Management Options to Reduce Pyrethroid Insecticides in Tailwater from Row Crops

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Introduction

Pyrethoid insecticides are used to protect a variety of row and orchard crops grown in California, and their use on orchard crops in particular has substantially increased over the past decade (Oros and Werner, 2005). They are used even more extensively in urban areas to control household and landscape insect pests. Pyrethroids are important in agricultural Integrated Pest Management (IPM) because they are economical and effective when biological and cultural methods are not adequate for controlling insect pests and they offer an alternative chemistry to use in rotation with other insecticides. Pyrethroids are relatively less toxic to humans than many other insecticides, with relatively short half-lives lending themselves to safe work environments and safe food supplies.

Increased use of pyrethroid insectides coincided with findings that organophosphates (OP's), another class of insecticides, were contributing to the degradation of surface water quality in both urban and agricultural areas of California. By the late 1990's reliance on OP's declined substantially in agricultural production and pyrethroids often replaced them as a first step to manage this water quality issue (Oros and Werner, 2005). Pyrethroids have a higher affinity to adsorb to fine silt and clay particles and organic material than OP's reducing their mobility in tailwater from irrigated fields and exposure to public waterways (Long, 2005).

By 2003, attention to pyrethroids and their affect on sediment quality in public waterways increased. They were shown to attach to suspended sediments in field runoff, enter receiving waters down gradient, and sometimes accumulating to levels toxic to aquatic species that inhabit sloughs, streambeds, and riverbeds (Weston et al., 2004). Today, numerous conventional pesticide use practices are emphasized to address this environmental concern and to retain the use of pyrethroids as a vital crop protection tool. Some of the primary management practices encouraged include: 1) monitoring of insect pests and beneficial insects to be certain that a crop pest is approaching economic thresholds that warrants control with an insecticide; 2) safe pesticide handling, mixing, and disposal; 3) proper sprayer calibration and use of drift control measures; and 4) preference for ground application methods when sensitive waterways are nearby (O'Connor-Mayer, 2000).

Since pyrethroids adsorb to soils, management practices that minimize the soil loss from irrigated fields are now commonly recommended as complementary measures to more conventional pesticide use practices. Such practices include sediment traps, vegetated drainage ditches, the use of polyacrylamide (PAM), an irrigation water amendment. While often recommended, the research experience with these techniques is relatively limited in California agriculture.

California Experience with Soil Loss and Pyrethroid Reduction Practices

Experiences reported by the Yolo County Resource Conservation District indicated on average 33 to 55 percent capture of sediments in field runoff with sediment traps (YCRCD, 2001). Effectiveness depended on characteristics of the flows and suspended sediments, trap design, and maintenance. A prominent question that remains is how effectively sediment traps can capture suspended fine silt and clay sediments, which are the primary soil particle size fractions that adsorb pyrethoids and that are more susceptible to transport from irrigated fields (Gan et al., 2005).

The first reported California experience with vegetated drainage ditches was initiated in 2004/05 by a collaborative research team of federal EPA and USDA scientists, UC Davis toxicologists, and the Yolo County Resource Conservation District (Denton, 2006). The investigations are underway and findings have not yet been reported widely. Prior to this project, some of the leading research with vegetated drainage ditches was conducted in the Mississippi Delta region. Published results of experience in the Mississippi Delta suggested vegetated drainages may effectively intercept up to 99 percent of pyrethroids in solution and adsorbed to suspended sediments in tailwater from agricultural fields (Cooper, 2004.) These out-of-state experiences with vegetated drainage ditches warrant further research and development within California.

Polyacrylamide (PAM) is a synthetic, high molecular weight, anionic and linear polymer that dissolves in irrigation water and can be used to flocculate soils and control suspended sediments in tailwater from farm fields (Wu, 2001). PAM has been commercially available since

1995 in California. One California study showed that PAM reduced suspended soil particles in furrow irrigation tailwater by as much as 99.7 percent (McCutchan, 1993) and had the potential to be an important tool to manage the quality of agricultural runoff from row crops. With the increasing attention on pyrethroid use in California agriculture and sediment toxicity in down gradient waterways, renewed investigations into PAM appear to have merit. One pertinent research question that merits consideration is whether PAM is environmentally safe for widespread agricultural use. Other questions related to PAM application rates and formulations, efficacy and duration, and use of PAM in combination with sediment traps and vegetated drainage ditches are of interest as well.

Current Experimentation with Soil Loss and Pyrethroid Reduction Practices

In 2006, the State Water Resources Control Board funded a collaborative field investigation of tailwater management practices that reduce soil loss and potential pyrethroid insecticide transport from irrigated fields. The research has been conducted by the University of California and California State University Chico. In 2006, sediment traps, vegetated drainage ditches, and PAM water amendment were evaluated in the experiments. A second year of experimentation will be conducted in 2007. Separately funded experiments with vegetated drainage ditches and PAM are also being conducted by the Department of Pesticide Regulation and the Coalition of Urban Rural Environmental Stewardship (CURES) in the San Joaquin Valley.

UC Experimental Methods and Results

In 2006, field trials were conducted on three research farms located near Davis, Chico, and Salinas, California. Processing tomato, lima bean, and lettuce were grown at each trial, respectively. Clay loam and loam soils were predominant at the Chico and Davis field sites, respectively. Similar experimental designs and methods were used at each location to evaluate sediment traps, vegetated drainage ditches, and PAM for removing suspended sediments and pyrethroids from tailwater runoff. The first season of experimentation at the Salinas trial was only recently completed and is not discussed here except for some preliminary observations regarding sediment traps.

The Chico and Davis experiments involved about 3 acres of a furrow irrigated row crop. The irrigated acreage at each site was split into four plots of about 0.75 irrigated acres per plot. Each plot consisted of about 10 furrows per plot with 60-inch beds between furrows. Gated pipe was used to deliver water at 12 to 16 gallons per minute (gpm) into each furrow and furrow lengths were a minimum of 650 feet long to simulate a commercial scale furrow irrigation system. The plots were cultivated and then sprayed before each irrigation with the pyrethroids lambda-cyhalothrin (Warrior) at Davis or zeta-cypermethrin (Mustang) at Chico using a ground applicator to create a realistic condition that had potential to result in transport of sediments and pyrethroids from irrigated fields. Testing was conducted during four irrigations at the Chico and Davis sites during the summer months of 2006.

Tailwater runoff was directed through a flume with a stilling well and automated datalogger at the bottom of each plot to measure runoff rates and the cumulative volume. Approximately 10-80 gallons of runoff was collected from the tailwater flowing through the flume using a diaphragm pump. The large volume of runoff was collected to insure enough suspended sediment was available to determine pyrethroid concentrations in the suspended sediment. Bed sediments were also analyzed for pyrethroids, and tested for toxicity using the amphipod, *Hyallela azteca*. Total suspended solids (TSS) were determined gravimetrically and the turbidity of the runoff was determined with a nephelometer before the tailwater was directed through either a sediment trap or a vegetated drain ditch. After the tailwater passed through a sediment trap or vegetated drainage ditch the same water quality sampling and determinations were repeated.

Sediment Traps

The sediment traps were dug with a backhoe and lined with plastic at the point where water entered to guard against erosion. At the Chico and Davis trials, the sediment traps were approximately 4 feet wide, 13 feet long, and 4 feet deep and designed to trap sediments in tailwater flows ranging from 60 to 100 gpm. The approximate ratio of irrigated area to the area of the sediment trap was 500:1 at Chico and Davis. Based upon experience from the Chico and Davis trials, the sediment traps at the Salinas trial were enlarged to 7 feet wide, 33 feet long, and 2 feet deep for similar runoff rates to provide a 90 minute settling time for suspended sediments in the runoff. The approximate ratio of irrigated area to the area of the sediment trap was about 50:1 at Salinas.

Replicated field evaluations of sediment traps during two irrigation events at both the Chico and Davis farm sites showed very little, if any, capture and reduction of sediments in tailwater from cultivated row crops grown on clay loam and loam soils. Figure 1 illustrates the concentration of total suspended sediments (TSS) in the runoff before and after it passed through a sediment trap when measured periodically during a two-hour period in one plot at the Davis trial in July. This response was representative of the other replicates at both the Chico and Davis trials. Toxicity tests with the aquatic test organism, *H. azteca* showed 92 to 100 percent mortality when exposed to sediments collected after the tailwater passed through a sediment trap. This also suggested that the sediment traps did not effectively reduce the TSS and pyrethroid insecticide associated with the sediment.

One possible explanation for the lack of sediment and pyrethroid reduction from the traps was that they were undersized in the Chico and Davis trials for the tailwater flows (average 90 gpm) that passed through them. As a result, the sediment traps were enlarged five fold at the Salinas trial but the design change did not improve the capture of sediments. An alternative explanation for this response is that most of the larger suspended sand and large silt particles, 10 to 250 µm diameter, settled out in the field due to constrictions on tailwater flow through the flumes. Settling velocities range from about 0.25 to 4 cm/sec for these larger sediments (Marshall and Holmes, 1979). In contrast, settling velocities for fine silt and clay particles are about 0.001 cm/sec and 0.0001 cm/sec, respectively. As a result, the settling velocities required for the suspended fine silt and clay particles, which tend to adsorb pyrethroids, may simply be too slow for sediment traps alone, to be practical and effective for managing fine suspended sediments and pyrethroids.

Vegetated Drain Ditches

The vegetated drainage ditches were constructed with a shallow “V” ditcher and tractor blade. The vegetated ditches were about 5 feet wide, 1.5 feet deep in the center of the ditch, and 160 feet long with about 0.05 percent grade. The approximate ratio of irrigated area to the area of the vegetated drainage ditch was 33:1 at all three trials. Tall fescue *(Festuca arundinacea)* sod was used to establish vegetation in the ditch. Sod was used at Chico and Davis in 2006 because the trials were not initiated until mid May after most of the rainfall had already occurred and the prime season for establishing the vegetation from seed had passed. Investigations in 2007 will evaluate the ease of establishing a vegetated drainage ditch from seed.

Replicated field evaluations of vegetated drainage ditches during two irrigation events at both Chico and Davis farm sites showed significant improvements in water and sediment quality after tailwater was filtered through the ditch. Figure 2 displays the concentration of TSS in the runoff before and after it was routed through a vegetated drain ditch during a two-hour period in one plot at the Chico trial in July. TSS concentrations were reduced 62 to 73 percent with vegetated drain ditches at the Chico site. This finding was representative of other replicates at the Chico trial and for both irrigation events. The effectiveness of the vegetated drainage ditches was less at Davis but may have been related to challenges with establishing vigorously growing fescue grass in the drainage ditches. Toxicity tests with *H. azteca* showed only 6-8% mortality when exposed to sediment collected at the end of the vegetated drainage ditches at the Chico site. This also suggested that vegetated drainage ditches have potential to effectively reduce TSS concentrations and pyrethroid insecticides associated with the sediments in field runoff.

PAM (polyacrylamide) Water Amendment

PAM was evaluated in one plot at each trial by continuously injecting an emulsified formulation of PAM into the main water supply at a concentration of 5 parts per million (ppm). A separate, gated irrigation pipeline at the head of this plot was used to deliver the amended water. The water quality of the runoff from this plot was compared to the water quality of the runoff from the other three plots where the irrigation water not treated with PAM and before the runoff from these plots was routed through a sediment trap or vegetated ditch. Preliminary testing was also conducted with granular and cake formulations of PAM as an alternative to direct injection into the irrigation water supply.

Field evaluations of PAM treated water at the Chico and Davis trials during four irrigation events at each site demonstrated that a 5 ppm concentration of PAM injected into the water supply was highly effective at reducing TSS in field runoff. Figure 3 shows a 98 percent reduction in TSS in one plot from the Chico trial. Similar results were observed in the other replicates and for the other irrigation events at the Chico and Davis trials.

While the use of PAM resulted in impressive reductions in TSS in the field runoff, sediment toxicity tests revealed no survival of the aquatic test organism, *H. azteca*, when exposed to sediment from the tailditch leaving the PAM plot. The reasons for the toxicity are unclear and experimental steps are being taken to understand it. One possible explanation is that the samples taken to evaluate toxicity were contaminated with pyrethoids since the sampling point was in close proximity to where the insecticide spray applicator turned around along the edge of the field so it may have been affected from field drift. In 2007, water samples and sediments from PAM plots will be collected from the tailwater ditch at a point further away from the edge of field to avoid risk of this type of contamination. Another possible explanation is that *H. azteca* is sensitive to PAM-treated tailwater. Laboratory tests are planned to determine if PAM has a direct, adverse effect on the survival of this aquatic organism.

Conclusions

After completion of the first of our planned two years of study, some important finding and questions have become apparent:

- ♦ Consistent with California field research dating back to 1993, irrigation water supplies treated with anionic polymers (PAM) are highly effective at flocculating fine suspended sediments in field runoff and preventing them and associated pyrethroid insecticides from being transported from fields. Questions remain unaddressed about the toxicity of PAM in irrigation runoff and survival of the aquatic test organism *H. azteca* exposed to PAM. Preliminary field research in 2006 also suggested that other formulations of PAM besides emulsions may be more convenient and as effective, which may aid adoption of PAM into routine farm management practices.

- ♦ Vigorously growing, vegetated drainage ditches show potential to significantly filter and reduce the TSS and associated pyrethroid insecticides from field runoff. High survival rates of the aquatic test organism, *H. azteca*, when subjected to sediments and water samples collected after the tailwater passed through 160 feet of vegetation, were also encouraging. Research in 2007 will seek to confirm the first year of findings and to address other aspects such as ease and cost of constructing vegetated tailwater ditches. More research and development may eventually be needed to adapt this management option from experimental to commercial scales.

- ♦ Sediment traps, by themselves, were not effective at capturing fine silts and clay suspended sediments and associated pyrethroid insecticides from field runoff. The settling velocities for these very fine suspended solids that pyrethroids attach to appear to be too slow for this management option to be practical. However, it is possible that sediment traps used in combination with PAM may be a viable management option deserving further research and development.

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Figures

Figure 1. Comparison of total suspended sediments (TSS) in irrigation runoff before and after the tailwater is routed through a sediment trap at the Davis field site.

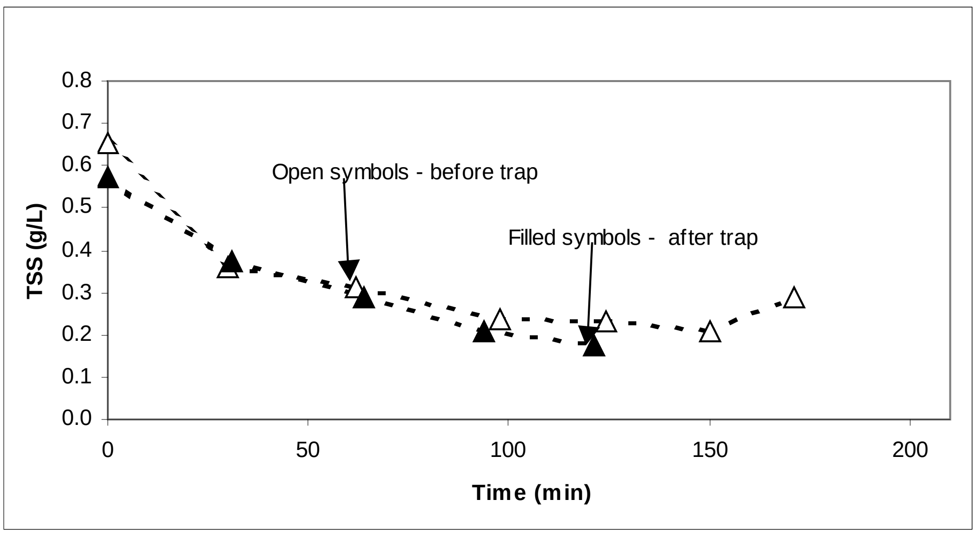

Figure 2. Comparison of total suspended sediments (TSS) in irrigation runoff before and after tailwater is routed through a vegetated drainage ditch at the Chico field site.

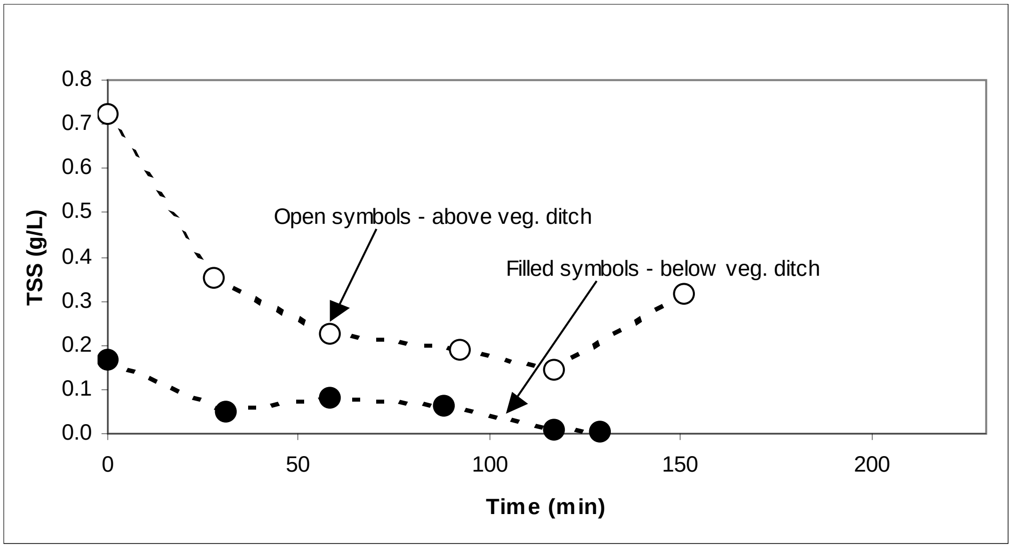

Figure 3. Comparison of total suspended sediments (TSS) in irrigation runoff at the Chico field site from three plots irrigated with untreated water and one plot irrigated with PAM treated water.