First Year Technical Memorandum

Management practices for mitigating off-site transport of soil-adsorbed pesticides

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INTRODUCTION

Studies of sediment quality in surface waters throughout California's Central Valley have shown the presence of pyrethroid insesticides at concentrations toxic to sensitive aquatic species. In 200 samples collected, 27% were toxic to the standard sediment species, Hyalella azteca, and in about 60% of these cases, pyrethroids were in sufficient concentration to explain the toxicity (Weston et al., in review). Chlorpyrifos adsorbed to sediment likely contributed to toxicity in 20% of the samples. It is clear that pyrethroids applied to the fields are not entirely remaining on those lands, but are moving in to agricultural drains, and ultimately in to natural surface water bodies. While either irrigation return flow or stormwater runoff could be responsible for this off-site transport, the prevailing evidence indicates that irrigation return is the greater factor behind transport of the pyrethroids off the fields (Weston et al., in review), though stormwater flows may be responsible for further downstream movement of contaminated sediments.

Pyrethroid insecticides are extremely insoluble, rapidly bind to soil particles, and are transported largely in the sediment-bound state (Gan et al., 2005). Their off-site transport is therefore largely a function of erosion of soils from agricultural lands, and any measures that mitigate this erosion, particularly that of the finer grain sizes that would carry more pyrethroids, should be effective at reducing pesticide loss. This study was intended to evaluate three erosion control methods with regards to their effectiveness at preventing movement of pyrethroid insecticides from cultivated fields. Though specifically studying pyrethroids, conclusions should be equally applicable to all sediment-sorbed organic pesticides. The results of the first year of field trials are described herein, and should be considered preliminary until further validation occurs in the second year of the study.

METHODS

General design

This study focused on row crops because pyrethroid insecticides are an important component of integrated pest management approaches used extensively in vegetable and row crop production throughout California. Furthermore, after planting and up to the point the crop canopy matures into full ground cover, cultivation is routinely practiced for weed control.

Cultivation loosens the soil increasing its susceptibility to erosion and the transport of pyrethroid insecticides that are adsorbed to the suspended sediments in the irrigation runoff. Three techniques were evaluated for effectiveness at reducing movement of soils and associated pesticides: 1) use of a vegetated tail ditch; 2) addition of polyacrylamide (PAM) to the irrigation water; and 3) use of a sediment trap. An unvegetated tail ditch served as a control. In order to assess these techniques with a variety of soil types, and increase the applicability of findings to more of California, experiments were conducted at Davis, Chico, and Salinas, California. The experiments conducted were very similar at all three sites. All three sites were public farms, either academic or government-owned, thus providing maximum control over farm management practices. Since production of a crop to harvest stage was not an objective, the choices of crop planted, pesticide used, irrigation frequency, etc. were intended to maximize the value and scientific validity of results, though at the same time remaining representative of typical commercial agricultural practices.

Specific details on the experimental design at Davis, Chico and Salinas are discussed later in more detail, but the basic farm layout at all study locations consisted of four plots (Figure 1). The plots were independent of one another with respect to management and measurement of their tailwater, and different erosion control measures could be practiced in each plot. After preparing the fields and planting the crops, an initial irrigation was done at each farm to insure proper functioning of all sampling equipment and to collect data on tailwater quality prior to application of pyrethroids. After the initial irrigation, and before each subsequent irrigation, the field was cultivated and a pyrethroid applied by ground application. The particular pyrethroid compound applied varied depending on the farm, but was selected to be one widely used commercially on the specific crop grown at each study site (e.g., lettuce is usually treated with permethrin, so permethrin was used on our Salinas study site where lettuce was grown). Rates of pyrethroid application were typically at the high end though within the acceptable range as given on the product label.

Herbicides were used at all three farms near the time of planting (e.g., Kerb, Treflan, Dual Magnum, Round-up), but no other pesticide other than the intended pyrethroid, was used during the period of crop growth. In addition, no insecticide had been used on any of the plots for at least four months (and maybe more) prior to the work at Salinas, and nine months prior to the work at Chico and Davis.

Approximately 24 hours after pyrethroid application, the plots were irrigated, and samples collected. Three to four irrigations were done, spaced 7-12 days apart, and between each irrigation the furrows were cultivated and the pesticide reapplied. The frequent cultivation was done to bury much of the pyrethroid so that concentrations on the surface soils did not continue to climb with each successive pyrethroid application, and to avoid the reduction in sediment resuspension over time that would typically be seen in repeated irrigations without soil disturbance. Cultivation between each irrigation event insured the soil was equally susceptible to erosion in every irrigation. The experiments conducted did not result in any discharge to surface waters; after leaving the experimental plots, runoff at all three farms was routed to ditches or ponds of sufficient capacity to hold all tailwater produced, and it ultimately infiltrated in to the soil.

Sampling each plot during an irrigation event consisted of: 1) measurement of irrigation runoff from the plot; 2) measurement of total suspended solids (TSS); 3) analysis of the suspended solids for pyrethroid content; 4) collection of bed sediment for toxicity testing; and 5) analysis of bed sediment for pyrethroid content. For tests involving sediment traps, vegetated ditches, and unvegetated ditches, effectiveness was judged by collecting samples above and below the mitigation measure, and comparing tailwater quality at the two sites. For tests involving use of PAM, effectiveness was judged by comparing tailwater from plots that received PAM to those that did not.

Methods specific to the Davis site

Soil at the Davis farm site was loam with percentages of sand, silt and clay of 40, 37, and 23%, respectively. The experimental plots at Davis were planted with tomatoes in 60-inch beds between furrows. Each of the four plots consisted of about nine beds, 600 ft long, for a total of 0.7 irrigated acres per plot. Water was provided to each furrow through gated pipes delivering 10-15 gpm per furrow. One plot (#4) was dedicated for PAM applications, and tailwater from the other three plots could be diverted to an unvegetated ditch, a vegetated ditch, or a sediment trap, depending on the study needs in any given irrigation. Each pyrethroid application was done with lambda-cyhalothrin (Warrior) at a rate of 3.84 oz/acre.

In the first irrigation (excluding the one used to test equipment as noted above) plots 1-3 were used to test three replicate sediment traps, and plot 4 was used for PAM. The sediment traps were 13 ft long, 4 ft wide, and 3 ft deep. They were lined with plastic at the upper end to minimize erosion as water entered the trap. The width to length ratio (1:3) and size of the trap was based on advice provided to us by Natural Resource Conservation Service (NRCS) staff, and was scaled to approximate the ratio of irrigated land to trap surface area as would be used at a commercial farm employing sediment traps. Based on the flow coming off each plot, which peaked at about 55 gpm, the residence time in the trap was approximately 21 minutes.

For the second irrigation, tailwater from plots 1-3 was diverted to three replicate vegetated ditches, 50 m in length, 1.3 m in width, 0.3 m deep, and with a shallow V cross-section (plot 4 remained a PAM treatment). While it had been intended to seed the ditch to establish grass, contractual difficulties in starting the project delayed starting the work until it was too late in the season for grass to be successfully started from seed. Instead, tall fescue sod (Festuca arundinacea) was purchased and used to line the ditch. Thus, the grass density used was higher than would be typically found, and particle removal efficiency probably represents best case conditions.

The third irrigation was used to test unvegetated ditches, representing control conditions with no attempt at soil retention. Duplicate ditches (plots 1 and 2) were used, 50 m in length and identical in configuration to the vegetated ditches except lacking grass.

In each of the three irrigations, plot 4 was dedicated to PAM treatment. PAM is an extremely large, linear polymer that has been used for erosion control in the U.S. since the mid-1990s. The polymer increases soil cohesion, thereby minimizing resuspension and flocculating soil particles that may be in suspension. PAM, as a liquid emulsion, was metered in to the irrigation water provided to plot 4 to achieve a concentration of 5 mg/l as the water entered the furrows. A separate irrigation pipeline served plot 4, allowed treatment of only this plot with PAM. There was also limited testing of PAM as a granular formulation. In the third irrigation, plot 3 was used for testing of granular PAM, spreading 1 oz over the ground at the head of each furrow.

The design described above resulted in triplicate assessments of each mitigation technique. The vegetated ditch and sediment trap triplicates were over space (plots 1, 2 and 3 within a given irrigation). The liquid PAM triplicates were over time (plot 4 in three irrigations). The unvegetated ditch was tested in duplicate in a single irrigation, and granular PAM was tested only once in a single plot.

Methods specific to the Chico site

Soil at the Chico farm site was a clay loam with percentages of sand, silt, and clay of 27, 47, and 26%, respectively. The Chico plots were planted in lima beans, and treated with the pyrethroid zeta-cypermethrin (Mustang) at a rate of 4.3 oz/acre. The experimental design at Chico was nearly identical to that at Davis, with only a few minor differences. First, there were 10 furrows per plot, rather than 9. Secondly, the flow to each furrow was 20 gpm rather than the 10-15 gpm at Davis, with a total of 30,000-40,000 gallons provided to each plot during the course of an irrigation. Thirdly, as a result of the greater water delivery rate, the flow coming off each plot peaked at about 90 gpm rather than 55 gpm. Finally, the sediment traps at Chico had sloped walls (vertical walls at Davis) and was somewhat deeper (4 ft rather than 3 ft), yielding a sediment trap residence time of about 9 minutes at peak runoff, rather than 21 minutes at Davis.

Methods specific to the Salinas site

Soil at the Salinas farm site was a Chualar sandy loam. The experimental plots in Salinas were planted in head lettuce, and treated with permethrin (Pounce) at a rate of 3.2 oz/ acre. Each of the four Salinas plots consisted of 45 beds at 40 inch spacing, and 270 feet long. As is customary in the Salinas area, the lettuce was irrigated by sprinklers Sprinkler lines were spaced every 8 beds and 5/32 nozzles were used to apply approximately 200 gall/min to each plot. The sprinklers provided 83,000-119,000 gallons to each plot during the course of an irrigation.

Based on the Chico and Davis experience, sediment traps were made larger at Salinas. They were 30 ft long, 7 ft wide, and 2 ft deep. With peak runoff from most plots at about 120 gpm, residence time was about 26 minutes. The vegetated ditches at Salinas were 50 m in length as at the other sites. They were seeded in barley, and the plants were 6-12 inches high at the times of the experiments. The emulsified PAM formulation was used at Salinas as well, though it was metered in to the irrigation water at 7.5 ppm rather than 5 ppm.

The Salinas trials employed a Latin square design in allocating the treatments among the plots. Each plot was prepared with a sediment trap, vegetated ditch, and unvegetated ditch, and the tailwater could be diverted to any one of these treatments in a given irrigation. The four treatments (the three listed above plus PAM) were randomly assigned to the four plots on the first irrigation. With each subsequent irrigation, the treatments were rotated to a different plot.

Thus, for example, plot 1 was assigned as a vegetated ditch treatment in the first irrigation, a sediment trap in the second, an unvegetated ditch in the third, and PAM treatment in the fourth. At Davis and Chico the same plot was always used for PAM in each irrigation since it was unknown when starting the experiments whether use of PAM would have any residual effect on sediment resuspension in subsequent irrigations. At the Salinas site however, PAM treatments were rotated among the plots because data from previous studies in the region by the same investigator had shown no residual effect. In addition the plots were cultivated between applications as they were at Chico and Davis, and the unvegetated ditch, which carried the PAM-treated water away when the plot was assigned as a PAM plot, was backfilled and retrenched prior to using it as an unvegetated ditch treatment in subsequent irrigations.

Flow measurements

Gated pipe was used to supply water to each plot. Inflow rates were periodically determined during irrigation by measuring the time for a volume of water to be discharged into a container. Outflow rates of the runoff from the plots was measured using a broad-crested or RBC flume (Davis), or trapezoidal and Parshall flumes (Chico). Flumes were installed in the tailwater ditch leading from each plot, either above (Davis and Chico) or below (Salinas) the mitigation treatment. The outflow rate was determined by measuring the depth of water at the head of the flume using a stilling well connected to the flume. The depth of water in the stilling was measured using a Global Water WL16 water level instrument (Global Water, Gold River, CA) which consists of a pressure transducer lowered into the stilling well and a data logger for recording the well water level. Instrument readings, made every minute, were compensated for temperature and barometric pressure changes. The water level data were downloaded into a computer and the flow rate calculated using the water levels and appropriate calibration relationships between water level and flow rate, provided by the flume manufacturers.

Suspended solids collection

Suspended sediments were collected above and below each mitigation treatment (sediment traps and the vegetated and unvegetated ditches) and immediately below the PAM treated plot. Two types of suspended sediment samples were obtained. First, for purposes of quantifying total suspended solids, 500 ml of tailwater were collected at each sampling site at approximately 30 minute intervals throughout every irrigation event. These samples were filtered on 934-AH glass fiber filters, and the retained material gravimetrically quantified after drying at 100°C overnight. The TSS was assumed to be constant for the 30 minute period represented by each sample, and was integrated with the flow data obtained from the flumes to determine total loading of suspended sediment during these 30 minute increments. The sum of suspended solids produced over all 30 min intervals in a given irrigation, divided by the total flow over that irrigation produced an average flow-weighted TSS measurement.

The second type of suspended sediment sample were those collected for chemical analyses. A diaphragm pump was used to obtain water from the tailditches and transfer it to 20-L stainless steel kegs. To the maximum extent possible, all surfaces the water contacted were stainless steel including the tubes through which it traveled. Only the pump head and a couple flexible joints in the transfer tubes were made of materials other than stainless steel. The number of kegs filled to represent a single sample depended on water turbidity. In highly turbid water, two 20-L kegs were filled. When little turbidity was evident, up to twelve 20-L kegs were collected for a single sample. The samples were collected at only one time point in each irrigation, typically within the first 30 minutes after runoff began from each plot, since with increasing time the suspended sediment concentration tended to decline. The kegs contained the tailwater were transferred to the lab the same day, and held at 4°C for 24-72 hr. The suspended sediment was separated from the water by continuous flow centrifugation (Whisperfuge, Westfalia Separator, Oelde, Germany) using a flow rate through the centrifuge of 1.5 L/min and a speed producing a force of 9000 g. The amount of suspended sediment recovered was highly variable, depending upon the particular farm and the mitigation treatment tested, but ranged from 2-140 g. The material was held at -30°C until chemical analysis.

Bed sediment collection

Bed sediments were collected at the same locations as the suspended sediments (above and below each mitigation treatment and a few meters below the PAM plots). To the extent possible, we attempted to collect material that appeared to be freshly deposited fine-grained sediment, rather than from more firmly-packed eroding surfaces, though the distinction was often difficult. A stainless steel scoop was used to scrape the upper 1 cm of sediment, and transfer it to a solvent-cleaned 4-L glass jar. Depending on availability, the amount of sediment collected at each site ranged from 1-3 L. Jars were held at 4ºC until further processing.

Bed sediment samples were thoroughly homogenized by hand mixing with a large spoon in a stainless steel bowl. Any large debris (gravel, plant matter) were removed by hand. Subsamples were then taken for chemical analysis (held at -30ºC) or toxicity testing (held at 4ºC)

Chemical analyses

Prior to the first application of pyrethroids at all sites, sediments were analyzed for eight pyrethroids (bifenthrin, cyfluthrin, cypermethrin, deltamethrin, esfenvalerate, fenpropathrin, lambda-cyhalothrin and permethrin), an organophosphate (chlorpyrifos), and 19 organochlorines (alpha-, beta-, delta-, and gamma-BHC, heptachlor, heptachlor epoxide, alpha- and gamma-chlordane, alpha- and beta-endosulfan, endosulfan sulfate, *p,p'*- DDE, *p,p'*- DDD, *p,p'*- DDT, aldrin, dieldrin, endrin, endrin ketone, and methoxychlor). Thereafter, both bed and suspended sediments were analyzed only for the specific pyrethroid that had been applied as part of the experiments (lambda-cyhlaothrin, permethrin, or cypermethrin, depending on the specific farm).

Frozen sediment was thawed, centrifuged to remove excess water and homogenized. Matrix-dispersion accelerated solvent extraction (ASE) and tandem solid phase extraction (SPE) cleanup methods were developed and validated in an earlier study (You et al., 2006). Two surrogates, 4,4'-dibromooctafluorobiphenyl and decachlorobiphenyl, were added to the sediment prior to extraction to verify extraction and cleanup efficiency. Approximately 10 g of sediment (wet weight) was mixed with 5 g of diatomaceous earth, 1 g of activated silica gel and 2 g of cleaned copper and transferred into a 33 ml stainless steel cell. After loading the cell on the ASE extractor (Dionex ASE 200, Sunnyvale, CA, USA), the sample was extracted with a solvent mixture of methylene chloride and acetone (1:1, v/v) at 100°C and 1500 psi. A static extraction time of 5 min and two extraction cycles were used. The extract was dried with 12 g of anhydrous Na_2SO_4 and concentrated to 5 ml under a stream of nitrogen at 50°C and 15 psi using a TurboVap II evaporator (Zymark, Hopkinton, MA, USA). After solvent exchange to hexane, the extract was concentrated to 1ml. Tandem SPEs with graphic carbon black and primary/secondary amine cartridges (Supecol, Bellefonte, PA, USA) were used for extract cleanup. The pesticides were eluted from the cartridges with 7 ml of 30% methylene chloride in hexane (v/v). The eluent was evaporated and redissolved in 1 ml of hexane acidified with 0.1% of acetic acid.

Analysis was performed on an Agilent 6890 series gas chromatograph equipped with an Agilent 7683 autosampler and an electron capture detector (Agilent Technologies, Palo Alto, CA). Two columns from Agilent, a HP-5MS (30m x 0.25mm; 0.25μm film thickness) and a DB-608 (30m x 0.25mm; 0.25μm film thickness) were used. Six external standards solutions ranged from 5 to 500 ng/ml were used for calibration. The calibration curves were linear within this concentration range. Additional dilution steps were needed for some field-collected samples to obtain concentrations within the calibration range. Qualitative identity was established using a retention window of 1% with confirmation on a second column. With method detection limits of 0.08-0.42 ng/g dry weight, the method reporting limits were set at 1 ng/g for all the analytes.

Toxicity testing

All toxicity tests were conducted with the amphipod, Hyalella azteca following standard protocols (USEPA, 2000). The sediment was placed in 400 ml beakers and 250 ml of moderately hard water was added, prepared by addition of salts to Milli-Q purified water (Millipore, Billerica, MA). Ten amphipods, 7-10 days of age, were added to each beaker. Tests continued for 10 days, during which two volume additions of water (500 ml) were added daily by an automatic delivery system, the organisms were fed 1 ml yeast/cerophyll/trout chow per beaker daily, and 16 hr light was provided daily. Ammonia, hardness, alkalinity, and pH were measured at the start and end of the test; temperature and dissolved oxygen were monitored throughout the test. Water quality data are not presented but were within permissible limits of the standard protocols. At test completion, the animals were recovered on a 425 μm screen and enumerated.

A control sediment sample was tested concurrently with each batch of farm sediments. For the Chico and Davis tests, control sediments were a blend of sediments from San Pablo Dam Reservoir near Orinda, CA and Lake Anza in Berkeley, CA (blend with 1.74% organic carbon). The sediment had been analyzed for 28 pesticides, including pyrethroids, chlorpyrifos, and organochlorines, and contained no detectable residues (<1 ng/g) except about 1 ng/g DDT. For the Salinas tests, control sediment was collected from the same farm as the test sediments, but was dug from about 2 ft deep within the soil where there was presumed to be little exposure to hydrophobic pesticides. Chemical data for this control material are not yet available, though amphipod survival in the toxicity tests using the material was consistently above 90%.

In most cases, samples were tested in a dilution series to determine the LC50 concentration. The test sediment and control sediment were mixed by hand to provide a test sediment concentration series of 3%, 6%, 12%, 25%, 50%, and 100% (dry weight basis). Tests were usually begun 24 hr after preparing the dilutions. Three replicate beakers were tested at each concentration step.

Toxicity testing statistics were performed using ToxCalc (Tidepool Scientific Software, McKinleyville, CA). LC50s were determined by the trimmed Spearman-Karber method.

Data availability

This report represents an interim deliverable, describing the results of the first year's work, with further studies yet to be completed. At the current time, all TSS data, all flow data, and all toxicity data from the three farms are available, and included in the results below. Chemistry data are presented for the Chico and Davis farms, but since the Salinas trials occurred much later (Oct.-Nov. 2006) the results of chemical analyses for that farm are not yet available. Ancillary data, such as sediment organic content and grain size characterization, are not yet available for any of the farms, but are not critical to the presentation of results. In addition, nominal PAM concentrations are given, but analytical confirmation in irrigation and tailwater samples is in progress.

RESULTS

Initial conditions

Prior to the first pyrethroid application at each farm and evaluation of mitigation techniques, a test irrigation was done to determine baseline conditions of bed and suspended sediments and to test sampling equipment and procedures. Samples below plots 1 and 2 were composited for both bed and suspended sediments, as were samples below plots 3 and 4.

Most importantly, there were no detectable pyrethroids in any sample, both bed and suspended sediments, collected during the test irrigations at either Davis or Chico (Salinas data not yet available). The sediments at the Davis site contained up to 86 ng/g DDE, as well as lesser quantities of DDT (up to 15.5 ng/g), DDD (up to 4.6 ng/g), dieldrin (up to 1.6 ng/g) and chlorpyrifos (up to 2.0 ng/g). All these concentration are at least two orders of magnitude below levels expected to be toxic to H. azteca, the species we used for toxicity testing. At the Chico site the same constituents were present, and at similar concentrations as at Davis, except that DDE was found at up to 308 ng/g. Again, this concentration is two orders of magnitude below toxic levels for H. azteca.

Toxicity tests of bed sediments collected below the experimental plots at all three farms during the test irrigation, prior to pyrethroid application, showed no toxicity in any sample. Survival was 93% or more in all samples but one, and was 81% in that one sample (depressed only because of unexplained low survival one of eight replicates).

Pyrethroid content and toxicity of bed sediments

After application of pyrethroids, bed sediments collected immediately below each plot caused complete mortality at nearly all plots and all farms (Table 1). In most cases, the sediment had to be diluted with control sediment to 3-20% of its initial concentration in order for half the test organisms to survive a 10-d exposure (i.e., the 10-d LC50). The sediment chemistry results were consistent with the toxicity findings, showing 2-31 ng/g lambda-cyhlaothrin in the sediments at Davis, and 9-76 ng/g cypermethrin in the sediments at Chico (Table 2). Based on reported H. azteca toxicity results averaged over several sediments that have been tested (Amweg et al., 2005; Maund et al., 2002), and assuming a typical sediment organic carbon content of 1%, the LC50s for both compounds would be expected to be about 4 ng/g. The LC50 for zeta-cypermethrin, as was applied at Chico, may be even lower because zeta-cypermethrin is a form of cypermethrin in which the relative abundance of the most toxic isomers has been enhanced. Thus, the sediments below the plots and prior to any mitigation exceeded pyrethroid LC50s by up to 8 times at Davis, and up to at least 19 times at Chico.

Sediment collected below the 50-m vegetated ditches at Davis and Chico showed survival comparable to that in the concurrently tested control sediments in most cases, and dramatic reductions in pyrethroid concentrations down to about 1-2 ng/g in most bed samples. Sediments below the unvegetated ditches and sediment traps were still toxic, though less so than above those treatments, and pyrethroid concentration of the bed sediments declined to about 2-5 ng/g. It is shown below, however, that the unvegetated ditches and sediment traps were not very effective at mitigating transport of pyrethroids adsorbed to suspended sediment, thus it is suspected that the apparent improvement in sediment quality below all these treatments may simply reflect an inability of the contaminated sediments to deposit within the area at the lower end of the drainage ditches rather than an indication that they were not reaching those points.

At the Salinas farm, the mitigation treatments had little or no effect on bed sediment toxicity (chemistry data not yet available). Undiluted sediment caused mortality of nearly all H. azteca, regardless of whether the sediment was collected above or below treatments, and there was little or no reduction in toxicity as measured by the LC50s.

Interpretation of the results from the PAM-treated plots is more difficult. It was expected bed sediment conditions would be substantially improved by use of PAM, and it is shown below that it reduced the transport of pyrethroids off the field, however, the bed sediments beneath the PAM plots remained quite toxic and with high pyrethroid concentrations. The bed samples below the PAM plots were taken from the same position relative to the pesticide-treated plot as the bed sediments collected above the other mitigation treatments below their respective plots, that is, about 3 m below the ends of the furrows, and the pyrethroid content and toxicity of the PAM plot samples were comparable to the “above” samples from the other plots. After completion of the Davis and Chico sites, it was suspected the PAM bed sediment collection site may have been contaminated during pesticide application rather than by runoff transport, since it is only a few meters from treated crop. Therefore when doing the Salinas work, the trenching for the drain was not done until after pesticide application, yet the same result of high toxicity and pyrethroid concentrations in bed sediment beneath the PAM plot was observed. It appears most likely that while PAM dramatically reduces transport of contaminated sediments from cultivated fields, it is not capable of preserving sediment quality only a few meters from the fields. It is possible that large sediment aggregates, even those created by the flocculating properties of the PAM, may be traveling these short distances as bedload, since as shown below there is very little suspended matter in PAM-treated runoff.

Suspended sediment comparison at the three farms

Data collected from the first irrigation at all three farms, from locations upstream of any mitigation treatment, are presented to illustrate general patterns in runoff at the sites (Figure 2). It is immediately apparent that there are dramatic differences in the amount of suspended solids in runoff between the sites. The Davis site had the lowest TSS levels, averaging about 0.1 g/l throughout much of the irrigation event. Runoff at Chico contained about 0.2 g/l for much of the irrigation. In contrast, Salinas TSS concentrations averaged about 1.5 g/l, 7 times greater than at Chico, and 15 times greater than at Davis.

There was a tendency for TSS concentrations to decline with time during an irrigation event. This result is due to the fact that the soil in the bottom of the furrows is more susceptible to resuspension in the initial pulse of water traveling down the furrow, than after subsequent flow over the same surface.

The most dramatic decline in TSS levels occurs in the first hour of runoff, a period when data are lacking at Salinas. This absence is due to the fact that TSS sampling, both above and below the mitigation treatments, began when water passed over the flume. The flumes at Chico and Davis were located above the mitigation treatment, while those at Salinas were located below them. Thus there was a lag time at Salinas of about an hour between initial runoff and when the water front reached the flume (as water filled the vegetated ditch, for example). However, during this early portion of the runoff period, only a small number of furrows had begun to flow, and thus the amount of runoff during this lag period is very small compared to the total volume lost during the full irrigation event.

Infiltration

In most cases, runoff from the experimental plots ranged from about 20-50% of the water applied (Table 3). The addition of PAM to the irrigation water has, in some trials elsewhere, increased infiltration of water in to the soil (Lentz and Sojka, 2000; McCutchan et al., 1993; Trout et al., 1995), though it has also been reported to decrease infiltration in some instances (Trout and Ajwa, 2001). At both the Davis and Chico sites, there was no clear effect of the PAM on water infiltration, though there was considerable variability among the plots, making demonstration of any trend difficult. However, at Salinas, PAM reduced infiltration (increased runoff). Runoff from the PAM treated plot was greater than the non-PAM plots in three out of the four irrigation events, and was the second highest value reported in the fourth event. This result is believed to be a result of the increased viscosity of the irrigation water upon addition of PAM, and the resulting inhibition of soil infiltration.

Unvegetated ditch suspended sediment results

It is possible that there may be some improvement in suspended or bed sediment quality with distance from the pyrethroid-treated field, even in the absence of active mitigation measures. Therefore, a shallow, unvegetated V-ditch, 50 m in length, was used as a control treatment against which the success of the mitigation treatments, particularly the 50-m vegetated ditch, could be compared. At the Davis site a substantial amount of suspended sediment was removed from the tailwater by the unvegetated ditch (Figure 3). The flow-weighted average TSS over the entire irrigation event was reduced by 34 and 74% in the two unvegetated ditch trials. At the Chico site however, TSS was dramatically increased with passage of the tailwater through the unvegetated ditch, possibly due to differences in erodability between soils at the Davis and Chico sites and the greater flow rate at Chico (and hence greater erosion potential). Flow-weighted average TSS concentrations in water exiting the ditch at Chico were about 5 times greater than concentrations entering the ditch. The trials at Salinas provided mixed results for the unvegetated ditches. In three of the trials, the unvegetated ditch reduced TSS by 7-31%, but in the fourth trial TSS was increased by 13%.

Pyrethroid concentrations on the suspended sediment traveling down the unvegetated ditch showed little change with distance (Table 4). Though about half the suspended sediment was deposited within the ditch at Davis, the lambda-cyhalothrin concentration on the remaining half was unchanged. In contrast, cypermethrin concentrations on suspended solids entering the ditch at Chico were far higher than on the solids leaving, reflecting the fact that the TSS rose dramatically within the ditch, essentially diluting the contaminated suspended solids with clean material eroded from the ditch walls.

It should be noted in Table 4 and subsequent tables providing data on pyrethroid content of suspended sediment, that this measure alone should not be used to evaluate the success of failure of a mitigation practice. Pyrethroid concentration on suspended sediment above and below each mitigation measure was measured in the event it was altered by the mitigation, perhaps decreasing due to erosion of clean sediment or increasing because pyrethroid-poor coarse sediments were retained by the mitigation measure while pyrethroid-rich fine sediments passed through. The pyrethroid content of suspended sediment and any change due to mitigation should be interpreted only in concert with data on how the mitigation affects the amount of sediment in the runoff.

Vegetated ditch suspended sediment results

The vegetated ditches at all farms consistently outperformed their unvegetated counterparts in removing suspended solids from the tailwater (Figure 4). At the Davis site, TSS reduction in the three replicate vegetated ditch trials was very consistent, with a decline of 76-81% in the average flow-weighted TSS throughout the irrigation. Every replicate trial at Chico showed a TSS reduction (37-72%), as did every replicate at Salinas (18-54%). Substantial reductions in TSS were observed regardless whether the ditches contained fescue initially put in place as sod (Davis and Chico), or barley established from seed (Salinas).

Pyrethroid concentrations on the suspended sediment were quite variable among samples, but showed no evidence of a consistent increase or decrease over the length of the vegetated ditch (Table 5). Two of the Chico plots showed an atypically low cypermethrin concentration in the samples taken below the vegetated ditch, with 592-736 ng/g in sediment entering the ditch, and only 10-57 ng/g in suspended sediment as it left the ditch. A decline of this magnitude would only be possible if large amounts of sediment were eroded from the ditch (diluting the contaminated material as was the case in the unvegetated Chico ditches) or if the grasses retained the finest particles (highest in pyrethroid concentration) while allowing only very coarse material to pass. There is no evidence of the former because TSS concentrations declined with passage down the ditch, and the later seems physically improbable. While the reason for the low values in the water exiting the ditches of plots 1 and 2 is unknown, these values are believed to be aberrant, and the pyrethroid concentration on TSS from plot 3 (376 ng/g) is probably more representative.

Sediment trap suspended sediment results

None of the sediment traps at any of the farms appeared to have any benefit for removal of suspended solids, or presumably, the pyrethroids associated with them (Figure 5). At Davis and Chico, the water leaving the traps usually contained higher concentrations of suspended material than the water that entered, as a result of erosion within the traps. The sediment traps had been recently dug for the purpose of this study, and it is likely that with time and repeated irrigation events, the walls and floor would become less erodable. However, we doubt that the traps would ever be an effective mitigation strategy for sediment-sorbed pesticides.

The traps size used was based on consultation with the NRCS, and designed to maintain a ratio between trap surface area and irrigated field surface area that was representative of commercial agriculture. With the flow rates used, the residence time in traps was only about 15-30 minutes, depending upon the farm. While this time is sufficient for most sand-sized particles and coarser material to settle out, it is far too short for effective removal of silts and clays, precisely the particle sizes on which most of the pyrethroids would be transported. Assuming a medium-sized silt particle (0.02 mm) and a settling velocity of 0.057 ft/min, it would require 35 min to settle to the bottom of the 2 ft trap used at Salinas, and 53 min for the 3 ft traps at Davis and 70 min for the 4 ft traps at Chico, The trap sizes and flow rates used provided only 9-26 min of settling time and would not have effectively retained even medium silt. To capture very fine silt would require a trap several hundred feet long, and to capture clay size particles would require a trap of an unrealistic size. Further testing of larger traps may be done in the second year of this project, and it may be possible to achieve a reduction in TSS, since in working farms they clearly retain sediment, yet we remain doubtful that they can be made effective for removal of sediment-bound pyrethroids on the finest particles. This finding is important because sediment ponds are commonly promoted as a measure for improving the water quality of surface runoff leaving a field, and such improvement may not be the case for sediment-bound pyrethroids.

No data are now available on the pyrethroid content of the suspended sediment passing through the trap. Chemical analyses of the Salinas samples are in progress, and the chemistry samples collected at Chico and Davis were not analyzed, since based on TSS data, the traps were clearly ineffective. If anything, the pyrethroid concentration on sediment flowing from the trap would likely be greater than that entering the trap, as coarse material of appreciable mass but little pyrethroid content settles out within the trap.

PAM suspended sediment results

The effectiveness of PAM in reducing suspended sediment in the tailwater was readily apparent even by casual observation during the field trials. At the Davis and Chico sites, tailwater from the PAM treated plots was virtually clear, with almost no visible suspended material. At the Salinas farm, the concentration of TSS in untreated water was far higher than at

Davis, and even with PAM, tailwater was never completely clear. However, PAM-treated runoff was only slightly cloudy, compared to the opaque, chocolate-brown appearance of untreated runoff.

These general observations were confirmed by the TSS data (Figure 6). Of the three farms, PAM performance was poorest at Davis, though still dramatic compared to the other mitigation strategies. Flow-weighted TSS concentrations over the full irrigation cycle at Davis declined by 66-96% with the addition of PAM. At Chico, the reduction in TSS was 95-98%, and at Salinas it was 91-97%.

The concentration of pyrethroids on the suspended sediment was quite variable, with lambda-cyhalothrin ranging from 86-500 ng/g at Davis, and cypermethrin ranging from 84-871 ng/g at Chico (Table 6). There was no indication of a consistent difference in concentrations with the addition of PAM.

All other references to PAM throughout this report refer to a liquid emulsion formulation metered in to irrigation water, but limited testing (one plot in one irrigation only) was done with PAM in granular form, spreading the granules at the head of each furrow. It was found to be completely ineffective, with TSS concentrations in the runoff comparable to non-PAM-treated plots. The granules appeared to be rapidly covered over with sediment, probably inhibiting their dissolution in to the overlying water.

Overall assessment of sediment and pyrethroid loading

All data presented previously have been concentration based, but it is informative to view the effectiveness of the various mitigation strategies from the standpoint of loading reductions achieved over a full irrigation event. To accomplish this, the TSS data was integrated with the flow measurements to obtain an estimate of total kg of sediment leaving the plots as runoff during the entire irrigation. The data on pyrethroid concentration of suspended solids were then used to convert the mass of sediment lost to the mass of pyrethroid lost during the irrigation, and these parameters determined with and without the mitigation measure.

The results of this analysis for the unvegetated ditches are shown in Table 7. At Davis, an irrigation resulted in the off-site transport of about 3-5 kg of sediment, or about 1-1.7 mg of pyrethroids, and the unvegetated ditch was successful in reducing these losses by about 60%. At the Chico the unvegetated ditch dramatically increased sediment loading, but had no effect in mitigating pyrethroid losses. Apparently at Davis, some of the suspended material deposited within the unvegetated ditch, whereas at the Chico site not only was there was no deposition, but there was a great deal of erosion from within the ditch. The difference may be due to either differences in erodability of the soil types at the farms, or to the greater flow rate and erosion potential at Chico (90 gpm vs. 50 gpm at peak flows). There were a few instances of an apparent increase in pyrethroid loadings due to the unvegetated ditch, but this result is most likely due simply to imprecision in the measurements. A surprising result of this analysis is the amount of sediment lost from the Salinas fields during irrigation. Each plot produced 48-171 kg of sediment during the unvegetated ditch trials, and 18-93 kg during the other trials discussed below. If scaled up to the 3.7 acre field used, the sediment lost during an irrigation was typically about 240 kg dry weight. The unvegetated ditches at Salinas had no effect on sediment loads moving off the plots.

The vegetated ditch achieved a 17-88% reduction (median 48%) in pyrethroid loading (Table 8). With use of the vegetated ditch the amount of pyrethroid lost from a plot during an irrigation is reduced from 0.34-6.10 mg down to 0.08-2.09 mg. It is likely that further reductions could be achieved by use of a longer vegetated ditch. The 50 m used was consistent with some past efforts (Moore et al., 2001), and was the maximum that could be accommodated in the space available at two of the three farms.

As noted previously, the sediment traps had essentially no effect (Table 9). Though pyrethroid chemistry data are not available, if it is assumed the pyrethroid concentration of suspended solids entering the trap is equal to that leaving, the median reduction in pyrethroid transport was 3%. Given the inherent uncertainty in the measurements, no improvement in water quality at all can be clearly shown.

The use of PAM achieved from a 78 to 100% reduction (median=93%) in pyrethroid loss (Table 10). With PAM, there was never more than 0.2 mg of pyrethroid lost during an irrigation event, whereas without it 1-20 mg would have been lost. As noted previously, PAM was unable to prevent sediment toxicity only a few meters below the treated plots, thus near-field impacts may be unavoidable. However, certainly far less sediment and pyrethroids are transported off-site with use of PAM than without it, and further evaluation of compound is clearly merited. Further research on the efficacy of PAM in various formulations is planned in the second year of the study. In addition, though PAM toxicity is generally considered to be very low, verification of this assumption is planned with several standard water and sediment toxicity testing species.

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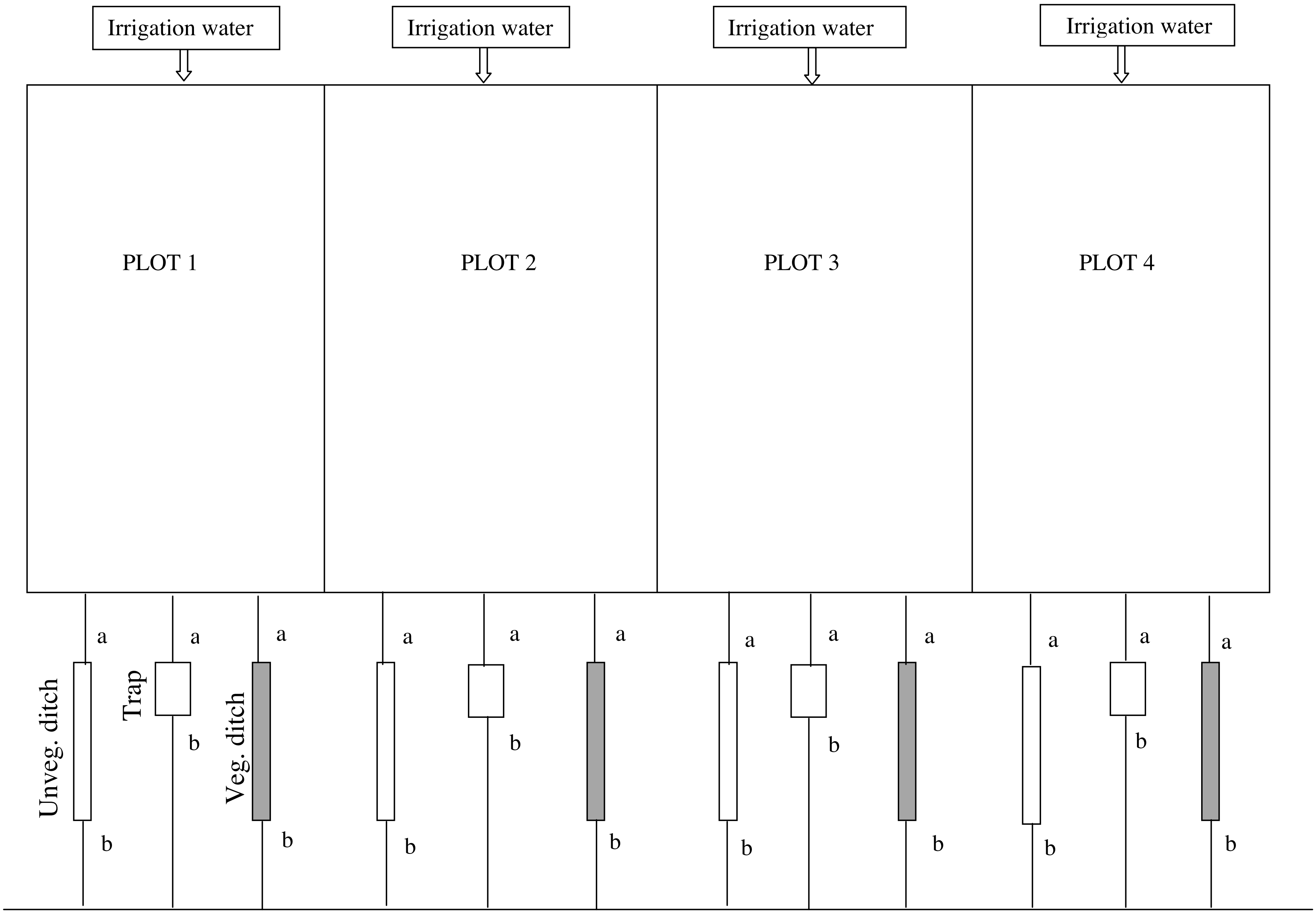

Figure 1. General schematic of plot layout. Specific farms had minor variations. Locations denoted by "a" and "b" are sampling points above and below the mitigation treatment, respectively.

Table 1. Toxicity of bed sediments to H. azteca in 10-d tests. Percent survival is shown above and below the mitigation treatment (or with and without use of PAM) for each of the replicate plots (usually 3-4). In most instances of low survival, the sediment was also tested in a dilution series to determine its LC50. Samples collected above the vegetated and unvegetated ditches and sediment traps serve as the "without PAM" control against which the success of the "with PAM" treatment can be evaluated.

Site and treatment	Survival (%) in 100% sediment above mitigation treatment or without use of PAM	LC50 (as % original sediment) above mitigation treatment or without use of PAM	Survival (%) in 100% sediment below mitigation treatment or with use of PAM	LC50 (as % original sediment) below mitigation treatment or with use of PAM
Davis				
Pre-test before pyrethroid application	95, 99			
Unvegetated ditch	0, 0	7.0, 9.5	26, 28	
Vegetated ditch	0, 0, 36	12.8, 16.0	91, 94, 94	
Sediment trap	0, 0, 0	7.4, 11.1, 13.7	0, 4, 8	
PAM	All above Davis data except pre-test provide "without PAM" data		0, 0, 0	3.9, 5.7, 13.6
Chico				
Pre-test before pyrethroid application	81, 95			
Unvegetated ditch	0, <20	4.8, 25.6	1, 19	23.2
Vegetated ditch	0, 0, 0	5.2, 6.4, 8.6	70, 93, 94	
Sediment trap	0, 0, 7	6.7, 27.0, 45.1	30, 54, 58	
PAM	All above Chico data except pre-test provide "without PAM" data		0, 0, 0	12.5, 24.7, 29.6
Salinas				
Pre-test before pyrethroid application	93, 99			
Unvegetated ditch	0, 0, 0, 0	2.0, 2.5, 3.7, 21.8	0, 0, 0, 0	3.5, 7.1, 17.2, 21.2
Vegetated ditch	0, 0, 0, 0	3.9, 5.9, 13.6, 15.0	0, 0, 7, <20	4.0, 7.7, 17.9, 40.2
Sediment trap	0, 0, 0, 0	2.2, 3.7, 8.7, 12.8	0, 0, 0, <23	8.7, 16.8, 14.2, 30.6
PAM	All above Salinas data except pre-test provide "without PAM" data		0, 0, 0, 0	7.2, 7.4, 12.3, 12.5

Table 2. Pyrethroid concentration of bed sediments above and below the mitigation treatment (or with or without use of PAM) for each of the replicate plots (usually 2-3). Davis data are lambda-cyhalothrin; Chico data are cypermethrin. Salinas chemistry data not yet available. Samples collected above the ditches and sediment traps serve as the "without PAM" control against which the success of the "with PAM" treatment can be evaluated.

Site and treatment	Pyrethroid concentration above mitigation treatment or without use of PAM (ng/g)	Pyrethroid concentration below mitigation treatment or with use of PAM (ng/g)
Davis		
Pre-test before pyrethroid application	0, 0	not relevant to pre-test
Unvegetated ditch	19.9, 30.9	2.2, 3.8
Vegetated ditch	2.0, 12.3, 14.6	1.4, 1.6, 2.1
Sediment trap	17.6	samples not analyzed[a]
PAM	All of above Davis data except pre-test provide "without PAM" data	18.5, 18.8, 53.7
Chico		
Pre-test before pyrethroid application	0. 0	not relevant to pre-test
Unvegetated ditch	9.2, 75.8	3.6, 5.4
Vegetated ditch	30.8, 35.6, 60.0	1.4, 2.1, 54.0
Sediment trap	17.6	samples not analyzed[a]
PAM	All of above Chico data except pre-test provide "without PAM" data	8.8, 9.7, 30.5

[a]Sediment traps showed negligible reduction in TSS, and thus bed sediment did not warrant cost of pyrethroid analysis.

Table 3. Runoff from the irrigated plots and the effect of liquid PAM added to the irrigation water.

Irrigation date	Total water applied per plot (gallons)	Runoff non-PAM plots (% of applied)	Runoff PAM plots (% of applied)
Davis			
7/13/06	23,170-28,283	18.8, 31.9, 42.1	48.1
7/21/06	26,410-28,496	30.4, 37.8, 39.1	30.1
8/3/06	21,422-30,848	14.9, 16.7, 21.8	16.2
Chico			
7/7/06	34760-41360	14.9, 22.9, 48.4	47.4
7/19/06	41,990-48,620	33.4, 46.9, 49.1	39.5
8/1/06	27,500-34,650	35.7, 39.2	21.0
Salinas			
10/19/06	119,400	8.4, 17.2, 24.3	29.2
10/26/06	119,600	10.4, 23.5, 32.6	48.1
11/2/06	100,800-101,300	16.0, 19.7, 33.9	42.3
11/9/06	83,100-88,300	28.2, 32.3, 47.1	41.7

Table 4. Pyrethroid concentration of suspended and bed sediments collected at locations above and below the unvegetated ditch. Davis data are lambda-cyhalothrin concentrations; Chico data are cypermethirn concentrations. Salinas chemistry data not yet available.

Plot	Conc. on TSS above unveg. ditch (ng/g)	Conc. on TSS below unveg. ditch (ng/g)
Davis – unvegetated ditch		
Plot 1	392	270
Plot 2	302	372
Chico – unvegetated ditch		
Plot 1	544	122
Plot 2	240	34

Table 5. Pyrethroid concentration of suspended and bed sediments collected at locations above and below the vegetated ditch. Davis data are lambda-cyhalothrin concentrations; Chico data are cypermethirn concentrations. Salinas chemistry data not yet available.

Plot	Conc. on TSS above vegetated ditch (ng/g)	Conc. on TSS below vegetated ditch (ng/g)
Davis – vegetated ditch		
Plot 1	86	212
Plot 2	343	195
Plot 3	246	358
Chico – vegetated ditch		
Plot 1	736	57
Plot 2	592	10
Plot 3	412	376

Table 6. Pyrethroid concentration of suspended and bed sediments collected immediately below the experimental plots, comparing results of plots that received PAM to those that did not. Davis data are lambda-cyhalothrin concentrations; Chico data are cypermethirn concentrations. Salinas chemistry data not yet available.

Irrigation event	Conc. on TSS without use of PAM (ng/g)	Conc. on TSS with use of PAM (ng/g)
Davis - PAM		
Irrigation 1	86, 343, 246	124
Irrigation 2	303[a]	500
Irrigation 3	302, 392	151
Chico - PAM		
Irrigation 1	412, 592, 736	871
Irrigation 2	752[a]	84
Irrigation 3	240, 544	139

[a] Single sample composited from three plots not receiving PAM.

Table 7. Total loading of pyrethroids in runoff over the irrigation event, and the reduction obtained by flow through 50 m unvegetated ditch. Pyrethroid concentration data from Davis site are lambda-cyhalothrin concentrations; Chico data are cypermethirn concentrations. Chemistry data from Salinas not yet available. A reduction in pyrethroid discharge, if shown in brackets, indicates a gain.

<table>
<tr><th>Plot or irrigation event</th><th>Total suspended sediment leaving plot during irrig. (kg)</th><th>Total suspended sediment after passage through unveg. ditch (kg)</th><th>Pyrethroid conc. of suspended sediment above ditch (ng/g)</th><th>Pyrethroid conc. of suspended sediment below ditch (ng/g)</th><th>Total pyrethroid load leaving plot during irrigation (mg)</th><th>Total pyrethroid load after passage through unveg. ditch (mg)</th><th>Reduction in pyrethroid discharge due to mitigation practice (%)</th></tr>
<tr><td colspan="8">Davis – unvegetated ditch</td></tr>
<tr><td>Plot 1</td><td>2.50</td><td>1.65</td><td>392</td><td>270</td><td>0.98</td><td>0.45</td><td>54</td></tr>
<tr><td>Plot 2</td><td>5.75</td><td>1.50</td><td>302</td><td>372</td><td>1.74</td><td>0.56</td><td>68</td></tr>
<tr><td colspan="8">Chico – unvegetated ditch</td></tr>
<tr><td>Plot 1</td><td>9.11 [a]</td><td>45.00 [a]</td><td>544</td><td>122</td><td>4.96 [a]</td><td>5.49 [a]</td><td>[11] [a]</td></tr>
<tr><td>Plot 2</td><td>12.05 [a]</td><td>59.74 [a]</td><td>240</td><td>34</td><td>2.89 [a]</td><td>2.03 [a]</td><td>30 [a]</td></tr>
<tr><td colspan="8">Salinas – unvegetated ditch</td></tr>
<tr><td>Irrigation 1</td><td>59.94</td><td>41.66</td><td colspan="4" rowspan="4">Salinas chemistry data not yet available</td><td>30 [b]</td></tr>
<tr><td>Irrigation 2</td><td>117.12</td><td>81.33</td><td>31 [b]</td></tr>
<tr><td>Irrigation 3</td><td>48.47</td><td>45.20</td><td>7 [b]</td></tr>
<tr><td>Irrigation 4</td><td>171.28</td><td>194.40</td><td>[13] [b]</td></tr>
</table>

[a] Data are not available over the full irrigation cycle from below the unvegetated ditch, thus sediment loading is only shown during the period for which data above and below the ditch are available. Loads over the full irrigation event would be approximately 60% greater.

[b] Since chemistry data are not yet available for the Salinas site, reductions in pyrethroid discharge are tentatively based only on reductions in amount of suspended solids, assuming pyrethroid content of those solids are the same above and below the unvegetated ditch.

Table 8. Total loading of pyrethroids in runoff over the irrigation event, and the reduction obtained by flow through 50 m vegetated ditch. Pyrethroid concentration data from Davis site are lambda-cyhalothrin concentrations; Chico data are cypermethirn concentrations. Chemistry data from Salinas not yet available.

Plot or irrigation event	Total suspended sediment leaving plot during irrig. (kg)	Total suspended sediment after passage through vegetated ditch (kg)	Pyrethroid conc. of suspended sediment above ditch (ng/g)	Pyrethroid conc. of suspended sediment below ditch (ng/g)	Total pyrethroid load leaving plot during irrigation (mg)	Total pyrethroid load after passage through vegetated ditch (mg)	Reduction in pyrethroid discharge due to mitigation practice (%)
Davis – vegetated ditch							
Plot 1	3.95	0.97	86	212	0.34	0.21	40
Plot 2	1.88	0.40	343	195	0.65	0.08	88
Plot 3	3.93	0.74	246	358	0.97	0.26	73
Chico – vegetated ditch							
Plot 1	8.29	2.36	736	376 [a]	6.10	0.89	85
Plot 2	3.22 [b]	1.23 [b]	592	376 [a]	1.91 [b]	0.46 [b]	76
Plot 3	8.83	5.57	412	376	3.64	2.09	42
Salinas – vegetated ditch							
Irrigation 1	18.08	11.45	Salinas chemistry data not yet available				37 [c]
Irrigation 2	45.57	25.92					43 [c]
Irrigation 3	68.70	56.72					17 [c]
Irrigation 4	68.73	31.84					54 [c]

[A] The measured pyrethroid concentrations at these locations were suspect, and thus data from plot 3 are applied to plots 1 and 2.
[b] Data are not available over the full irrigation cycle from below the vegetated ditch, thus sediment loading is only shown during the period for which data above and below the ditch are available. Loads over the full irrigation event would be approximately four times greater.
[c] Since chemistry data are not yet available for the Salinas site, reductions in pyrethroid discharge are tentatively based only on reductions in amount of suspended solids, assuming pyrethroid content of those solids are the same above and below the vegetated ditch.

Table 9. Total loading of pyrethroids in runoff over the irrigation event, and the reduction obtained by flow through sediment traps. Chemistry data were not collected at Chico and Davis since it was apparent TSS reduction was minimal, thus the values shown for reduction in pyrethroid discharge are based only on reductions in amount of suspended solids, assuming pyrethroid content of those solids are the same above and below the sediment trap. Salinas chemistry data not yet available. A reduction in pyrethroid discharge, if shown in brackets, indicates a gain.

Plot or irrigation event	Total suspended sediment leaving plot during irrig. (kg)	Total suspended sediment after passage through sediment trap (kg)	Pyrethroid conc. of suspended sediment above trap (ng/g)	Pyrethroid conc. of suspended sediment below trap (ng/g)	Total pyrethroid load leaving plot during irrigation (mg)	Total pyrethroid load after passage through sediment trap (mg)	Reduction in pyrethroid discharge due to mitigation practice (%)
Davis – sediment trap							
Plot 1	16.10	13.97	Samples not analyzed				13 [b]
Plot 2	9.71	9.00					7 [b]
Plot 3	3.93	0.74					[11] [b]
Chico – sediment trap							
Plot 1	11.49 [a]	11.37 [a]	Samples not analyzed				1 [b]
Plot 2	17.36 [a]	23.73 [a]					[37] [b]
Plot 3	39.95 [a]	47.70 [a]					[19] [b]
Salinas – sediment trap							
Irrigation 1	92.75	72.48	Salinas chemistry data not yet available				22 [b]
Irrigation 2	33.53	24.13					28 [b]
Irrigation 3	44.59	38.71					13 [b]
Irrigation 4	57.65	59.72					[4] [b]

[a] Data are not available over the full irrigation cycle from below the sediment trap, thus sediment loading is only shown during the period for which data above and below the trap are available. Loads over the full irrigation event would be approximately 50% greater.

[b] Since chemistry data are not available, reductions in pyrethroid discharge are tentatively based only on reductions in amount of suspended solids, assuming pyrethroid content of those solids are the same above and below the sediment trap.

Table 10. Total loading of pyrethroids in runoff over the irrigation event, and the reduction obtained by addition of PAM to the irrigation water. Pyrethroid concentration data from Davis site are lambda-cyhalothrin concentrations; Chico data are cypermethirn concentrations. Chemistry data from Salinas not yet available. Data shown for columns without PAM represent the median of results from 2-3 plots measured during the same irrigation event as the "with PAM" value.

Irrigation event	Total suspended sediment leaving plot during irrig. without use of PAM (kg)	Total suspended sediment leaving plot during irrig. with use of PAM (kg)	Pyrethroid conc. of suspended sediment without use of PAM (ng/g)	Pyrethroid conc. of suspended sediment with use of PAM (ng/g)	Total pyrethroid load leaving plot during irrigation without use of PAM (mg)	Total pyrethroid load leaving plot during irrigation with use of PAM (mg)	Reduction in pyrethroid discharge due to mitigation practice (%)
Davis – PAM							
Irrigation 1	3.93	1.50	246	124	0.97	0.19	81
Irrigation 2	9.76	0.46	303	500	2.96	0.23	92
Irrigation 3	4.13	0.54	347	151	1.43	0.08	94
Chico – PAM							
Irrigation 1	8.83	0.24	592	871	5.23	0.21	96
Irrigation 2	26.81	0.66	752	84	20.16	0.06	100
Irrigation 3	17.53	0.37	392	139	6.87	0.05	99
Salinas – PAM							
Irrigation 1	59.94	3.48	Salinas chemistry data not yet available				94[a]
Irrigation 2	45.57	9.69					78[a]
Irrigation 3	48.47	7.58					84[a]
Irrigation 4	68.73	6.72					90[a]

[a] Since chemistry data are not yet available for the Salinas site, reductions in pyrethroid discharge are tentatively based only on reductions in amount of suspended solids, assuming pyrethroid content of those solids are the same with and without use of PAM.