 1) was generated from data collected from the 2009 Mississippi state agricultural overview (*17*).

Table 1. General agricultural economic impact of using a constructed wetland for pesticide mitigation for field sizes of 8 ha, 16 ha, and 32 ha[a]

			Annual Gross Profit Loss (5%)		
Crop	*Average Yield*	*Average Price*	*32 ha*	*16 ha*	*8 ha*
Soybeans	94 bu/ha	$9.15 / bu	$1,376	$688	$344
Corn	311 bu/ha	$3.70 / bu	$1,841	$921	$461
Rice	7510 kg / ha	$0.28 / kg	$3,364	$1,682	$841
Cotton	772 kg / ha	$1.53 / kg	$1,890	$945	$472

[a] bu = bushel

Not only would a farmer lose 5% of his production landscape, but he would also lose 5% of his potential annual gross profits. In an era of economic uncertainty, this risk is unacceptable to many farmers and landowners. Therefore, it was necessary to design innovative management practices that were environmentally efficient, and also economically palatable to farmers and landowners. One had to look no further than the agricultural fields themselves and the surrounding landscape. Investigations began immediately into the potential of vegetated agricultural drainage ditches for pesticide mitigation.

Vegetated Agricultural Drainage Ditch Studies

Historically, agricultural ditches have primarily served a hydrologic purpose: facilitate drainage from production acreage following storms. Little thought or value was placed on their maintenance or design. Closer examination of these ecosystems showed they can, to some degree, mimic wetland areas with their hydric soils, hydrophytes, and a measurable hydroperiod. Conventional wisdom then deduced these areas could be managed and manipulated similarly to constructed wetlands. The use of agricultural drainage ditches was attractive because they were often prevalent features in the farming landscape that required no additional acreage removal from production to realize their mitigation potential. Research was needed to confirm drainage ditch ability of pesticide mitigation.

In 1998, a small-scale study was initiated to evaluate the transport and fate of the pesticides atrazine and lambda-cyhalothrin in an agricultural drainage ditch. A 50 m portion of a ditch within the Beasley Lake watershed (Mississippi) was chosen for the experiment. Using a diffuser, the pesticides were amended directly into the ditch, and water, sediment, and plant samples were collected spatially and temporally for 28 d. Within one hour of initiation of the simulated storm event, 61% and 87% of the measured atrazine and lambda-cyhalothrin concentrations, respectively, were associated with the ditch vegetation as opposed to the sediment or aqueous phases. At the 28 d sampling, 86% and 97% of the measured atrazine and lambda-cyhalothrin, respectively, were associated with the ditch vegetation (*18*). Using linear regression analysis of the maximum observed pesticide concentrations in water, it was determined that both atrazine and lambda-cyhalothrin could be mitigated to a no observed effects concentration (NOEC) (≤ 20 µg/L for atrazine; ≤ 0.02 µg/L for lambda-cyhalothrin) within the 50 m reach of the ditch (*18*).

Following the success of this initial study, further examinations into the potential of vegetated agricultural drainage ditches for pesticide mitigation were conducted. A longer ditch (650 m) within the Thighman Lake watershed (Mississippi) was chosen for the next set of experiments. A spatial and temporal sampling scheme, similar to those previously detailed from other studies was used. Two pyrethroid insecticides, lambda-cyhalothrin and bifenthin were released in a slurry mixture to simulate a storm runoff event. Three hours following the initiation of the event, 95% and 99% of the measured lambda-cyhalothrin and bifenthin concentrations, respectively, were associated with ditch vegetation. Aqueous concentrations of lambda-cyhalothrin and bifenthrin at the inlet site (site 0) at 3 h were 374 and 666 µg/L, respectively. During the same time frame, but 200 m downstream, aqueous concentrations were 5.23 and 7.24 µg/L, respectively, for lambda-cyhalothrin and bifenthrin. Samples collected at the 400-m collection site indicated no chemical residues. Using regression analyses, it was determined that both lambda-cyhalothrin and bifenthin aqueous concentrations could be reduced to 0.1% of their original concentration within 280 m of the vegetated drainage ditch. Mass balance calculations confirmed the significance of pesticide sorption to plant material as the major sink for the system (*19*).

A second study was initiated a year later in the same 650-m ditch in the Thighman Lake watershed. During this experiment, the pyrethroid insecticide esfenvalerate was mixed with suspended sediment (400 mg/L) to simulate a storm runoff event. Spatial and temporal water, sediment, and plant collections were similar to those described by Bennett et al. (*19*). Three hours following the initiation of the event, 99% of the measured pesticide was associated with the ditch vegetation. Excluding the injection site (which had no vegetation), measured esfenvalerate concentrations were associated more in plants than in sediment by a ratio of 6:1. Regression analyses determined that a ditch length of 509 m would be necessary to reduce the maximum aqueous pesticide concentration at the injection site to 0.1% of its original concentration (*20*).

Although three successful pesticide mitigation studies had been conducted in the Mississippi Delta with vegetated drainage ditches, the concept was still untested in sites outside the midsouthern US. Scientists in California were interested in the potential demonstrated by the management practice, especially given the state's pesticide concerns caused by organophosphate and pyrethroid insecticide runoff. Two ditches (100 m in length) were constructed along the edge of a tomato field in Yolo County, California. Both ditches had V-shaped cross-sections, which is commong to the growing region. One of the V-ditches was vegetated with annual ryegrass (*Lolium multiflorum*) and barley (*Hordeum vulgare*). Lamb's quarter (*Chenopodium album*), an invasive weed, was prevalent within the vegetated ditch. The second ditch was maintained with no vegetation (bare). A simulated irrigation runoff event containing a mixture of diazinon, permethrin, and crushed, sieved soil (45 kg) was amended equally into both of the ditches. To compare transport and fate of the pesticides, spatial and temporal sampling of water, sediment, and plants occurred as with previous experiments. Differences in half-distances (distance required to reduce initial concentration by 50%) were noted among the two V-ditches, indicating the importance of vegetation in pesticide mitigation. For the *cis-* and *trans-* isomers of permethrin, half- distances in the V-vegetated ditches ranged from 21-22 m. However, in the non-vegetated V-ditch, half distances for the same pesticide more than doubled to 50-55 m. The greatest difference was noted in diazinon half-distances. The half-distance for diazinon in V-vegetated ditches was 56 m, while nearly tripling to 158 m in the non-vegetated V-ditch (*21*). Due to the success and collaborative nature of this research, the California state office of the USDA Natural Resources Conservation Service (NRCS) agreed to designate vegetated agricultural drainage ditches (VADDs) as an eligible cost-share management practice within the Environmental Quality Incentives Program (EQIP). Within this program, farmers and landowners can apply for up to 75% cost-sharing for installing practices improving natural resource conditions. As a result of this research, this practice is listed in the state's electronic field office technical guide (eFOTG) as 607A – Surface Drainage, Field Ditch – Vegetated Agricultural Drainage Ditch. While not listed officially in Mississippi's eFOTG, NRCS engineers continue to promote practice 607A to improve runoff water quality (*22*).

Rice Fields – A Dual Benefit?

Continuing to think outside the box and, after the success of both constructed wetland and vegetated drainage ditch research, the question was posed, "Is there a practice that combines beneficial aspects of both wetlands and ditches?" Research plans were then focused on the pesticide mitigation potential of diverting storm runoff through rice (*Oryza sativa*) fields. This situation provides the potential benefits of phytoremediation without loss of valuable production acreage. One obvious question, however, is whether or not any pesticides sorbed by the rice would be translocated to the harvested (and consumed) seed. This separate question is currently being examined using separate smaller-scale studies.

To initially address the possibility of rice fields for pesticide mitigation, three ponds were chosen at the University of Mississippi Field Station. Two ponds were planted with equal densities of rice, while one pond remained non-vegetated to serve as a control. A simulated storm runoff event containing diazinon was amended equally to each of the three ponds. The event simulated runoff of 0.05% of the recommended pesticide application rate from a 32 ha field. Water, sediment, and rice (where applicable) samples were collected spatially and temporally for the duration of the experiment (72 h). The experiment was conducted twice, once during the typical rice growing season (pre-harvest), and once after rice had begun to senesce (post-harvest). Significant ($p < 0.05$) decreases in aqueous diazinon concentrations were noted between the inflow and outflow of both ponds planted with rice, during the pre-harvest and post-harvest experiments. Actual pesticide sorption to rice was minimal (1-3% of mass distribution); however, temporal sampling indicated that diazinon reached the sediment of outflow samples twice as fast in the non-vegetated pond when compared to either rice pond. Decreases in sediment diazinon concentrations of 77-100% from inflow to outflow were noted in the rice ponds, while diazinon sediment concentrations decreased less than 2% from inflow to outflow in the non-vegetated pond (*23*). Diazinon adsorption to rice tissue was further tested with rice senescence. Senescence to rice tissues showed significant decreases in tissue mass ($r^2=0.985$); however, there were no corollary increases in diazinon concentrations in the water column. Control vegetation placed within the treatment rice field showed negligible diazinon concentrations throughout senescence suggesting a lack of mobility and transfer of diazinon from senescing tissues (*24*).

Conclusion

Potential contamination of aquatic receiving systems from agricultural pesticide runoff is a challenging issue, requiring a preventative approach for a successful outcome. Additionally, multiple management practices should be considered together, rather than seeking one silver bullet solution. Solutions begin on the field, with more efficient pesticide application technology to reduce spray drift and attempts to confine applications to the most opportune weather conditions. Even with the most cautious application management approach, sudden weather events causing storm runoff are out of the control of the farmer. The challenges then shift toward management practices that intercept runoff, reducing the potential for pesticides to contaminate aquatic systems. This chapter has discussed some traditional (constructed wetlands) and innovative (vegetated ditches and rice fields) methods by which to mitigate pesticides in storm runoff. Although these basic practices have demonstrated great potential, little is known about the specific mechanisms of why these systems work. How does the hydrology affect the success of these management practices? How do variations in vegetation affect the pesticide reduction? How responsive can ditch mitigation become under more conservative water use practices and under changing climatic conditions? What is the role of the microbial community in these systems? These are just some of the questions future research needs to address. With a difficult economic future, solving the problems of pesticide pollution in agricultural runoff will require scientists and farmers to closely interact and think “outside the box” for possible solutions

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